# The Impacts of Highway Expansion on Population Redistribution:

# An Integrated Spatial Approach

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**ABSTRACT** The influence of highways on transforming human society and promoting population redistribution has been investigated in several disciplines. The impacts of highway expansion, which is the primary highway construction activity nowadays, are not addressed in existing literature. This research examines the function that highway expansion serves in the process of population redistribution. Specifically, this research takes an integrated spatial regression approach to study the impacts of highway expansion on population growth at the municipal level in the 1980s and 1990s in Wisconsin. The findings suggest that highway expansion does not have significant direct effects on population redistribution when compared to other contextual factors. Highway expansion appears to influence population redistribution indirectly by strengthening spatial lag effects through its role as a catalyst of change.

Highways have served an important function in transforming human society and promoting population redistribution. Several theories have been offered, each supported by numerous empirical studies, to explain the effects that highways have on economic and population growth. The widespread literature regarding this topic is located within several diverse disciplines, such as planning, economics, geography, and sociology (Chi, Voss, and Deller 2006).

Presently most highway and interstate highway systems have been completed. Current highway construction activities primarily focus on expanding or improving existing highways instead of building new highways. According to the executive director of the National

Academies' Transportation Research Board, "[m]uch of the existing highway systems, particularly interstates and primary arterial highways, must be reconstructed in the coming years" (Skinner 2002, p. 34). It is essential to know the impacts of highway expansion on population redistribution as well as economic growth and development. In this study, highway expansion refers to added travel lanes based on existing highway segments, for example, expanding a highway from 2 lanes to 4 or more lanes.

Building highways is a longstanding method of development. The Interstate Highway Act of 1956 advanced the rapid development of new highway infrastructure. Highway expansion has received fervent protest from neo-liberalists, environmentalists, and local communities, as they realized the negative effects that result from highway constructions, such as unequal distribution of highway access, spatial mismatch, less frequent family interactions, and transportation-related stress (Yago 1983). In contrast, most governmental decision makers supported highway expansion by arguing that it can promote economic growth and development, decrease traffic congestion, increase travel safety, and assist the more efficient use of existing roads.

The general perception is that highway expansion has similar effects as newly-built highways, but the effects are not as strong as with newly-built highways. While highway effects have been studied in several disciplines, the impacts of highway expansion are not addressed in current literature. This study attempts to understand the function that highway expansion serves in affecting population redistribution. Specifically, this study places highway expansion within the historical context of population redistribution, and takes an integrated spatial regression approach to examine the impacts from 1980-2000 at the minor civil division level in Wisconsin.

This manuscript is organized into six additional sections. Highway impacts on population redistribution are first reviewed and an integrated spatial approach is proposed to investigate the influence of highway expansion on population redistribution. Following this is a section describing the research data, and a section discussing the analytical approach. Findings are then reported regarding the impacts of highway expansion on population redistribution from 1980-2000 at the minor civil division level in Wisconsin. Finally, this paper is closed with a concluding summary and discussion section.

## Prior Research

It is essential to know the impacts of highway expansion on population redistribution as well as, economic growth and development because current highway construction activities primarily focus on expanding or improving existing highways rather than building new highways (Skinner 2002). However, the impacts of highway expansion have rarely been addressed in existing literature. Even so, we can achieve a preliminary understanding of highway expansion's impacts by reviewing the sizeable literature of highway impacts, which can assist in designing an effective research procedure for investigating highway expansion's impacts. A vast literature, distributed across several disciplines (e.g., planning, economics, geography, and sociology), has resulted in a multifaceted mixture of theoretical and empirical approaches to describe the effects that highways have on population redistribution. This literature suggests that highway effects on population redistribution vary with different geographical scales and stages of highway construction, and across rural, suburban, and urban areas (Chi et al. 2006).

First, the effects vary at different scales, such as regions (e.g., Morrison and Schwartz 1996), counties (e.g., Lichter and Fuguitt 1980), municipalities (e.g., Humphrey 1980; Humphrey and Sell 1975), and neighborhoods (e.g., Corsi 1974). Studies at each of these scales have produced dissimilar and conflicting findings. For example, at the larger scales highways effects are found to be primary (Dalenberg and Partridge 1997) or secondary to other factors (e.g., Hulten and

Schwab 1984). At the smaller scales, the effects are found to be significant (e.g., Smith, Deaton, and Kelch 1978) or insignificant (e.g., Dorf and Emerson 1978).

Second, the effects differ in the three stages of highway construction — pre-construction, construction, and post-construction periods. In the pre-construction period, population growth is a positive causal factor of highway construction (Lichter and Fuguitt 1980; Miller 1979). In the construction period, highway construction may affect population growth either positively or negatively (Chi et al. 2006). On one hand, the inconvenience caused by construction makes people unwilling to move in, and the temporary closure of business affects local economic development. On the other hand, the increased future value attracts people to move in. In the post-construction period, an improved or newly-built highway may not only serve to increase but may also decrease population, depending on the broader and secular trend in overall regional population growth (Voss and Chi 2006).

Third, highway effects on population redistribution vary across rural, suburban, and urban areas. The majority of studies on nonmetropolitan counties discovered that highways have a positive effect on population growth by drawing in migrants and fostering employment growth (e.g., Humphrey and Sell 1975; Lichter and Fuguitt 1980). However, a convenient highway can also attract rural residents to travel to the urban areas for employment prospects and urban amenities — a backwash or negative spillover effect (Boarnet 1998). In suburban areas, enhanced or newly-built highways strengthen the process of suburbanization, and generally have a positive effect on economic growth and development in addition to associated population growth (Moore et al. 1964). Highway effects in urban areas are uncertain because new or improved highways can either assist or thwart the development of urban areas depending on numerous other factors and the net effects of spread and backwash (Boarnet 1998, 1999).

These complex findings lead to different definitions and explanations of the function that highways serve in affecting population redistribution. Regional economic theories are particularly robust at describing the effects of highway construction on economic and population growth. For example, neoclassical growth theory regards highway infrastructure as an input into the production process via production relationships (Boarnet 1997; Eberts 1990), an enhancer to increase the productivity of other inputs such as labor (Dalenberg and Partridge 1997; Eberts 1994), or a household amenity factor to attract workers (Dalenberg and Partidge 1997; Eberts 1994). Growth pole theory regards highway investments as a catalyst for change – an improved highway is neither necessary nor sufficient to influence population growth in its surrounding areas (Thiel 1962). Location theory regards highway infrastructure as a facilitator for the flow of raw materials, capital, finished goods, consumers, and ideas among central places and their neighborhoods and a barrier of these flows (Thompson and Bawden 1992), as a means of importing inputs into and exporting outputs out of a location (Vickerman 1991), or as necessary but not sufficient means for local economic growth and development (Halstead and Deller 1997).

These differences may be due to the limited examination and understanding of highway effects on economic and population growth. Many existing studies do not sufficiently control for other influential factors of economic and population growth, and do not appropriately take into account the spatial dynamics of highway effects (Voss and Chi 2006). Considering these issues, this study attempts to study the effects of highway expansion on population redistribution by take a relatively integrated spatial approach (see below).

## An Integrated Spatial Approach

All through human history, population redistribution has developed from an evolutionary process driven by an array of determinants. Regional scientists, demographers, human geographers, and other scholars have studied population distribution and settlement patterns and explored geophysical, agglomerative, and urbanization determinants of changes (Jaret 1983; Morris 1994; Moore and Thorsnes 1994). An extensive review of the pertinent literature results in more than 70 variables that are believed to significantly affect population redistribution theoretically or empirically. Thirty-seven influential variables are selected for this study based on: 1) theoretical or empirical relationships judged to be important to this study, and 2) the availability of data. The variable categories include demographic characteristics, socioeconomic conditions, physical infrastructure, environmental and geophysical factors, cultural resources, and potential legal constraints.

First, for years it has been known that some demographic characteristics of a population are important determinants of population redistribution. Population density, age structure, racial and ethnic composition, institutional populations, educational attainments, migration, and female-headed households with children are some of the most principal demographic characteristics found to affect population growth (Friedman and Lichter 1998; Humphrey 1980; Humphrey et al. 1977; Johnson and Purdy 1980; Lutz 1994; Mincer 1978).

Second, socioeconomic conditions are known to affect population redistribution as well. Some of these principal impacts on population growth include employment opportunities, crime rate, school performance, income growth and distribution, public transportation, public water, new housing, buses, county seat status, and real estate value (Clark and Murphy 1996; Fuguitt, Brown, and Beale 1989; Johnson 1999; Johnson and Beale 1994; Lyson and Gillespie 1995; Schachter and Althaus 1989; Smith, Tayman, and Swanson 2000).

Third, transportation accessibility is important for population redistribution as well as local economic growth and development. In addition to highway expansion, other pertinent factors of accessibility include residential preference, accessibility to airports and highways, highway infrastructure, and journey to work (Chi et al. 2006; Fuguitt and Brown 1990; Fuguitt and Zuiches 1975; Humphrey 1980; Voss and Chi 2006; Zuiches and Rieger 1978).

Fourth, environmental and natural resource characteristics are known to influence population redistribution. Landfills and other noxious sites, level and type of resource extraction, and propensity to natural disasters are some of the main characteristics that influence population redistribution. In recent decades, natural resource characteristics such as water features, terrain relief (e.g., viewsheds), and landscape aesthetics (e.g., regional land use and cover) have been regarded as influences on population growth primarily through the role of natural amenities, which are considered as one of the key sources of non-metropolitan population growth (Brown et al. 1997; English, Marcouiller, and Cordell 2000; Fuguitt and Brown 1990; Fuguitt et al. 1989; Johnson 1999; Johnson and Beale 1994; Johnson and Purdy 1980; Marcouiller 1997; Zuiches and Rieger 1978). In this study, forest, water, the lengths of lakeshore, riverbank, and coastline, golf courses, and slope represent the natural amenities.

Finally, the potential for land conversion and development limits population redistribution. The land developability of a region is determined by its geophysical characteristics (tax-exempt lands, slope, water, and wetland), built-up lands (existing residential, commercial, and industrial developments, as well as transportation infrastructure), cultural and aesthetical resources, and legal constraints (e.g., programs such as comprehensive plans, “smart growth” laws, zoning ordinances, farmland protection programs, land use planning legislation, as well as environmental regulations such as the Clean Water Act, shoreland and wetland zoning, etc.). Relevant literature includes developable lands (Cowen and Jensen 1998), qualitative environmental corridors (Lewis 1996), quantitative environmental corridors (Cardille, Ventura, and Turner 2001), and the growth management work (Land Information & Computer Graphics

Facility 2000, 2002). In this study, land development and conversion is represented by water, wetlands, slope, tax-exempt lands, and built-up lands.

Patterns of spatial autocorrelation are often found in population redistribution, which have been well explained by regional economic theories, population geography theories, and the results of residential preference studies. For example, the growth pole theory uses the concepts of spread and backwash to study the mutual geographic dependence of economic growth and development, which then produces population redistribution (Perroux 1955). Rural demographers find in studies of residential preference that migrants favor locations somewhat rural or truly sub-urban within commutable distance of large cities (Brown et al. 1997; Fuguitt and Brown 1990; Fuguitt and Zuiches 1975). Migratory factors such as improved quality-of-living and increased employment opportunities in a location (city, village, or town) not only draw migrants to relocate into its territory, but also draw migrants to relocate into neighboring locations because of the convenience provided by transportation infrastructure. These factors and effects demonstrate spatial dependence in general, which should be controlled in empirical models of population redistribution.

The determinants and their spatial relationships are often not properly managed in modeling highway effects on population redistribution. When pertinent variables are omitted from the model, the potential outcomes are numerous (Dalenberg and Partridge 1997). Because model estimation and statistical inference may be unreliable if spatial effects exist but are not considered in a model, accounting for spatial interactions between population redistribution and influential factors is essential (Chi and Zhu 2008). An integrated spatial examination of highway expansion's effects on population redistribution utilizes all potentially relevant theories and data sets. The proposed approach somewhat develops from the historical and spatial contexts of population redistribution and together incorporate the characteristics of natural and cultural amenities, local demographic characteristics, socioeconomic conditions, transportation capacity, and geophysical limits.

## Data

The research case for this study is the state of Wisconsin. This study investigates the effects of highway expansion on population redistribution at the minor civil division (MCD) level. Population data are from decennial censuses 1970-2000 (Figure 1). The Wisconsin Department of Transportation provided the highway expansion data from 1970 to 1990 at five-year intervals, and the data are restricted to highway expansion of two lanes to four or more lanes (Figure 2). Other influential factors of population redistribution are quantified by a variety of datasets. Demographic and socioeconomic data are obtained from the U.S. Census Bureau, the Wisconsin Department of Public Instruction, the Federal Bureau of Investigation, and the State of Wisconsin Blue Books. Transportation infrastructure data come from the Wisconsin Department of Transportation, the Wisconsin Bureau of Aeronautics, the National Atlas of the United Sates, and the Department of Civil and Environmental Engineering at the University of Wisconsin-Madison. The data of geophysical factors and natural amenity characteristics are provided by the Wisconsin Department of Natural Resources, the U.S. Geological Survey, and the Environmental Remote Sensing Center and the Land Information and Computer Graphics Facility of the University of Wisconsin-Madison.

[FIGURE 1 ABOUT HERE]

[FIGURE 2 ABOUT HERE]

Previous studies indicate that highway effects on population redistribution widely differ when studied at different scales, ranging from communities to municipalities to counties to regions, as a result of the scale effect of the modifiable areal unit problem (Fotheringham and

Wong 1991). The MCD is an appropriate scale to match the population-highway dynamics in Wisconsin. Wisconsin is a "strong MCD" state and its MCDs are functioning governmental units (with towns, cities, and villages that have elected officials who provide services and raise revenues). The MCD geography is comprised of non-nested, mutually exclusive and extensive political territories. The primary advantage of using MCDs is their relevance to public policy-making and planning[1]. Another advantage in using MCDs as units of analysis is that transportation planners often forecast traffic demands at the level of city, village, and town.

MCD boundaries are not static over time: boundaries change, new MCDs emerge, old MCDs disappear, names change, and status in the geographic hierarchy shifts (e.g., towns become villages and villages become cities). Three rules are applied to modify the data to account for these changes: 1) new MCDs must be merged back into their original MCDs from which they emerge; 2) the difficulty of disappearing MCDs can be resolved by dissolving the original MCDs into their current "home" MCDs; and 3) occasionally, several individual MCDs must be merged into one super-MCD to establish a consistent data set. Following these rules, the final analytical dataset is composed of 1,837 MCDs with an average size of 29.56 square miles.

## Analytical Approach

This study investigates the effects of highway expansion on population redistribution from 1980-2000 at the MCD level in Wisconsin. The population redistribution process demonstrated diverse patterns in the two decades — "deconcentration slowdown" in the 1980s and "rural rebound" in the 1990s (Johnson 1999). This research examines the impacts of highway

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[1] In most parts of the State, census tracts have an average size similar to MCDs and provide an alternative unit of analysis. However, census tracts are geographic units delineated by the Census Bureau only for counting population purposes, and they have no political or social meanings.

expansion separately in two sets of models — the first set evaluates the effects of highway expansion completed in 1970-75 and 1975-80 on population growth in 1980-90, and the second set evaluates the effects of highway expansion concluded in 1980-85 and 1985-90 on population growth in 1990-2000 (Figure 3). Comparing the two different redistribution processes can provide a more complete understanding of highway expansion's impacts on population redistribution, and indicate the consistency of the effects.

[FIGURE 3 ABOUT HERE]

In both model sets, two ordinary least squares (OLS) regression models, one controlling influential factors of population redistribution and the other not, are first fitted to the data to reveal the importance of synthetically considering the influential factors of population redistribution. Model diagnostics are then performed to check the model assumptions. If spatial autocorrelation in the OLS residuals is found (as in this study), three spatial regression models — a spatial lag model (SLM), a spatial error model (SEM), and a spatially autoregressive moving average (SARMA) model — are employed to re-evaluate the effects of highway expansion on population redistribution. These different models will finally be assessed and compared using log likelihood, Akaike's Information Criterion (AIC) and Schwartz's Bayesian Information Criterion (BIC).

## Response and Explanatory Variables

The representation of the response and explanatory variables follows the depiction specified in Voss and Chi (2006), where they observed that highway effects on population change are better depicted by the dummy representation than the distance one. In the first set of models, the response variable is a rate of population growth, expressed as the natural log of the ratio of the 1990 census population over the 1980 census population (the left map of Figure 1). The explanatory variables are four dummy variables indicating MCDs within 10 miles of highway expansion in 1970-75, within 10-20 miles from highway expansion in 1970-75, within 10 miles of highway expansion in 1975-80, and within 10-20 miles from highway expansion in 1975-80, respectively (the two upper maps of Figure 4). If a MCD fits into a distance buffer category, it is coded as 1; 0 otherwise. In the second set of models, the response variable is expressed as the natural log of the ratio of the 2000 census population over the 1990 census population (the right map of Figure 1). The explanatory variables are four dummy variables indicating MCDs within 10 miles of highway expansion in 1980-85, within 10-20 miles from highway expansion in 1980-85, within 10 miles of highway expansion in 1985-90, and within 10-20 miles from highway expansion in 1985-90, respectively (the two lower maps of Figure 4).

[FIGURE 4 ABOUT HERE]

## Controlled Variables

Other explanatory variables of population redistribution (termed "controlled variables" in this article) are also considered, as numerous variables are potentially associated with population growth, and a range of problems may occur if pertinent explanatory variables are omitted (Dalenberg and Partridge 1997). However, the large number of variables may cause the multicollinearity problem. To solve this issue, the 37 influential factors of population redistribution are categorized, and principal component analysis and the spatial overlay methods are used to develop five indices: 1) demographic characteristics, 2) social and economic conditions, 3) transportation accessibility, 4) natural amenities, and 5) land conversion and development. The first four indices are developed by principal component analysis and the last index by spatial overlay methods. In total, each model has six controlled variables including these five indices and population growth rate in the previous decade.

### A Simultaneous Consideration of Spatial Lag and Spatial Error Dependence

Each set of models are estimated by two OLS regressions, a spatial lag model, a spatial error model, and a SARMA model. The three spatial regression models are to encompass spatial dependence into the model. In spatial econometric terms, spatial lag and spatial error dependence are the two most frequently referred forms of spatial dependence.

However, spatial lag and spatial error dependence are examined separately in numerous studies of highway-population dynamics that account for spatial dependence. For example, Voss and Chi (2006) use a spatial lag model and a spatial error model to study highway effects on population growth. They found that their examination of spatial dependence appears to have little effect on the original OLS coefficient estimates and their significance. In addition, their diagnostics show that both spatial lag and spatial error dependence remain in one or more of the models. Thus, the questions are “Are the models specified appropriately?”, or, “Can the models be improved?” Simultaneously considering both spatial lag and spatial error dependence is one potential improvement, which can be achieved in a simple SARMA model combining a first-order spatial lag term with a first-order spatial error term.

### The Optimal Spatial Weight Matrix

Selecting an optimal spatial weight matrix for each model in a data-driven approach is another possible improvement. To account for spatial dependence in spatial regression models, it is essential to create a neighborhood structure for each location by specifying those locations on a lattice that are considered as its neighbors (Anselin 1988). Specifically, we need to designate a spatial weight matrix corresponding to the neighborhood structure such that the resulting variance-covariance matrix can be expressed as a function of a small number of estimable parameters relative to the sample size (Anselin 2002). However, many studies select a spatial weight matrix without sound justification or evaluating the selected spatial weight matrix to others. While a spatial weight matrix is needed for spatial regression modeling, the selection of neighborhood structure usually receives little theoretical guidance in practice. A spatial weight matrix often is defined exogenously, and comparison of several spatial weight matrices should be done before choosing a justifiable one. For example, we can develop and compare several spatial weight matrices, and choose the one that achieves a high coefficient of spatial autocorrelation in combination with a high level of statistical significance, although currently there is little theoretical support for this method (Chi and Zhu 2008; Voss and Chi 2006).

In this study, the magnitudes and significance of Moran's I for each model are independently examined and tested by using 40 different spatial weight matrices. The optimal weight matrix to select is the one that achieves the highest coefficient of spatial autocorrelation in combination with a high level of statistical significance. The spatial weight matrices include the rook's case and queen's case contiguity weight matrices with order 1 and order 2, the k-nearest neighbor weight matrices with k ranging from 3 to 8 neighbors, and the general distance weight matrices and the inverse-distance weight matrices with power 1 or power 2, from 0 to 100 miles at 10-mile increments based on the distance between the centroids of MCD.

The optimal weight matrix for running the spatial lag model is chosen by comparing Moran's I of population growth rate. The optimal weight matrix for running the spatial error model is selected on the basis of Moran's I of the OLS residuals. The SARMA needs two spatial weight matrices, one based on Moran's I of population growth which is the spatial lag term, and the other based on the Moran's I of the SEM residuals which is the spatial error term. In addition, a z-score (the test statistic for the significance of the Moran's I statistic) is computed as the ratio of Moran's I and the corresponding standard error. The p-values are calculated using a normal approximation.

For Set 1 models, the 5-nearest neighbor weight matrix, which encompasses the highest spatial autocorrelation of the response variable (the left panel of Appendix A), is chosen for running the spatial lag model. The 5-nearest neighbor weight matrix, which encompasses the highest spatial autocorrelation of the residuals (the middle panel of Appendix A), is also chosen for running the spatial error model. The SARMA model has both a spatial lag term and a spatial error term. The 5-nearest neighbor weight matrix is chosen to account for the spatial lag term, and the squared inverse distance (distance decay) within 10 miles weight matrix is chosen to control for the spatial error term as this matrix encompasses the maximum spatial autocorrelation of the residuals after fitting a spatial lag model (the right panel of Appendix A).

For Set 2 models, the 4-nearest neighbor weight matrix is chosen for running the spatial lag model (the left panel of Appendix B), and the 5-nearest neighbor weight matrix is chosen for the spatial error model (the middle panel of Appendix B). The SARMA model employs the 4-nearest neighbor weight matrix to account for the spatial lag term and the squared inverse distance within 10 miles to encompass the spatial error term (the right panel of Appendix B).

## Findings

### The Impact of Highway Expansion on Population Growth from 1980-90

Two OLS regression models – one controlling population growth's other influential factors and the other without controlling those factors – are first run to examine highway effects on population growth from 1980-1990. In the OLS model that does not control other influential factors of population growth (OLS 1; the first panel of Table 1), the results show that for MCDs within 10 miles and 10-20 miles from the segments of highway expansion, highway expansion segments completed 5-9 years prior the population growth period does not have a significant effect on population growth from 1980 to 1990, while highway expansion segments completed just before the population growth period does have a significant positive impact on population growth. However, the significant impacts on population growth for MCDs within 10 miles of and 10-20 miles from the segments of highway expansion completed from 1975-80 disappear after controlling the influential factors of population growth (OLS 2; the second panel of Table 1).

[TABLE 1 ABOUT HERE]

The consideration of spatial lag and/or spatial error terms in the spatial lag model, spatial error model, and the SARMA model does not change the conclusion. The effects of highway expansion remain insignificant on population growth from 1980-90. All three spatial regression models appear to improve data fitting compared to the OLS regression models, based on the fact that the AIC and BIC values are smaller for the spatial regression models. Of all three spatial regression models, the SARMA model has obvious improvement over the spatial lag and spatial error models, judging from the AIC and BIC values. Thus, the most appropriate model to interpret the regression coefficients is the SARMA model.

None of the four highway expansion variables have significant impacts on population growth from 1980-90. Population growth rate in the previous decade has positive effects on population growth, and one percent growth in the previous decade contributes 0.118 percent growth. MCDs that underwent rapid growth in the 1970s tended to keep growth into the 1980s. Natural amenities have negative effects on population growth. This supports results of other studies that metropolitan areas, which are low in natural amenities, have experienced renewed growth in the 1980s (Johnson 1999).

Both spatial lag and spatial error effects explain population growth significantly. The spatial lag effects come from the spatially-lagged population growth. Each MCD gains 0.686 percent for each percent of weighted population growth in its neighbors. For Set 1 models, each MCD is specified to have five neighbor MCDs. If each of the five neighbors has gained 10% population growth, the spatial lag effects contribute 6.86% population growth to the MCD. The 6.86% growth is not from “organic” growth, but rather comes as a “gift” from its neighbors. The spatial lag effects can be understood somewhat as an indirect effect of highway expansion on population growth. Expanded highways provide improved accessibility to connect the MCDs together. Improved transportation infrastructure provides people additional autonomy in choosing their residency MCDs. When population growth in a MCD’s neighbors leads to an increase of housing prices, it drives residents of neighbor MCDs and in-migrants to the MCD where housing prices are lower until an equilibrium is reached. In contrast, when population decline in a MCD’s neighbors leads to a decrease of housing prices, it drive people out of the MCD to its neighbor MCDs until an equilibrium is reached. Thus, highway expansion is best regarded as a catalyst of change in strengthening the spatial lag effects of population redistribution. The significant spatial error term reveals spatial dependence in errors, which may be caused by not including important explanatory variables in the model. The inclusion of the spatial error effects assist in controlling the unknown variables.

## The Impact of Highway Expansion on Population Growth from 1990-2000

Two OLS regression models are also run to examine highway effects on population growth from 1990-2000, one model considering other controlled influential factors of population growth, and the other model not. The results demonstrate that for MCDs within 10 miles and 10-20 miles from the segments of highway expansion, highway expansion completed 5-9 years prior the population growth period does not have significant effects on population growth from 1990-2000, whereas highway expansion completed just before the population growth period does have a significant positive impact on population growth in the OLS model that does not account for controlled influential factors of population growth (OLS 1; the first panel of Table 2). Controlling other influential factors of population growth (OLS 2; the second panel of Table 2) does not change the results.

[TABLE 2 ABOUT HERE]

These two explanatory variables remain significant in the spatial lag model and spatial error model, although the regression coefficients and significance are lesser in magnitude. However, these two explanatory variables are no longer significant in the SARMA model. The SARMA model offers the best model fitting balanced with model parsimony, based on the log likelihood, AIC, and BIC statistics. Thus, the most appropriate model to interpret the regression coefficients is the SARMA model.

None of the four highway expansion variables have significant impacts on population growth from 1990-2000. Population growth rate in the previous decade has positive effects on population growth from 1990-2000, and each percent growth in the previous decade contributes 0.187 percent growth. Natural amenities have positive effects on population growth from 1990-2000, which supports the observation of rural rebound in the 1990s (Johnson 1999).

Both spatial lag and spatial error effects are significant in explaining population growth. Each MCD gains 0.717 percent growth for each percent of weighted population growth in its neighbor MCDs. Highway expansion, through its role as a catalyst of change, influences population redistribution indirectly by strengthening the spatial lag effects. The spatial lag effects are much greater than the temporal effects. The significant spatial error effects indicate that their inclusions assist to control the unknown variables.

# Conclusion

This study separately examines the impact of highway expansion on population redistribution in 1980-90 and 1990-2000 at the MCD level in Wisconsin. Wisconsin experienced different population redistribution patterns in the two decades — deconcentration slowdown in the 1980s and rural rebound in the 1990s. A comparison of highway expansion's effects in two population redistribution patterns offers a more comprehensive understanding of the effects. Specifically, the effects are examined by: 1) thoroughly examining population redistribution's determinants, 2) systematically selecting the optimal spatial weight matrix, and 3) simultaneously including both spatial lag and spatial error dependence into one spatial regression model.

The findings show that highway expansion has no significant direct impacts on population redistribution when influential factors of population distribution as well as spatial dependence of population growth and models' residuals are appropriately controlled. The systematic controlling of influential factors of population growth and the simultaneous consideration of the spatial lag dependence and spatial error dependence assist the improvement of the overall model fitting balanced with model parsimony, and thus, provide a more complete understanding of highway expansion's impacts on population redistribution. The analysis provides diverse results of the impacts of highway expansion when either of the influential factors, spatial lag effects, or spatial error effects is not appropriately considered, as many existing studies do. For example, highway expansion finished in the 1975-80 period affects population growth from 1980-90 significantly when none of the three elements are considered. Highway expansion finished in the 1985-90 period affects population growth from 1990-2000 significantly until all three elements are simultaneously controlled.

Highway expansion seems to influence population redistribution indirectly by strengthening the spatial lag effects through its role as a catalyst of change. The spatial lag effects in both the

1980s and 1990s are positively significant in promoting population redistribution. From the individual perspective, highway infrastructure operates as a facilitator as well as a barrier for people to connect between residency location, work location, and shopping location. From the business perspective, highway infrastructure also operates as a facilitator as well as a barrier for raw materials, capital, finished goods, consumers, and ideas among central places and their neighborhoods (Thompson and Bawden 1992). Highway expansion decreases travel time among neighboring places, which in turn lessens the socioeconomic distance among them. Highway expansion offers improved accessibility and tends to incorporate several neighboring places into one larger place. Population growth (or decline) in one location will cause population growth (or decline) in its neighboring locations until an equilibrium is achieved. Highway expansion itself does not encourage or discourage population redistribution directly, yet highway expansion can bring neighboring places nearer and influence population redistribution indirectly by strengthening the spatial lag effects through its role as a catalyst of change.

## References

Anselin, Luc. 1988. *Spatial Econometrics: Methods and Models*. Dordrecht, Netherlands: Kluwer Academic Publishers.

——. 2002. "Under the Hood: Issues in the Specification and Interpretation of Spatial Regression Models." *Agricultural Economics* 27:247-267.

Boarnet, Marlon G. 1997. "Highways and Economic Productivity: Interpreting Recent Evidence." *Journal of Planning Literature* 11:476-486.

——. 1998. "Spillovers and the Locational Effects of Public Infrastructure." *Journal of Regional Science* 38:381-400.

——. 1999. "Road Infrastructure, Economic Productivity, and the Need for Highway Finance Reform." *Public Works Management and Policy* 3:289-303.

Brown, David L., Glenn V. Fuguitt, Tim B. Heaton, and Saba Waseem. 1997. "Continuities in Size of Place Preferences in the United States, 1972-1992." *Rural Sociology* 62:408-428.

Cardille, J. A., Stephen J. Ventura, and M. G. Turner. 2001. "Environmental and social factors influencing wildfires in the Upper Midwest, USA." *Ecological Applications* 11:111-127.

Chi, Guangqing, Paul R. Voss, and Steven C. Deller. 2006. "Rethinking Highway Effects on Population Change." *Public Works Management and Policy* 11:18-32.

Chi, Guangqing and Jun Zhu. 2008. "Spatial Regression Models for Demographic Analysis." *Population Research and Policy Review* 27:17-42.

Clark, D. and C. Murphy. 1996. "Countywide Employment and Population Growth: An Analysis of the 1980s." *Journal of Regional Science* 36:235-256.

Corsi, Thomas M. 1974. "A Multivariate Analysis of Land Use Change: Ohio Turnpike Interchanges." *Land Economics* 50:232-241.

Cowen, David J. and John R. Jensen. 1998. "Extraction and Modeling of Urban Attributes Using Remote Sensing Technology." Pp. 164-188 in *People and Pixels: Linking Remote Sensing and Social Science*, edited by D. Liverman, E. F. Moran, R. R. Rindfuss, and P. C. Stern. Washington D. C.: National Academy Press.

Dalenberg, Douglas R. and Mark D. Partridge. 1997. "Public Infrastructure and Wages: Public Capital's Role as a Productive Input and Household Amenity." *Land Economics* 73:268-284.

Dorf, R. and M. Emerson. 1978. "Determinants of Manufacturing Plant Location for Non-Metropolitan Communities in the West North Central Region of the U.S." *Journal of Regional Science* 18:109-120.

Eberts, Randall W. 1990. "Public Infrastructure and Regional Economic Development." *Economic Review* 26:15-27.

——. 1994. "Some Empirical Evidence on the Linkage between Public Infrastructure and Local Economic Development." Pp. 83-96 in *Industy Location and Public Policy*, edited by H. W. Herzog and A. M. Schlottmann. Knoxville: University of Tennessee Press.

English, Donald B.K., David W. Marcouiller, and H. Ken Cordell. 2000. "Tourism Dependence in Rural America: Estimates and Effects." *Society and Natural Resources* 13:185-202.

Fotheringham, A. Stewart and David W.S. Wong. 1991. "The Modifiable Areal Unit Problem in Multivariate Statistical Analysis." *Environment and Planning A* 23:1025-1034.

Friedman, Samantha and Daniel T. Lichter. 1998. "Spatial Inequality and Poverty Among American Children." *Population Research and Policy Review* 17:91-109.

Fuguitt, G. and D. Brown. 1990. "Residential Preferences and Population Redistribution." *Demography* 27:589-600.

Fuguitt, Glenn V. and James J. Zuiches. 1975. "Residential Preferences and Population Distribution." *Demography* 12:491-504.

Fuguitt, Glenn V., David L. Brown, and Calvin L. Beale. 1989. *Rural and Small Town America*. New York: Russell Sage Foundation.

Halstead, John M. and Steven C. Deller. 1997. "Public Infrastructure in Economic Development and Growth: Evidence from Rural Manufacturers." *Journal of Community Development Society* 28:149-169.

Hulten, Charles R. and Robert M. Schwab. 1984. "Regional Productivity Growth in U.S. Manufacturing, 1951-78." *American Economic Review* 74:152-162.

Humphrey, Craig R. 1980. "The Promotion of Growth in Small Urban Places and its Impact on Population Change." *Social Science Quarterly* 61:581-594.

Humphrey, Craig R. and Ralph R. Sell. 1975. "The Impact of Controlled Access Highways on Population Growth in Nonmetropolitan Communities, 1940-1970." *Rural Sociology* 40:332-343.

Humphrey, Craig R., Ralph R. Sell, John A. Krout, and R. Thomas Gillaspy. 1977. "Net Migration Turnaround in Pennsylvania Nonmetropolitan Minor Civil Divisions, 1960-1970." *Rural Sociology* 42:332-351.

Jaret, Charles. 1983. "Recent Neo-Marxist Urban Analysis." *Annual Review of Sociology* 9:499-525.

Johnson, Kenneth M. 1999. "The Rural Rebound." *PRB Reports on America* 1:1-21.

Johnson, Kenneth M. and Calvin L. Beale. 1994. "The Recent Revival of Widespread Population Growth in Nonmetropolitan Areas of the United States." *Rural Sociology* 59:655-667.

Johnson, Kenneth M. and Ross L. Purdy. 1980. "Recent Nonmetropolitan Population Change in Fifty-year Perspective." *Demography* 17:57-70.

Land Information & Computer Graphics Facility. 2000. "Mapping Growth Management Factors: A Practical Guide for Land Use Planning." University of Wisconsin-Madison, Madison, WI.

——. 2002. "Population and Land Allocation: Evolution of Geospatial Tools Helps Citizens Engage in Land-Planning Process." University of Wisconsin-Madison, Madison, WI.

Lewis, Philip H. 1996. *Tomorrow by Design: A Regional Design Process for Sustainability*. New York, NY: John Wiley & Sons.

Lichter, Daniel T. and Glenn V. Fuguitt. 1980. "Demographic Response to Transportation Innovation: The Case of the Interstate Highway." *Social Forces* 59:492-512.

Lutz, Wolfgang. 1994. *Population-Development-Environment: Understanding Their Interactions in Mauritius*. New York: Springer-Verlag.

Lyson, Thomas A. and Gilbert W. Gillespie. 1995. "Producing More Milk on Fewer Farms: Neoclassical and Neostructural Explanations of Changes in Dairy Farming." *Rural Sociology* 60:493-504.

MacNeill, Jim, Pieter Winsemius, and Taizo Yakushiji. 1991. *Beyond Interdependence: The Meshing of the World's Economy and the Earth's Ecology*. New York.

Marcouiller, David W. 1997. "Toward Integrative Tourism Planning in Rural America." *Journal of Planning Literature* 11:337-357.

Miller, J. P. 1979. "Interstate Highways and Job Growth in Nonmetropolitan Areas: A Reassessment." *Transportation Journal* 19:78-81.

Mincer, J. 1978. "Family Migration Decisions." *Journal of Political Economy* 86:749-773.

Moore, Charles Thomas, Morris L. Mayer, Harry A. Lipson, and George Joyce. 1964. "A Study of the Expected Economic and Social Impact of Interstate Highways in the Industrial and Commercial Trading Area of Birmingham, Alabama -- the First Phase." Department of Marketing, University of Alabama, Tuscaloosa, AL.

Moore, Terry and Paul Thorsnes. 1994. *The Transportation/Land Use Connection*. Washington, DC: The American Planning Association.

Morris, A. 1994. *History of Urban Form Before the Industrial Revolutions*. England: Longman Ltd.

Morrison, Catherine J. and Amy Ellen Schwartz. 1996. "State Infrastructure and Productive Performance." *The American Economic Review* 86:1095-1111.

Perroux, Francois. 1955. "Note sur la Notion de pole de croissance." *Economie AppliqueÂe* 8:307-320.

Schachter, J. and P. Althaus. 1989. "An Equilibrium Model of Gross Migration." *Journal of Regional Science* 29:143-159.

Skinner, R. E. 2002. "Highway research for the 21st century." *Issues in Science and Technology* 19:31-35.

Smith, E. D., B. J. Deaton, and D. R. Kelch. 1978. "Location Determinants of Manufacturing Industry in Rural Areas." *Southern Journal of Agricultural Economics* 10:23-32.

Smith, Stanley K., Jeff Tayman, and David A. Swanson. 2000. *State and Local Population Projections: Methodology and Analysis*. New York, NY: Kluwer Academic/Plenum Publishers.

Thiel, Floyd I. 1962. "Social Effects of Modern Highway Transportation." *Highway Research Board Bulletin* 327:1-20.

Thompson, Chris and Tim Bawden. 1992. "What are the Potential Economic Development Impacts of High-Speed Rail?" *Economic Development Quarterly* 6:297-319.

Vickerman, R. W. 1991. "Transport Infrastructure in the European Community: New Developments, Regional Implications and Evaluation." Pp. 36-50 in *Infrastructure and Regional Development*, vol. 1, *European Research in Regional Science*, edited by R. W. Vickerman. London: Pion Limited.

Voss, Paul R. and Guangqing Chi. 2006. "Highways and Population Change." *Rural Sociology* 71:33-58.

Yago, Glenn. 1983. "The Sociology of Transportation." *Annual Review of Sociology* 9:171-190.

Zuiches, James J. and Jon H. Rieger. 1978. "Size of Place Preferences and Life Cycle Migration: A Cohort Comparison." *Rural Sociology* 43:618-633.

Figure 1. Population Growth from 1980-2000 at the MCD Level in Wisconsin

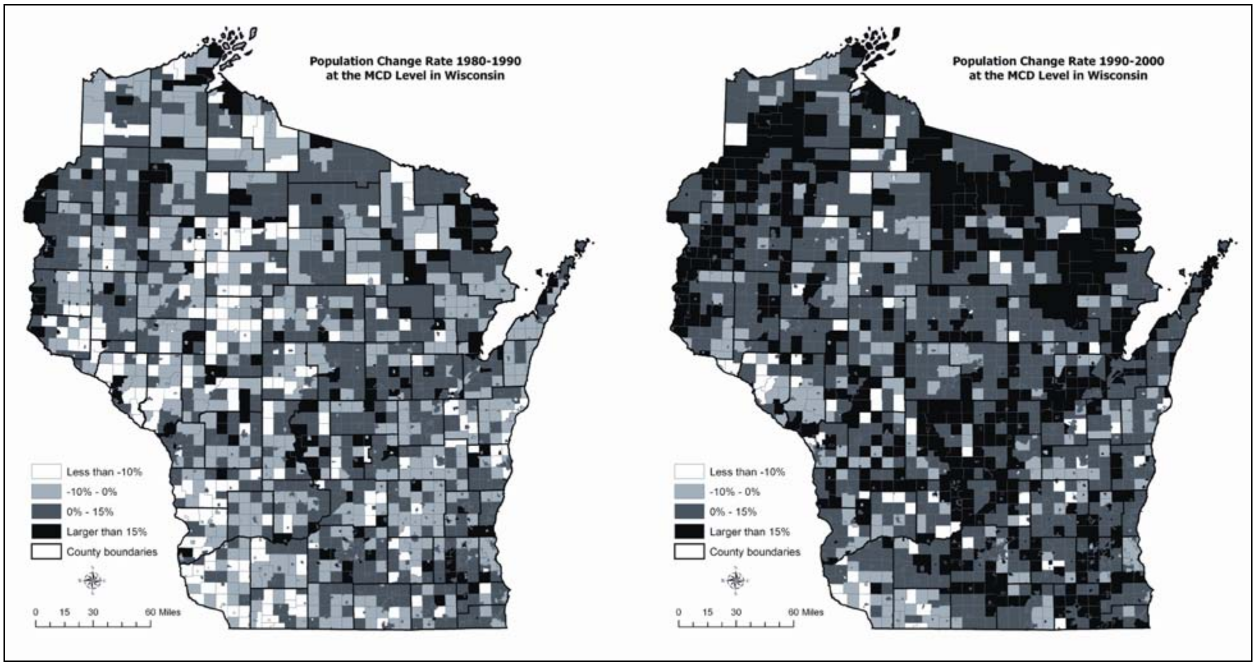

Figure 2. Highways and Expansions from 1970-90 in Wisconsin

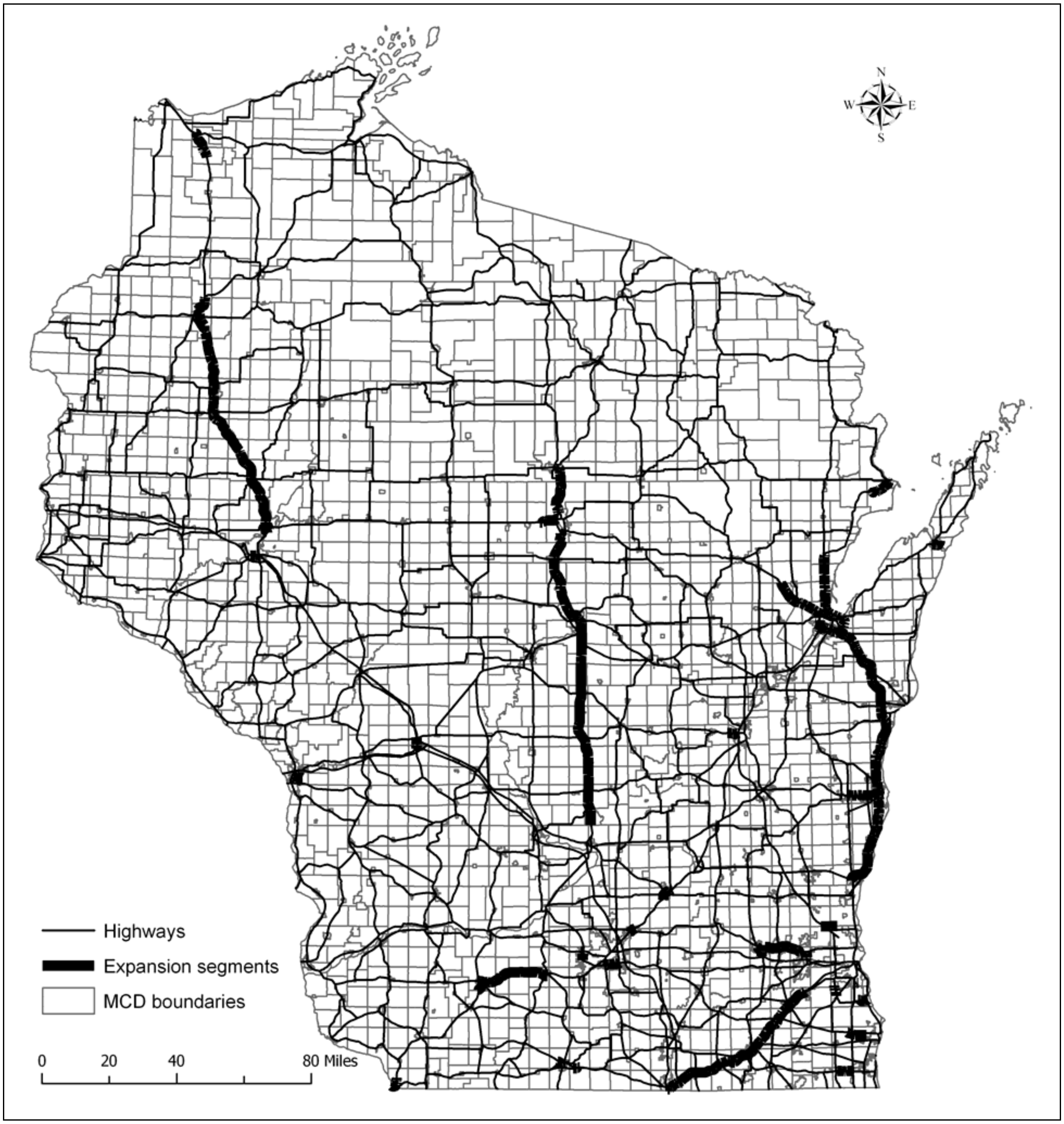

Figure 3. Two Groups of Models

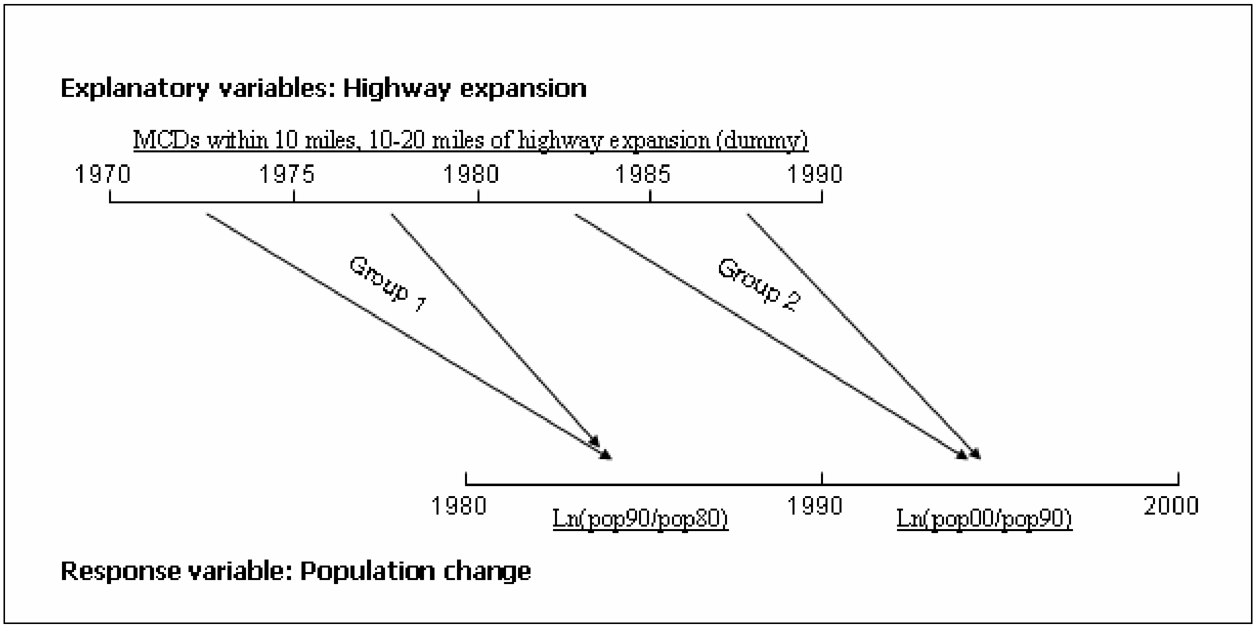

Figure 4. Wisconsin MCDs and Highway Expansions from 1970-90

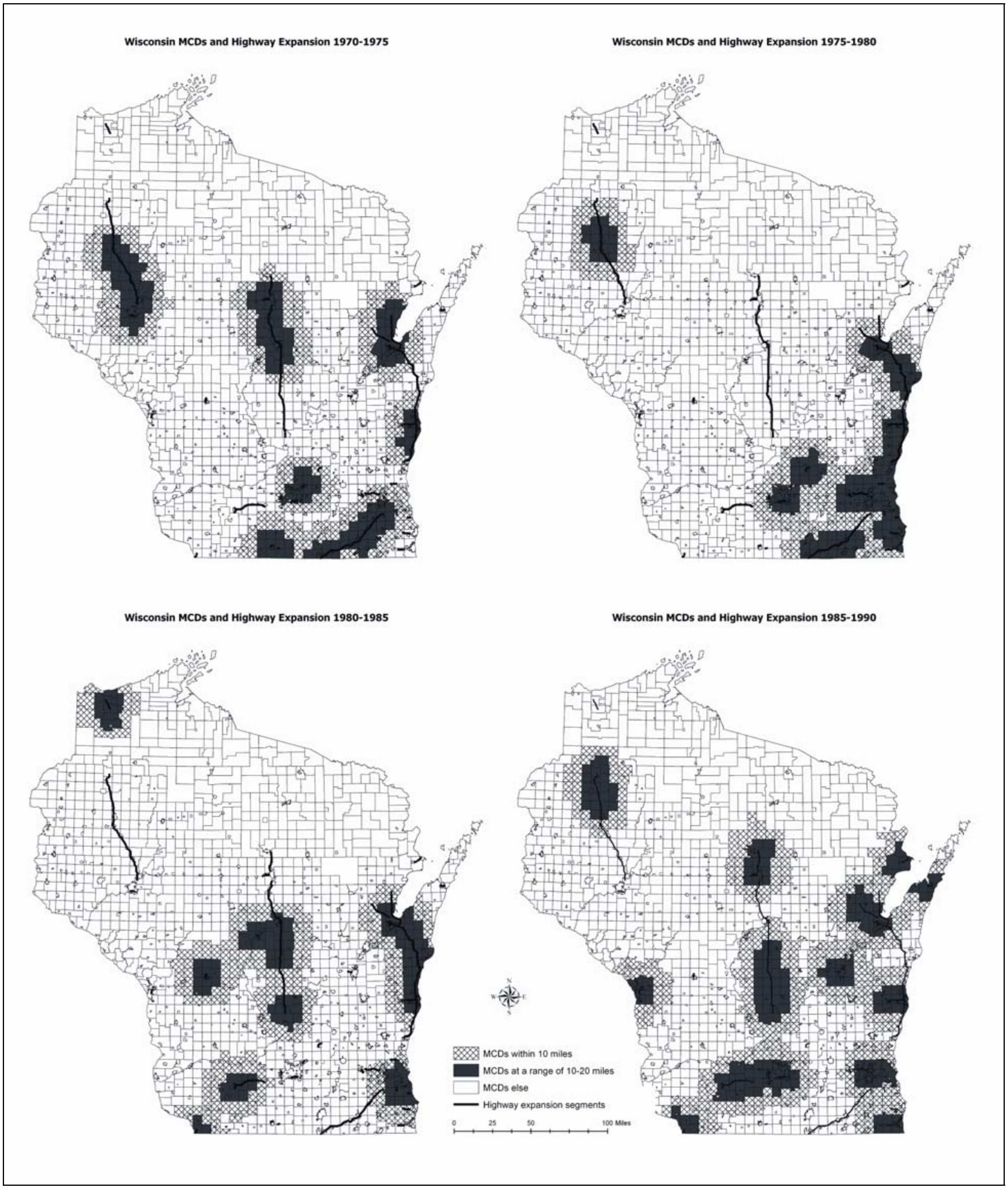

Table 1. Regressions of Highway Expansion on Population Growth from 1980-1990

| | OLS 1 | OLS 2 | SLM | SEM | SARMA |
|---|---|---|---|---|---|
| *Explanatory variables* | | | | | |
| Within 10 miles of highway expansion, finished 5-9 years before population growth period | 0.010 | 0.005 | 0.003 | 0.004 | -0.0002 |
| | (0.009) | (0.010) | (0.009) | (0.011) | (0.007) |
| At a range of 10-20 miles from highway expansion, finished 5-9 years before population growth period | 0.002 | -0.001 | -0.002 | -0.002 | -0.003 |
| | (0.009) | (0.008) | (0.008) | (0.009) | (0.006) |
| Within 10 miles of highway expansion, finished 0-4 years before population growth period | 0.024** | -0.019 | -0.017 | -0.018 | -0.014 |
| | (0.008) | (0.011) | (0.010) | (0.012) | (0.007) |
| At a range of 10-20 miles from highway expansion, finished 0-4 years before population growth period | 0.033*** | 0.011 | 0.009 | 0.011 | 0.005 |
| | (0.009) | (0.009) | (0.009) | (0.010) | (0.006) |
| *Controlled variables* | | | | | |
| Population growth rate from 1970-80 | 0.196*** | 0.177*** | 0.156*** | 0.156*** | 0.118*** |
| | (0.014) | (0.014) | (0.014) | (0.014) | (0.013) |
| Demographic characteristics in 1980 | / | 0.010** | 0.010** | 0.011** | 0.007* |
| | | (0.004) | (0.004) | (0.004) | (0.003) |
| Social and economic conditions in 1980 | / | 0.009*** | 0.006* | 0.009** | 0.002 |
| | | (0.003) | (0.003) | (0.003) | (0.002) |
| Transportation accessibility in 1980 | / | 0.000 | 0.001 | 0.002 | 0.002 |
| | | (0.002) | (0.002) | (0.003) | (0.002) |
| Natural amenities in 1980 | / | -0.010*** | -0.009*** | -0.010*** | -0.006*** |
| | | (0.002) | (0.002) | (0.002) | (0.002) |
| Land conversion and development in 1980 | / | -0.016 | -0.014 | -0.017 | -0.005 |
| | | (0.015) | (0.014) | (0.015) | (0.012) |
| Constant | -0.024*** | 0.000 | -0.001 | 0.004 | -0.007 |
| | (0.004) | (0.011) | (0.011) | (0.012) | (0.009) |
| Spatial lag effects | / | / | 0.217*** | / | 0.686*** |
| | | | (0.033) | | (0.032) |
| Spatial error effects | / | / | / | 0.189*** | -0.405*** |
| | | | | (0.035) | (0.029) |
| *Measures of fit* | | | | | |
| Log likelihood | 1374.99 | 1416.09 | 1438.04 | 1435.60 | 1505.24 |
| AIC | -2737.98 | -2810.18 | -2852.09 | -2849.19 | -2986.48 |
| BIC | -2704.89 | -2749.50 | -2785.90 | -2788.52 | -2920.29 |

Notes: * significant at p≤0.05 for a two-tail test; ** significant at p≤0.01 for a two-tail test; *** significant at p≤0.001 for a two-tail test; standard errors in brackets.

Table 2. Regressions of Highway Expansion on Population Growth from 1990-2000

| | OLS 1 | OLS 2 | SLM | SEM | SARMA |
|---|---|---|---|---|---|
| *Explanatory variables* | | | | | |
| Within 10 miles of highway expansion, finished 5-9 years before population growth period | -0.008 | -0.009 | -0.006 | -0.010 | -0.005 |
| | (0.013) | (0.013) | (0.012) | (0.016) | (0.009) |
| At a range of 10-20 miles from highway expansion, finished 5-9 years before population growth period | -0.009 | -0.015 | -0.013 | -0.016 | -0.009 |
| | (0.011) | (0.010) | (0.009) | (0.012) | (0.007) |
| Within 10 miles of highway expansion, finished 0-4 years before population growth period | 0.042*** | 0.039*** | 0.027* | 0.038** | 0.010 |
| | (0.010) | (0.011) | (0.011) | (0.014) | (0.008) |
| At a range of 10-20 miles from highway expansion, finished 0-4 years before population growth period | 0.041*** | 0.036*** | 0.028** | 0.039*** | 0.010 |
| | (0.008) | (0.009) | (0.009) | (0.010) | (0.006) |
| *Controlled variables* | | | | | |
| Population growth rate from 1980-90 | 0.311*** | 0.295*** | 0.239*** | 0.205*** | 0.187*** |
| | (0.028) | (0.029) | (0.028) | (0.029) | (0.027) |
| Demographic characteristics in 1990 | / | 0.002 | 0.004 | 0.006 | 0.010 |
| | | (0.005) | (0.005) | (0.005) | (0.004) |
| Social and economic conditions in 1990 | / | 0.009** | 0.006* | 0.007* | 0.004 |
| | | (0.003) | (0.003) | (0.004) | (0.002) |
| Transportation accessibility in 1990 | / | -0.010*** | -0.008** | -0.008* | -0.003 |
| | | (0.003) | (0.003) | (0.003) | (0.002) |
| Natural amenities in 1990 | / | 0.002 | 0.002 | 0.001 | 0.005* |
| | | (0.003) | (0.003) | (0.003) | (0.002) |
| Land conversion and development in 1990 | / | 0.013 | 0.013 | 0.017 | 0.016 |
| | | (0.018) | (0.018) | (0.020) | (0.014) |
| Constant | 0.083*** | 0.077*** | 0.054*** | 0.076*** | 0.014 |
| | (0.005) | (0.014) | (0.014) | (0.015) | (0.011) |
| Spatial lag effects | / | / | 0.265*** | / | 0.717*** |
| | | | (0.030) | | (0.030) |
| Spatial error effects | / | / | / | 0.302*** | -0.400*** |
| | | | | (0.033) | (0.029) |
| *Measures of fit* | | | | | |
| Log likelihood | 933.48 | 944.39 | 982.76 | 995.90 | 1050.81 |
| AIC | -1854.96 | -1866.78 | -1941.53 | -1969.79 | -2077.61 |
| BIC | -1821.86 | -1806.10 | -1875.33 | -1909.12 | -2011.42 |

Notes: * significant at p≤0.05 for a two-tail test; ** significant at p≤0.01 for a two-tail test; *** significant at p≤0.001 for a two-tail test; standard errors in brackets.

# Appendix A. Selection of Optimal Spatial Weight Matrix for Examining Highway Expansion's Effects on Population Growth 1980-1990 in Spatial Regression Models Based on Moran's I

| Spatial regression models (Variables for calculating spatial autocorrelation) | SLM (Population growth) | SEM (OLS residuals) | SARMA (SLM residuals) |
|---|---|---|---|
| Rook contiguity, Order 1 | 0.1576*** | 0.0347* | -0.0558** |
| Rook contiguity, Order 2 | 0.1554*** | 0.0682*** | 0.0357*** |
| Queen contiguity, Order 1 | 0.1542*** | 0.0317* | -0.0504** |
| Queen contiguity, Order 2 | 0.1384*** | 0.0622*** | 0.0337*** |
| 3 nearest neighbors | 0.1715*** | 0.0576*** | -0.0418* |
| 4 nearest neighbors | 0.1790*** | 0.0658*** | -0.0293 |
| 5 nearest neighbors | 0.1873*** | 0.0762*** | -0.0147 |
| 6 nearest neighbors | 0.1813*** | 0.0710*** | -0.0129 |
| 7 nearest neighbors | 0.1833*** | 0.0711*** | -0.0061 |
| 8 nearest neighbors | 0.1795*** | 0.0695*** | -0.0021 |
| General distance, 10 miles | 0.1745*** | 0.0657*** | 0.0007 |
| General distance, 20 miles | 0.1257*** | 0.0527*** | 0.0224*** |
| General distance, 30 miles | 0.0870*** | 0.0374*** | 0.0180*** |
| General distance, 40 miles | 0.0629*** | 0.0277*** | 0.0140*** |
| General distance, 50 miles | 0.0462*** | 0.0197*** | 0.0140*** |
| General distance, 60 miles | 0.0349*** | 0.0123*** | 0.0099*** |
| General distance, 70 miles | 0.0279*** | 0.0086*** | 0.0055*** |
| General distance, 80 miles | 0.0218*** | 0.0047*** | 0.0039** |
| General distance, 90 miles | 0.0158*** | 0.0015* | 0.0018 |
| General distance, 100 miles | 0.0118*** | 0.0000 | -0.0001 |
| Inverse distance, 10 miles, power 1 | 0.1648*** | 0.0533*** | -0.0359* |
| Inverse distance, 10 miles, power 2 | 0.1472*** | 0.0336* | -0.0629*** |
| Inverse distance, 20 miles, power 1 | 0.1364*** | 0.0571*** | 0.0036 |
| Inverse distance, 20 miles, power 2 | 0.1367*** | 0.0417*** | -0.0319* |
| Inverse distance, 30 miles, power 1 | 0.1094*** | 0.0482*** | 0.0078 |
| Inverse distance, 30 miles, power 2 | 0.1249*** | 0.0389*** | -0.0263* |
| Inverse distance, 40 miles, power 1 | 0.0910*** | 0.0420*** | 0.0092* |
| Inverse distance, 40 miles, power 2 | 0.1172*** | 0.0372*** | -0.0231* |
| Inverse distance, 50 miles, power 1 | 0.0775*** | 0.0364*** | 0.0087* |
| Inverse distance, 50 miles, power 2 | 0.1118*** | 0.0356*** | -0.0215* |
| Inverse distance, 60 miles, power 1 | 0.0675*** | 0.0327*** | 0.0086** |
| Inverse distance, 60 miles, power 2 | 0.1077*** | 0.0345*** | -0.0204* |
| Inverse distance, 70 miles, power 1 | 0.0604*** | 0.0281*** | 0.0070* |
| Inverse distance, 70 miles, power 2 | 0.1048*** | 0.0332*** | -0.0199* |
| Inverse distance, 80 miles, power 1 | 0.0545*** | 0.0240*** | 0.0056* |
| Inverse distance, 80 miles, power 2 | 0.1025*** | 0.0320*** | -0.0196* |
| Inverse distance, 90 miles, power 1 | 0.0491*** | 0.0213*** | 0.0048* |
| Inverse distance, 90 miles, power 2 | 0.1005*** | 0.0312*** | -0.0192* |

| | | | |
|---|---|---|---|
| Inverse distance, 100 miles, power 1 | 0.0450*** | 0.0186*** | 0.0038 |
| Inverse distance, 100 miles, power 2 | 0.0989*** | 0.0305*** | -0.0190* |

Notes: * significance at 0.05, ** significance at 0.01, ***significance at 0.001.

Appendix B. Selection of Optimal Spatial Weight Matrix for Examining Highway Expansion's Effects on Population Growth 1990-2000 in Spatial Regression Models Based on Moran's I

| Spatial regression models | SLM | SEM | SARMA |
|---|---|---|---|
| (Variables for calculating spatial autocorrelation) | (Population growth) | (OLS residuals) | (SLM residuals) |
| Rook contiguity, Order 1 | 0.1993*** | 0.1033*** | -0.0154 |
| Rook contiguity, Order 2 | 0.1375*** | 0.0717*** | 0.0253* |
| Queen contiguity, Order 1 | 0.1932*** | 0.1044*** | -0.0014 |
| Queen contiguity, Order 2 | 0.1225 | 0.0555*** | 0.0168 |
| 3 nearest neighbors | 0.1982*** | 0.1004*** | -0.0369* |
| 4 nearest neighbors | 0.2136*** | 0.1199*** | -0.0097 |
| 5 nearest neighbors | 0.2118*** | 0.1220*** | 0.0025 |
| 6 nearest neighbors | 0.1992*** | 0.1129*** | 0.0033 |
| 7 nearest neighbors | 0.1986*** | 0.1117*** | 0.0121 |
| 8 nearest neighbors | 0.1931*** | 0.1069*** | 0.0147 |
| General distance, 10 miles | 0.1906*** | 0.1085*** | 0.0209 |
| General distance, 20 miles | 0.1193*** | 0.0565*** | 0.0189*** |
| General distance, 30 miles | 0.0810*** | 0.0356*** | 0.0137*** |
| General distance, 40 miles | 0.0561*** | 0.0213*** | 0.0077** |
| General distance, 50 miles | 0.0415*** | 0.0159*** | 0.0064** |
| General distance, 60 miles | 0.0315*** | 0.0116*** | 0.0049** |
| General distance, 70 miles | 0.0243*** | 0.0075*** | 0.0030* |
| General distance, 80 miles | 0.0181*** | 0.0037*** | 0.0012 |
| General distance, 90 miles | 0.0132*** | 0.0003 | -0.0006 |
| General distance, 100 miles | 0.0097*** | 0.0009 | -0.0011 |
| Inverse distance, 10 miles, power 1 | 0.1844*** | 0.0973*** | -0.0262 |
| Inverse distance, 10 miles, power 2 | 0.1772*** | 0.0846*** | -0.0487** |
| Inverse distance, 20 miles, power 1 | 0.1361*** | 0.0740*** | 0.0029 |
| Inverse distance, 20 miles, power 2 | 0.1491*** | 0.0726*** | -0.0278* |
| Inverse distance, 30 miles, power 1 | 0.1073*** | 0.0557*** | 0.0033 |
| Inverse distance, 30 miles, power 2 | 0.1339*** | 0.0617*** | -0.0268* |
| Inverse distance, 40 miles, power 1 | 0.0868*** | 0.0448*** | 0.0037 |
| Inverse distance, 40 miles, power 2 | 0.1236*** | 0.0555*** | -0.0259* |
| Inverse distance, 50 miles, power 1 | 0.0735*** | 0.0372*** | 0.0036 |
| Inverse distance, 50 miles, power 2 | 0.1171*** | 0.0513*** | -0.0253* |
| Inverse distance, 60 miles, power 1 | 0.0639*** | 0.0309*** | 0.0025 |
| Inverse distance, 60 miles, power 2 | 0.1122*** | 0.0481*** | -0.0252* |
| Inverse distance, 70 miles, power 1 | 0.0564*** | 0.0272*** | 0.0022 |
| Inverse distance, 70 miles, power 2 | 0.1085*** | 0.0459*** | -0.0251* |
| Inverse distance, 80 miles, power 1 | 0.0503*** | 0.0237*** | 0.0014 |
| Inverse distance, 80 miles, power 2 | 0.1055*** | 0.0440*** | -0.0251** |
| Inverse distance, 90 miles, power 1 | 0.0452*** | 0.0212*** | 0.0011 |
| Inverse distance, 90 miles, power 2 | 0.1031*** | 0.0426*** | -0.0250** |

| | | | |
|---|---|---|---|
| Inverse distance, 100 miles, power 1 | 0.0413*** | 0.0183*** | 0.0004 |
| Inverse distance, 100 miles, power 2 | 0.1012*** | 0.0412*** | -0.0251** |

Notes: * significance at 0.05, ** significance at 0.01, ***significance at 0.001.