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*Research Article*

# Population Change and Its Driving Factors in Rural, Suburban, and Urban Areas of Wisconsin, USA, 1970–2000

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Population growth (or decline) is influenced by many factors that fall into the broad realms of demographic characteristics, socioeconomic conditions, transportation infrastructure, natural amenities, and land use and development across space and time. This paper adopts an integrated spatial regression approach to investigate the spatial and temporal variations of these factors' effects on population change. Specifically, we conduct the analysis at the minor civil division level in Wisconsin, USA, from 1970 to 2000. The results suggest that the factors have varying effects on population change over time and across rural, suburban, and urban areas. Their effects depend upon the general trend of population redistribution processes, local dynamics, and areal characteristics. Overall, a systematic examination of population change should consider a variety of factors, temporal and spatial variation of their effects, and spatial spillover effects. The examination should have the flexibility to identify and incorporate influential factors at a given point in time and space, not to adhere to a single set of drivers in all circumstances. The findings have important implications for population predictions used for local and regional planning.

## 1. Introduction

Land-use conflicts, regional/tribal warfare, environmental degradation, and competition for scarce resources are all exacerbated by growing populations. Holistic or systematic approaches are becoming critically important in tackling the complexity of development and population change [1–3]. Research findings have suggested that population growth (or decline) is determined jointly by demographic, social, economic, political, geographic, and cultural forces as well as temporal and spatial influences [4]. However, the majority of existing research is focused on only some of the factors and influences and does not consider others [5]. This might be due to the fact that development and population change are complex and require interdisciplinary knowledge, but existing studies are often conducted within disciplinary boundaries [3, 6]. In addition, simulating the complexity of population change requires well-grounded expertise in methodology, and putting together a dataset with a variety of variables across space and time is expensive. A wide range of results is possible by omitting relevant factors and influences from empirical models [7]. Therefore, because the various studies tend to focus on specific factors and influences within disciplinary boundaries and omit others, the existing research on population change often generates different and sometimes conflicting findings [8]. This had led to a gap in the literature of a systematic view of population change. This paper attempts to help fill this gap by systematically examining population change's influential factors as well as their temporal and spatial dynamics. This study provides a more dynamic and less biased estimates of the effects and a more comprehensive understanding of population change.

Development and population change are complex—they have exhibited spatial variations in different time periods driven by different factors. For example, we recognize several distinctive periods in the United States history: monocentric cities from about 1850 to 1930, the rise of suburban patterns around the beginning of the 20th century, "turnaround migration" bringing people back to amenity-rich rural areas in the 1970s, "renewed metropolitan growth" in the 1980s, rural rebound in the 1990s, and selective deconcentration in the 2000s (for an extensive literature review, see [9]). These different population redistribution processes—centralization, decentralization, rural renaissance, renewed metropolitan growth, rural rebound, and selective deconcentration—are characterized by different principal driving factors. One important factor in a certain time period may become unimportant in another, and vice versa. When the principal determinants change, population redistribution patterns also change. These factors can be characterized in broad realms, including demographic characteristics, socioeconomic conditions, transportation accessibility, natural amenities, and policies and biophysical conditions related to land use and development [8].

What makes studying development and population change more complex is that the effects of the driving factors vary across space. Population change and its driving factors can be spatially correlated [10, 11]. While most existing urban and regional development literature sees urban or metropolitan areas as the growth engine but rural or nonmetropolitan areas as the residuals and therefore conducts research separately in these areas, these areas have been found to interact with each other and together affect development and population change [3]. In addition, some factors may be more important in some areas than in others, thus displaying spatial variations in their influence on population change [12, 13].

Recent developments in spatial demographic research coupled with an upsurge in availability of geographically referenced data and sophisticated software packages for spatial analyses allow a comprehensive, holistic analysis of driving factors' effects on population change over time and across space. Our central research question is the following: how do the driving factors' effects on population change vary over time and across space? Specifically, we ask three subquestions: what is the relative importance of the driving factors in explaining population change? Do the effects change over time, and if so, how? Do the effects vary across rural, suburban, and urban areas, and if so, how?

To answer these questions, we adopt an integrated spatial approach to examine population change and its driving factors in time periods with different population redistribution processes and across rural, suburban, and urban areas. The integrated spatial approach, which was initially developed in Chi [5] for the purpose of studying highway impacts on population change, provides an integrated way to study population change and its driving factors spatially and temporally. The approach considers a variety of factors that drive population change, examines the spatial variations of their effects, and selects the optimal spatial weights matrix among many ones. We apply this approach to data related to population change at the minor civil division (MCD) level in Wisconsin, USA, from 1970–2000, by considering four elements: a wide range of factors, the temporal variation of their effects on population change, the spatial variation of the effects, and spatial spillover effects of population change. Wisconsin is chosen as a study area because our *a priori* understanding suggested that we would observe spatial and temporal variability in the influence of population change drivers and because appropriate data were readily available.

In the following sections, we first describe the research area and data and address the methodology. We then report the results from two perspectives: the relative importance of the driving factors in explaining population change over time and their relative importance across rural, suburban, and urban areas. Finally, we conclude this paper with a summary and discussion section.

## 2. Data

We focus on population change from 1970 to 2000 at the MCD level in the state of Wisconsin in the United States as the research case to study the spatial and temporal variations of the driving factors' effects on population change. Wisconsin is a "strong MCD" state, meaning that its MCDs (towns, cities, and villages) all act as functioning governmental units. In other words, each MCD has elected officials who raise revenues for their localities and provide services to their constituents. The great advantage of using MCDs as the unit of analysis is their relevance to local planning. The MCD geography in Wisconsin consists of political territories that are mutually exclusive. MCD boundaries were not stable from 1970 to 2000 because over time boundaries shift, new MCDs emerge and old MCDs disappear, MCD names change, and the statuses of the MCDs in the state's jurisdictional hierarchy change (e.g., towns become villages and villages become cities). Because of such changes, we adjusted the data to establish a spatially consistent data set over time. This resulted in an analytical data set consisted of 1,837 MCDs, where the average size of an MCD was 29.6 square miles, and the range was from 0.1 to 368. The average MCD population was 2,920 persons in 2000, with a range from 37 to 596,974.

We classified the MCDs into rural, suburban, and urban areas based on the 2000 Census Urbanized Areas and 2000 Metropolitan and Micropolitan Statistical Areas (MMSAs) defined by the U.S. Office of Management and Budget. We categorize the MCDs that fall into the Census Urbanized Areas as urban areas, the MCDs that fall into the MMSAs but not the Census Urbanized Areas as suburban areas, and the MCDs that fall out of the MMSAs and Census Urbanized Areas as rural areas (Figure 1) (There are many classifications of rural, suburban, and urban areas, but a standard classification does not exist [14]. Our categorization is useful for evaluation purposes but not necessarily an accurate reflection of Wisconsin's conditions).

For this study, decennial U.S. Census Bureau censuses from 1970 to 2000 (with commercial reworking done by Geolytics, Inc.) provide the population data. The U.S. Census Bureau, the Federal Bureau of Investigation, and the State of Wisconsin Blue Books provide additional demographic data and socioeconomic data. The National Atlas of the United Sates, the Wisconsin Department of Transportation, the Wisconsin Bureau of Aeronautics, and the Department of Civil and Environmental Engineering of the University of Wisconsin-Madison provide the transportation infrastructure data. The U.S. Geological Survey, the Wisconsin

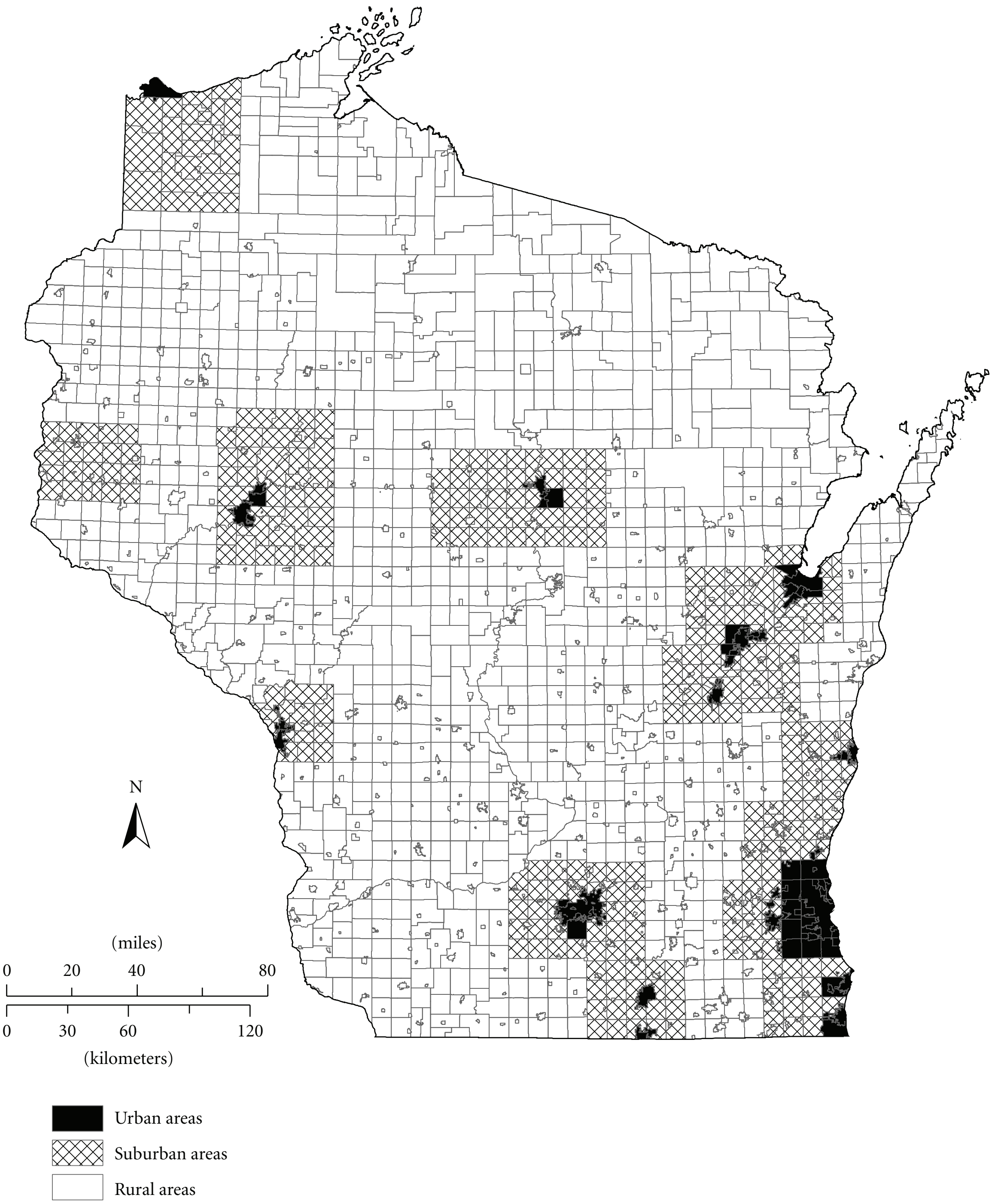


Figure 1: The classification of rural, suburban, and urban areas in Wisconsin.

Department of Natural Resources, and the Environmental Remote Sensing Center and the Land Information & Computer Graphics Facility of the University of Wisconsin-Madison provide data on the geophysical factors and natural amenity characteristics. These primary and secondary data are used to generate variables at the MCD level.

*2.1. Population Change.* For this study, population change in terms of population counts as reported by the U.S. Bureau of Census is the dependent variable and is expressed as the natural log of population at a census year over the population ten years earlier. For example, the measure of growth rate from 1970 to 1980 is the natural log of the 1980 population

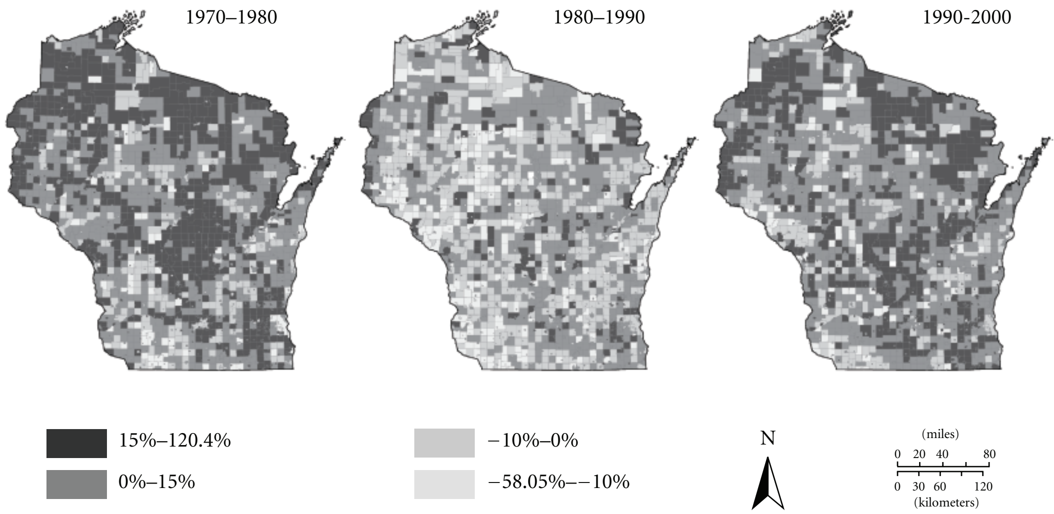


Figure 2: Population growth in 1970–1980, 1980–1990, and 1990–2000 in Wisconsin.

divided by the 1970 population. Calculating population change this way helps us achieve the normal "bell-shaped" distribution, makes interpreting the population change rate easier (growth is shown by a positive value; decline is shown by a negative value; no change at all is shown by zero), and controls the effect of initial population size [15].

Figure 2 shows population change in three time periods: 1970–1980, 1980–1990, and 1990–2000. From 1970 to 1980, relatively high population growth occurred in rural and suburban areas. A majority of MCDs experienced population decline from 1980 to 1990, the slowest growth decade in the history of Wisconsin. From 1990 to 2000, relatively high population growth occurred in Northern Wisconsin, Central Wisconsin, and some suburban areas. There were more MCDs with high growth rates from 1970 to 1980 than from 1990 to 2000.

*2.2. Driving Factors of Population Change.* Regional scientists, demographers, human geographers, and researchers in other disciplines have studied the mechanism and driving factors of population change and found a variety of factors that cause the changes (see [8, 16] for a review of the literature). In many studies, these factors are chosen by a specific disciplinary perspective rather than an integrated perspective informed by multiple disciplines. A wide range of results are possible by excluding relevant variables from a model, and such exclusions potentially bias parameter estimates for the variables included in the model [7]. A holistic examination of population change and its driving factors has been called for in many studies (e.g., [17]). This demand has been addressed by the frameworks of coupled human and environment research (e.g., [18]), human ecology [19], integrative tourism planning [20, 21], and others. These systematic approaches produce useful information about the complex interactions between population change and its driving factors and enable local planners and decision makers to examine "what if" planning scenarios. A more extensive review of the factors and frameworks has been separately prepared and is found in a companion paper available from the authors. These frameworks generally categorize the factors of population change into the realms of demographic characteristics, socioeconomic conditions, physical infrastructure, environmental and geophysical factors, cultural resources, and potential legal constraints.

Within these realms of population change's driving factors, for this study we selected 30 variables based on data availability and judgment about the Wisconsin situation to examine the factors' relationships with population change. These variables include the following:

(i) demographic characteristics (population density, percent young, percent old, percent blacks, and percent Hispanics),

(ii) socioeconomic conditions (unemployment rate, income, percent population with high school education, percent population with Bachelor's degree, percent college population, percent housing units using public water, percent seasonal housing, real estate value, county seat status, percent workers in retail industry, and percent workers in agriculture industry),

(iii) transportation accessibility (proximity to central cities, proximity to airports, proximity to major highways, highway density, and public transportation),

(iv) natural amenities (percent forest coverage, percent water coverage, percent wetland coverage, percent public land coverage, lengths of lakeshore/riverbank/coastline, golf courses, and viewshed),

(v) land use and development (water, wetland, slope, tax-exempt lands, and built-up lands).

The variables of demographic characteristics and socioeconomic conditions as well as public transportation are measured in 1970, 1980, and 1990. Instead of being measured in all three time points, the proximity variables of transportation accessibility as well as the variables of natural amenities and land use and development are measured in one time point (2000 and 1992–1993, resp.) because these variables do not change much over the time studied, 1970–2000. These variables have been discussed in detail in Chi [16].

Using all of these variables in a statistical analysis could induce multicollinearity to regression models that affects the models' efficiency. This problem of multicollinearity can be solved by reducing the dimensions of variables. Principal factor analysis (PFA) and spatial overlay methods were applied for reducing model data dimensions as well as generating indices. PFA with varimax rotation and the Kaiser [22] criterion was used to generate indices for four of the five groups of variables—demographics (local demographic characteristics), livability (social and economic conditions), accessibility (transportation infrastructure), and desirability (natural amenities). The varimax rotation, which is the most common rotation method in factor analysis, was implemented for better facilitating the interpretation of factors. The Kaiser criterion, which keeps the factors with eigenvalues over 1, was used to determine the number of factors to be used for representing each index. The PFA method is useful for evaluating the relative importance of the four groups of variables.

The ModelBuilder function of ArcGIS [23] was used in this study to generate the developability (land availability for development) from land use and development variables. The developability of a region is determined by its geophysical characteristics, built-up lands, cultural resources, and legal constraints. Ideally we want to use all of the four types of variables to derive the developability index. However, due to the limitation of data availability, we used only geophysical characteristics and built-up lands to generate the developability index. These variables include water, wetland, slope, tax-exempt lands (public and institutional land not available for development), and built-up lands. Small fine-scale pixels (30 meters by 30 meters) of developable lands were derived from the ModelBuilder analysis and subsequently aggregated to their corresponding MCDs. The developability index is expressed as the proportion of developable lands in each MCD. When studying land use and development variables' collective effects on population change, existing social demographic studies often aggregate them into one or more indices by PFA or other statistics-based weighted aggregation methods [24]. However, such generated indices cannot provide an accurate estimate of the amount of lands available for development because some of the layers may overlap; for example, water may overlap with parks. The ModelBuilder function can recognize the overlapped areas and count them only once; thus, it provides a more accurate estimate of land developability. For details about this approach, refer to Chi [25].

From the 30 driving factors as addressed above, we employed PFA and the ModelBuilder function to produce indices for demographics, livability, accessibility, desirability, and developability, as discussed below (Table 1).

(i) Demographics. Two demographic indices each were generated for representing local demographics in 1970, 1980, and 1990. The first index accounted for 26%–35% variance, mainly explained by the percentages of young and old. The second index accounted for 23%–29% variance, explained by population density and the percentages of blacks and Hispanics. Thus, demographic index 1 can be seen as an age-structure factor, and demographic index 2 can be roughly seen as a race factor.

(ii) Livability. Three livability indices each were generated for representing developmental amenities and urban-like conditions suitable for convenient lifestyles and quality of living in 1970, 1980, and 1990. Livability index 1 accounted for approximately 33% of total variance in each of the three years and was mainly explained by income, real-estate value, and educational attainments. Livability index 2 accounted for 15%–19% variance and was mainly explained by the percentage of housing units using public water and more workers in retail than agricultural industries. Livability index 3 accounted for 10%–13% variance and was mainly explained by the percentage of seasonal housing units. These three factors can be interpreted as wealth and education, modernization, and luxury. Accessibility.

(iii) Accessibility. Two accessibility indices were generated for each year. Accessibility index 1 accounted for about 33% variance and was mainly explained by proximity to central cities and highway density. Accessibility index 2 accounted for 20% variance and was explained by public transportation. The two indices can be interpreted as proximity and infrastructure and public transportation.

(iv) Desirability. Three desirability indices, which totally accounted for 63% of total variance, were retained for representing the natural amenities desirable for living in certain MCDs. The first index was mainly explained by the percentages of forest, wetland, and public land areas; the second by viewsheds; the third by the length of riverbank/lakeshore/coastline and golf courses. The three factors can be interpreted separately as green space, scenery, and recreation.

(v) Developability. Only one index was generated to represent the available lands for conversion and development. The proportion of developable lands in each MCD provides an interesting mechanism to predict the direction and trend of land development. For descriptive purposes, it logically presents an explanatory element of population redistribution.

## 3. Methodology

In this study, we adopted and modified the integrated spatial approach developed in Chi [5] to examine the effects of the driving factors on population change in Wisconsin in 1970–1980, 1980–1990, and 1990–2000 across rural, suburban, and urban areas. Specifically, our methodology includes four

Table 1: Principal factor analysis by varimax rotation with Kaiser criterion.

(a)

| Demographic variables | 1970 factor loadings | | 1980 Factor loadings | | 1990 factor loadings | |
|---|---|---|---|---|---|---|
| | Factor 1 | Factor 2 | Factor 1 | Factor 2 | Factor 1 | Factor 2 |
| Variance explained | 26.73% | 23.91% | 35.00% | 27.82% | 31.43% | 28.72% |
| Population density | −0.162 | 0.445 | 0.251 | 0.408 | −0.264 | 0.437 |
| Percent of young population (ages 12–18) | 0.635 | 0.033 | −0.799 | −0.093 | 0.784 | −0.008 |
| Percent of old population (ages ≥ 65) | −0.447 | 0.020 | 0.760 | −0.036 | −0.559 | −0.013 |
| Percent of blacks | 0.137 | 0.483 | −0.026 | 0.578 | 0.084 | 0.592 |
| Percent of Hispanics | 0.031 | 0.030 | −0.024 | 0.462 | 0.031 | 0.470 |

(b)

| Livability variables | 1970 factor loadings | | | 1980 factor loadings | | | 1990 factor loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Factor 1 | Factor 2 | Factor3 | Factor 1 | Factor 2 | Factor3 | Factor 1 | Factor 2 | Factor3 |
| Variance explained | 33.43% | 14.95% | 10.33% | 32.84% | 19.23% | 12.67% | 32.84% | 18.71% | 12.82% |
| Unemployment rate | −0.141 | 0.059 | −0.394 | −0.329 | 0.081 | 0.478 | −0.379 | 0.094 | 0.412 |
| Median household income | 0.712 | −0.083 | 0.198 | 0.812 | −0.095 | −0.261 | 0.873 | −0.139 | −0.243 |
| Percent of population with high school degree | 0.659 | 0.196 | 0.126 | 0.749 | 0.122 | −0.078 | 0.730 | 0.074 | −0.121 |
| Percent of population with bachelor's degree | 0.803 | 0.210 | 0.086 | 0.734 | 0.270 | −0.035 | 0.771 | 0.241 | 0.000 |
| Percent of college population | 0.283 | 0.131 | 0.109 | 0.354 | 0.227 | −0.122 | 0.351 | 0.233 | −0.127 |
| Percent of housing units using public water | 0.210 | 0.749 | 0.259 | −0.003 | 0.817 | −0.314 | −0.026 | 0.786 | −0.299 |
| Percent of seasonal housing units | −0.135 | −0.107 | −0.460 | −0.097 | −0.103 | 0.706 | −0.138 | −0.099 | 0.868 |
| Median house value | 0.842 | 0.265 | 0.175 | 0.918 | −0.027 | −0.031 | 0.895 | −0.001 | 0.030 |
| County seat status | 0.047 | 0.334 | 0.110 | −0.019 | 0.349 | −0.103 | −0.033 | 0.352 | −0.084 |
| Percent of workers in retail industry | 0.062 | 0.510 | −0.101 | 0.173 | 0.602 | 0.242 | 0.092 | 0.504 | 0.231 |
| Percent of workers in agricultural industry | −0.358 | −0.754 | 0.330 | −0.246 | −0.765 | −0.299 | −0.257 | −0.736 | −0.237 |

(c)

| Accessibility variables | 1970 factor loadings | | 1980 factor loadings | | 1990 factor loadings | |
|---|---|---|---|---|---|---|
| | Factor 1 | Factor 2 | Factor 1 | Factor 2 | Factor 1 | Factor 2 |
| Variance explained | 32.18% | 20.06% | 33.68% | 20.00% | 33.60% | 20.04% |
| Proximity to central cities | 0.550 | –0.073 | 0.556 | 0.034 | 0.561 | 0.014 |
| Proximity to airports | 0.394 | 0.004 | 0.376 | 0.123 | 0.382 | 0.072 |
| Proximity to major highways | –0.009 | 0.029 | –0.004 | –0.021 | –0.001 | –0.030 |
| Highway density | 0.687 | 0.121 | 0.649 | 0.247 | 0.650 | 0.325 |
| Percent of workers using public transportation to work | 0.140 | 0.259 | 0.412 | 0.341 | 0.172 | 0.416 |

(d)

| Desirability variables | Factor loadings | | |
|---|---|---|---|
| | Factor 1 | Factor 2 | Factor 3 |
| Variance explained | 27.07% | 20.46% | 15.26% |
| Percent of forest area | 0.732 | 0.073 | 0.079 |
| Percent of water area | 0.062 | –0.123 | 0.019 |
| Percent of wetland area | 0.489 | –0.420 | 0.157 |
| Percent of public land area | 0.468 | –0.091 | 0.053 |
| Length of riverbank/lakeshore/coastline | 0.369 | 0.257 | 0.646 |
| Golf courses | –0.007 | –0.092 | 0.387 |
| Viewsheds (12.5%–20% slope) | 0.161 | 0.928 | 0.080 |

steps: ordinary least squares (OLSs) regression, selection of an optimal spatial weights matrix, spatial dependence regression, and spatial regime regression.

First, the generated indices were incorporated into three OLS regression models to examine and compare their effects on population change in 1970–1980, 1980–1990, and 1990–2000. Their performance is evaluated on the basis of measures of fit, which include log likelihood, Akaike's Information Criterion (AIC) [26], and Schwartz's Bayesian Information Criterion (BIC) [27]. Log likelihood tests can be performed to compare models that are nested. If two models are not nested, AIC and BIC are often used. AIC and BIC penalize models that are overly complex when evaluating the fit of the model to the data. Models having a smaller AIC or BIC are considered better models in terms of model fitting balanced with model parsimony [28]. The OLS model residuals may exhibit spatial autocorrelation, and if so, the spatial autocorrelation should be controlled for by using a spatial weights matrix.

Second, we selected the optimal spatial weights matrix by following the procedure developed in Chi [5]. From fourty possible spatial weights matrices, we selected the one that captures the maximum spatial autocorrelation of the OLS model residuals across the three periods. The fourty weights matrices include the rook's case and queen's case contiguity weights matrices with order 1 and order 2; the $k$-nearest neighbor weights matrices, with $k$ ranging from 3 to 8 neighbors; the general distance weights matrices and the inverse-distance weights matrices with power 1 or power 2, from 0 to 100 miles at 10-mile increments based on the distance between the centroids of MCDs. For a review of other spatial weights matrices and other selection procedures of the optimal spatial matrix, refer to Aldstadt and Getis [29].

Third, the selected spatial weights matrix was used to diagnose for the type of spatial dependence in the OLS model residuals, from which the appropriate spatial regression model can be indicated. The diagnostics include Lagrange Multiplier (LM) tests for the lag dependence, error dependence, and a combination of both lag and error dependences, and robust LM tests for the lag dependence and error dependence. LM tests assist in detecting spatial dependence in the form of an omitted spatially lagged dependent variable and/or spatial error dependence [30]. Robust LM tests assist in diagnosing the pertinence of the spatial dependence if the LM tests for both the lag and error dependence are significant [31]. Based on the results of the spatial dependence tests, the appropriate spatial regression models are specified to further examine the effects of population change's driving factors in the Wisconsin MCDs in 1970–1980, 1980–1990, and 1990–2000.

Finally, we employed the spatial regime model, which can estimate coefficients separately for rural, suburban, and urban areas, to further examine the spatial variations of the driving factors' effects on population change in each of the three time periods. The spatial regime model can simultaneously consider spatial dependence and variations of the coefficients across rural, suburban, and urban areas [32]. The coefficient stability for each variable and the overall structural stability can be diagnosed by the spatial Chow test [33].

## 4. Results

*4.1. Influences of Indices on Population Change in 1970–80, 1980–90, and 1990–2000.* The indices were initially used in three OLS regression models to explain population change separately in 1970–1980, 1980–1990, and 1990–2000. In the OLS models, we assume that the model residuals were independently and identically distributed. However, such an assumption cannot hold if spatial dependence exists in the model. Therefore, we used 40 different spatial weights matrices as mentioned in the previous section to diagnose the spatial dependence in the OLS model residuals based on Moran's I statistics. The OLS model residuals exhibit significant spatial dependence in all three models by all 40 weights matrices. Moran's I statistic of model residuals generally decreases as the distance of spatial weights matrices increases from 10 miles to 100 miles in each of the three periods. The $k$-nearest neighbor weights matrices capture higher spatial dependence of model residuals than the distance-based weights matrices and the queen and rook contiguity matrices do in each of the three periods, except in 1970–1980, when the $k$-nearest neighbor matrices capture slightly less spatial dependence than the first-order queen and rook matrices. The $k$-nearest neighbor weights matrix is often preferred for data analysis of census units for three reasons [28]. First, the distance-based spatial weights matrices tend to make too many neighbors for urban areas but too few neighbors for rural areas, which becomes an issue for studying the influential factors' effects on population change across rural, suburban, and urban areas. Second, queen and rook contiguity matrices tend to make either too many or too few neighbors depending upon the number of rings. Third, the $k$-nearest neighbor matrix can provide a finer number of neighbors. In this study, the 5-nearest neighbor weights matrix captures the highest spatial dependence of all models' residuals. Thus, we chose it for further detecting the type of spatial dependence in the OLS model residuals as well as for accounting for spatial dependence in spatial regression models. The diagnostics show that both spatial lag and spatial error dependence exist in the 1970–1980 model residuals with spatial lag dependence being stronger; only spatial lag dependence exists in the 1980–1990 and 1990–2000 model residuals (Table 2). To make a consistent comparison across the three decades, we decided to use spatial lag models to account for spatial dependence.

The captured spatial lag dependence is significant in explaining population change in 1970–1980, 1980–1990, and 1990–2000 (Table 3). The consideration of spatial lag dependence in the spatial lag models improves model fitting to data balanced with model parsimony, based on the fact that the log likelihood value is larger and the AIC and BIC values are smaller for each corresponding spatial regression model. Thus, the more appropriate model to interpret the regression coefficients is the spatial lag model rather than the OLS model. For better interpreting and comparing the effects of the indices on population change, we reported the standardized coefficients rather than the unstandardized coefficients. The former allow comparisons of the relative importance of each index to others within each model and to itself across the three models.

Table 2: OLS regressions of population change in 1970–1980, 1980–1990, and 1990–2000.

| | 1970–1980 | 1980–1990 | 1990–2000 |
|---|---|---|---|
| *Indices* | | | |
| Demographics 1 (age structure) | −0.051* | 0.086** | 0.042 |
| Demographics 2 (race) | −0.120*** | 0.055* | −0.088** |
| Livability 1 (education) | 0.064** | 0.234*** | 0.155*** |
| Livability 2 (modernization) | 0.034 | 0.183*** | 0.166*** |
| Livability 3 (luxury) | −0.197*** | 0.118*** | 0.331*** |
| Accessibility 1 (proximity and infrastructure) | 0.076** | 0.016 | 0.039 |
| Accessibility 2 (public transportation) | −0.026 | −0.030 | −0.007 |
| Desirability 1 (green space) | 0.128*** | 0.049 | −0.073 |
| Desirability 2 (scenery) | −0.139*** | −0.027 | 0.013 |
| Desirability 3 (recreation) | −0.068* | −0.024 | −0.018 |
| Developability | 0.081** | 0.108*** | 0.095** |
| *Diagnostics for spatial dependence* | | | |
| LM (error) | 112.49*** | 68.92*** | 76.92*** |
| Robust LM (error) | 8.92** | 0.49 | 2.01 |
| LM (lag) | 141.40*** | 78.16*** | 93.59*** |
| Robust LM (lag) | 37.83*** | 9.72** | 18.68*** |
| *Measures of fit* | | | |
| Log likelihood | −2488.170 | −2487.980 | −2478.590 |
| AIC | 5000.340 | 4999.960 | 4981.180 |
| BIC | 5066.530 | 5066.150 | 5047.370 |

Notes: AIC = Akaike's Information Criterion. BIC = Schwartz's Bayesian Information Criterion. $^{*}P \le .05$; $^{**}P \le .01$; $^{***}P \le .001$.
The coefficients displayed have been standardized in order to compare the relative importance of each variable to other variables within each model and to the variable itself across the three models.

The magnitude and significance of the standardized coefficients exhibit obvious variations within each of the three decades and across the three decades. First, the two demographic indices had negative effects on population growth in 1970–1980 but positive effects in 1980–1990; only demographic index 2 affected population growth in 1990–2000 (negatively). Demographic index 1 in 1970 is an age-structure index and is associated positively with young population but negatively with old population. More young population than old population in 1970 led to population decline from 1970 to 1980. Demographic index 1 in 1980 is also an age-structure index but is associated negatively with young population and positively with old population. More young population than old population in 1980 led to population decline from 1980 to 1990. The findings are consistent with the long-standing view that young population has higher mobility potential than old population; young people are more likely movers, but old people are more likely stayers [34]. Areas with more young population and less old population are likely to experience population decline.

Demographic index 2 is a race index. Higher percentages of blacks and Hispanics were associated with population decline in 1970–1980 and 1990–2000 but with population growth in 1980–1990. In Wisconsin, blacks and Hispanics mainly live in metropolitan areas [35]. In 1980–1990 when the population redistribution pattern was renewed metropolitan growth, the MCDs with higher percentages of blacks and Hispanics grew because those MCDs likely are in metropolitan areas. In contrast, in 1970–1980 and 1990–2000 when rural areas grew, the MCDs with higher percentages of blacks and Hispanics experienced population decline.

Second, only one livability index affected population growth in 1970–1980, but all three livability indices had positive effects on population growth in 1980–1990 and 1990–2000. In 1970–1980, livability index 3 had negative effects on population growth. However, livability index 3 is negatively associated with seasonal housing units in 1970 (see Table 1). Thus, a negative coefficient of livability index 3 on population growth represents a positive effect of seasonal housing units on population growth. The 1970s is the first decade in Wisconsin when migrants moved to rural areas rich in natural amenities. The MCDs with higher percentages of seasonal housing units attracted migrants. Therefore, seasonal housing units (luxury) played a stronger role than wealth, education, and modernization in attracting population in that decade.

In 1980–1990, all three livability indices had positive effects on population growth, but wealth, education, and modernization had stronger effects on population growth than seasonal housing did. Wisconsin experienced metropolitan growth in the 1980s mainly due to economic

Table 3: Spatial lag models of population change in 1970–1980, 1980–1990, and 1990–2000.

| | 1970–1980 | 1980–1990 | 1990–2000 |
|---|---|---|---|
| *Indices* | | | |
| Demographics 1 | −0.052* | 0.098*** | 0.032 |
| Demographics 2 | −0.094*** | 0.058* | −0.083** |
| Livability 1 | 0.042 | 0.183*** | 0.114*** |
| Livability 2 | 0.037 | 0.173*** | 0.146*** |
| Livability 3 | −0.157*** | 0.082** | 0.268*** |
| Accessibility 1 | 0.054* | 0.010 | 0.036 |
| Accessibility 2 | −0.014 | −0.028 | −0.005 |
| Desirability 1 | 0.095** | 0.050 | −0.055 |
| Desirability 2 | −0.102*** | −0.018 | 0.014 |
| Desirability 3 | −0.044 | −0.006 | −0.012 |
| Developability | 0.075* | 0.103*** | 0.084** |
| Spatial lag | 0.327*** | 0.267*** | 0.290*** |
| *Measures of fit* | | | |
| Log likelihood | −2432.660 | −2454.770 | −2438.580 |
| AIC | 4891.320 | 4935.540 | 4903.170 |
| BIC | 4963.020 | 5007.250 | 4974.870 |

Notes: AIC = Akaike's Information Criterion. BIC = Schwartz's Bayesian Information Criterion. $^{*}P \le .05$; $^{**}P \le .01$; $^{***}P \le .001$.
The coefficients displayed have been standardized in order to compare the relative importance of each variable to other variables within each model and to the variable itself across the three models.

disruptions such as the farm debt crisis, deindustrialization, and urban revival. The economic perspective of livability was more appreciated than the seasonal housing perspective in economic downturn [8]. In 1990–2000, however, seasonal housing units played a stronger role than wealth, education, and modernization did. Rural areas rebounded in the 1990s in Wisconsin [9] and thus the MCDs with higher percentages of seasonal housing attracted more migrants.

Third, accessibility, which is found to be an important factor of population change in many existing studies (see [36] for a summary of the literature), had no effects on population change in 1980–1990 and 1990–2000. Only accessibility index 1 had significant but negligible effects on population change in 1970–1980. This finding supports the notion that accessibility is a facilitator of population flows [5]. When rural areas rebound, transportation accessibility acts as a facilitator to promote movement from urban areas to rural areas. When metropolitan areas grow, transportation accessibility still acts as a facilitator to move people from rural to urban areas. Improved accessibility promotes population flows from one area to another, but accessibility itself does not create population growth or decline.

Fourth, two desirability indices had significant effects on population change in 1970–1980, a decade characterized as having "turnaround migration" in the USA [37, 38]. The long-standing trends of outmigration from rural to urban areas reversed for the first time in the history of the US as natural beauties attracted migrants to rural areas. Natural amenities such as forests, wetlands, national parks, and wildlife reserves attracted migrants to those recreational counties. Recent rural policy and decision-making increasingly relies on natural amenities as rural growth engines [8]. However, none of the desirability indices had statistically significant effects on population change in 1980–1990 and 1990–2000. This may be due to the fact that natural amenities have spatially varying effects on population change, which will be explored in the next subsection.

Fifth, developability had positive effects on population growth in all three decades. The more lands are available for development, the more likely population growth is to occur. This observation is consistent in the various population redistribution processes of turnaround migration, renewed metropolitan growth, and rural rebound. It suggests that land developability is necessary for population growth and development.

Sixth, the spatial lag effects are significant in all three decades and are the strongest compared to other variables. Population change is a phenomenon often found to be spatially autocorrelated. Population growth (or decline) in an area can be influenced by population growth (or decline) in surrounding areas. The observed spatial dependence of population change has been well explained by several theories and numerous studies (for a summary of the literature, please see [10, 11, 28]).

Overall, spatial lag effects and developability had relatively consistent effects on population change at the MCD level within any temporal context: population change in an area spills over to its neighbors; population growth and development require available lands. However, the effects of the other indices varied in terms of both significance and magnitude. Their effects on population change depend upon interactions among them as well as the general population redistribution trends; any of the indices by themselves are not sufficient for promoting population growth. In addition, the

Table 4: Spatial regime models of population change in 1970–1980, 1980–1990, and 1990–2000 by rural, suburban, and urban areas.

| | 1970–1980 | | | | 1980–1990 | | | | 1990–2000 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R | S | U | Instab | R | S | U | Instab | R | S | U | Instab |
| *Indices* | | | | | | | | | | | | |
| Demographics 1 | −0.100*** | 0.017 | 0.505** | ** | 0.169*** | −0.017 | 0.114 | — | 0.027 | −0.171* | 0.438* | ** |
| Demographics 2 | 0.005 | −0.336** | −0.132* | ** | 0.123*** | 0.073 | −0.091 | ** | −0.102** | 0.030 | −0.099 | — |
| Livability 1 | −0.017 | 0.120* | −0.093 | — | 0.185*** | 0.186*** | −0.002 | — | 0.109* | 0.246*** | −0.069 | ** |
| Livability 2 | −0.024 | 0.250*** | −0.052 | *** | 0.083* | 0.344*** | 0.505 | ** | 0.101** | 0.239** | 0.066 | — |
| Livability 3 | −0.152*** | 0.007 | −0.409 | * | 0.064 | −0.051 | 0.411 | — | 0.284*** | −0.222* | −0.337 | *** |
| Accessibility 1 | 0.134 | −0.023 | 0.007 | — | 0.013 | −0.097 | −0.043 | — | 0.072 | −0.015 | −0.019 | — |
| Accessibility 2 | −0.023 | −0.020 | 0.056 | — | 0.025 | −0.029 | 0.024 | — | 0.003 | 0.041 | 0.035 | — |
| Desirability 1 | 0.147*** | 0.036 | −0.483 | * | 0.075 | 0.102 | −0.805** | ** | −0.049 | 0.153 | −0.206 | — |
| Desirability 2 | −0.081*** | −0.051 | 0.682 | — | −0.012 | −0.005 | 0.289 | — | 0.030 | −0.121 | −0.183 | — |
| Desirability 3 | −0.043 | −0.044 | −0.007 | — | 0.004 | −0.090 | 0.259* | * | −0.012 | −0.053 | 0.023 | — |
| Developability | 0.111** | −0.032 | 0.248 | — | 0.108** | 0.047 | 0.419** | * | 0.063 | 0.181* | 0.176 | — |
| Spatial lag | 0.265*** | 0.293*** | 0.084 | — | 0.228*** | 0.209*** | 0.053 | — | 0.230*** | 0.202*** | 0.087 | — |
| *Measures of fit* | | | | | | | | | | | | |
| Log likelihood | | −2361.06 | | | | −2389.78 | | | | −2389.39 | | |
| AIC | | 4800.13 | | | | 4857.57 | | | | 4856.78 | | |
| BIC | | 5015.25 | | | | 5072.69 | | | | 5071.90 | | |

Notes: *R* = Rural areas; *S* = Suburban areas; *U* = Urban areas; *Instab* = Instability of coefficients.
AIC = Akaike's Information Criterion. BIC = Schwartz's Bayesian Information Criterion.
$^{*}P \le .05$; $^{**}P \le .01$; $^{***}P \le .001$.
The coefficients displayed have been standardized in order to compare the relative importance of each variable to other variables within each model and to the variable itself across the three models.

difference of the effects may be due to the fact that spatial variation exists in the effects of these indices. Also, proximity to urban agglomeration affects population dynamics across space [39]. We next examine the effects of the indices on population change separately in rural, suburban, and urban areas using a spatial regime model.

*4.2. Influences across Rural, Suburban, and Urban Areas.* The results show that the indices' effects on population change varied across rural, suburban, and urban areas (Table 4). First, demographic indices had varying effects on population change across the three areas over the three decades; no consistent findings can be reached. The effects of the indices could be positive, negative, or none in any of the three areas. This finding may simply be due to the fact that demographic characteristics (age structure and racial composition specifically) are not the determining factors of population growth, which is jointly determined by many other factors such as transportation accessibility, natural amenities, and land use and development. These factors are often ignored in traditional social demographic research but are considered by other disciplines as important in explaining population change. As this research suggests, population change is affected by many factors differently over time and across space. Population change should be investigated in a more holistic manner.

Second, livability played an important role in affecting population change only in rural and suburban areas but not in urban areas over the three decades. Convenient lifestyles and quality of living in rural and suburban areas are assets appreciated by migrants. In contrast, convenient lifestyles and quality of living are perceived to be part of urban life and thus do not add more to urban population growth. In addition, urban population change is more restricted by existing constraints such as land available for development and policies such as comprehensive land use plans and zoning ordinances [5]. For example, if a district is converted from a residential area to an area allowing commercial development, the district will likely lose population no matter how livable it is. The divisions of residential, commercial, and other developments combined with zoning regulations complicate population change. Analyzing the effects of land use programs on urban population change, which is not included in this study, may provide insights into the process of urban population change. Moreover, urban population dynamics may be better modeled at finer geographic levels such as census tracts, block groups, and blocks [5]. Urban populations are more dense than suburban and rural populations; population interactions in urban areas are more intensive. For instance, well-being could be dramatically different between two neighboring tracts—slums on one side of the street but the wealthy living on the other side [40].

Third, accessibility had no effects on population change in rural, suburban, or urban areas in any of the three decades. This finding best supports the notion that accessibility acts as a facilitator of population flows [5]. Accessibility itself does not promote or hinder population growth. Accessibility operates as a facilitator for people to connect to their residential locations, work locations, and shopping locations and may contribute to the spatial lag effects of population change. With higher accessibility, people can live in one location but work in another. When one area experiences net inmigration, housing prices will increase and in turn drive some of the migrants to surrounding areas, where housing prices are lower, until they reach equilibrium. In contrast, when one area experiences net outmigration, housing prices will decrease and in turn attract some residents from surrounding areas to this area. Transportation accessibility is best regarded as a facilitator in strengthening the spatial lag effects of population redistribution. Nevertheless, there are many other definitions of the role that transportation accessibility plays in affecting population change (see [36] for a summary of the literature). Apparently the definition of facilitator can best explain our findings.

Fourth, desirability had effects on rural and urban population change but not suburban population change. Desirability played an important role in rural areas in 1970–1980, a decade of turnaround migration. This finding is consistent with those from rural demography literature in which the post-1970 turnaround migration was thought to be a function of the attractive power of natural amenities in rural America [37, 38, 41]. Desirability did not affect suburban population change in any of the three decades. This may be simply due to the fact that migrants select suburban areas for their convenient access to both natural amenities in rural areas and urban amenities in urban areas. In urban areas, recreation had positive effects, but green space had negative effects on urban population growth only in 1980–1990, a decade of renewed metropolitan growth. Similar to the effects of livability, the effects of desirability on urban population change depend on constraints such as land available for development and policies such as comprehensive land use plans and zoning ordinances, and their effects might be better studied at a finer geographic level.

Fifth, developability exhibited different effects over time and across the three areas. The availability of lands for development promoted rural population growth in 1970–1980 and 1980–1990. Developability appeared to be important for attracting migrants in 1970–1980, when population started to move to rural areas for natural amenities for the first time. The trend of rural land development in the 1970s continued into the 1980s although this was a decade of renewed metropolitan growth. Developability has significant effects on suburban population growth only in 1990–2000. When population redistribution patterns switch from renewed metropolitan growth to rural rebound, suburban areas may benefit from their locational advantage to access both rural natural amenities and urban amenities. In urban areas, developability had effects on population growth only in 1980–1990, when metropolitan areas renewed their growth.

Sixth, spatial lag has positive and similar effects on rural and suburban population growth in each of the three decades. Population growth (or decline) in rural and suburban areas is affected by population growth (or decline) in surrounding areas. However, there were no significant spatial lag effects in urban areas. Again, this may be due to the fact that urban population change is more constrained by existing development and restricted by land use and policy regulations. The divisions of residential, commercial, and other developments combined with zoning regulations may influence the spatial dynamics of population change.

It should also be noted that some of the indices' effects on population change were statistically different across rural, suburban, and urban areas. In 1970–1980, five indices (the two demographic indices, two of the three livability indices, and one desirability index) had statistically different effects on population change across the three areas. In 1980–1990, five indices (one demographic index, one livability index, two desirability indices, and the developability index) also had statistically different effects on population change across these areas. In 1990–2000, one demographic index and two livability indices exhibited different effects on population change across these areas.

The findings are in line with prior research on the spatial heterogeneity of population dynamics and economic growth and development (e.g., [12, 13, 39]). Population growth exhibits spatial variations. The influential factors' effects on population growth also vary spatially. Moreover, the spatial variations of population growth and that growth's relationship to its influential factors vary over time when population redistribution trends change. Population growth and development can be better understood within its spatial and temporal contexts informed by an interdisciplinary perspective.

## 5. Summary and Discussion

*5.1. Summary.* Population growth (or decline) and development is affected by a variety of factors that fall into broad realms of demographic characteristics, socioeconomic conditions, transportation accessibility, natural amenities, and land development, as categorized generally in existing studies. These factors' effects on population change, however, are not constant over time or across space. The effects exhibit spatial dependence and variations and vary with population redistribution trends. A systematic understanding of population change and its relationship to its driving factors requires a systematic consideration of influential factors across space and time. In this study, we focused on population change from 1970 to 2000 at the MCD level in Wisconsin, USA, to investigate the relative importance of factors explaining population change over three time periods with different population redistribution patterns and across rural, suburban, and urban areas.

The results suggest that the factors examined have varying effects on population change across the three areas over the three decades. First, rural and suburban population growth (or decline) is affected by population growth (or decline) in surrounding areas, no matter whether in periods of turnaround migration, renewed metropolitan growth, or rural rebound. Urban population change, however, is not associated with population change in surrounding areas—urban growth may be more restricted by existing land use and policies. Second, for a similar reason, livability also does not affect urban population change yet has effects on rural and suburban population change. Third, transportation accessibility does not affect population change but acts as a facilitator of population flows; accessibility itself does not promote population change in any of the three areas in any of the three decades. Accessibility seems to strengthen the spatial lag effects of population change. Fourth, the effect of desirability on population change depends upon the general population redistribution process. Desirability promotes rural population growth in turnaround migration periods and promotes urban population growth in renewed metropolitan growth periods. Desirability has no effect on suburban population growth—migrants may select suburban areas simply for the convenience in accessing both rural natural amenities and urban amenities. Fifth, developability promotes population growth in all three decades in general. But when population change is examined separately in the three areas, the effects rely more on the population redistribution process—developability has effects on rural population growth in turnaround migration and the following period, on suburban population growth in rural rebound periods, and on urban population growth in renewed metropolitan growth periods. Sixth, demographics has mixed effects on population change in the three areas—possibly due to the fact that other factors play stronger roles in affecting population change.

These specific findings could be generalized to some other regions of the US as well as to other developed countries at levels that act as functioning governmental units and have geographic sizes similar to MCDs. However, the findings are more generalizable to states with local characteristics (demographic composition, socioeconomic conditions, transportation infrastructure, natural amenities, and land developability) and population redistribution trends (rural renaissance in the 1970s, urban growth in the 1980s, and rural rebound in the 1990s) similar to those of Wisconsin.

*5.2. A Framework of Population Change.* This study suggests that a systematic examination of population change should consider four elements, which can be generalized to other population change studies. First, population change is affected by a wide range of factors; none of the factors can individually determine the direction and magnitude of population change. These factors often interact with, and are contingent on, each other to jointly influence population change. For instance, it would be difficult to promote population growth and economic development in an area with strong livability and desirability if that area did not have a well-developed transportation network [42]. In addition, statistically, the exclusion of relevant factors from the model biases parameter estimates for the variables included in the model and thus potentially leads to inaccurate or biased results. Therefore, it is essential to consider factors from a variety of disciplines when examining population change.

Second, the factors have different effects on population change in time periods with different population redistribution processes, which are driven by different major factors. The same factor could be important in one time period but unimportant in another or could have positive effects on population growth in one time period but negative in another. For example, quality of life and amenities are central determinants of migration in good economies, but job opportunities are more important in times of economic downturn [8]. The factors' effects on population change depend upon the general trend of population redistribution processes.

Third, population change exhibits spatial spillover effects, that is, population change in one area can spill over to its neighboring areas. Development and improvement in transportation networks increase population interactions and flows among places nearby and even places far away: highway networks connect neighboring places together, and proximity to airports connects distant places together [43]. The spillover effects, however, could be either positive (a "spread" effect) or negative (a "backwash" effect), depending upon the mutual geographic dependence of economic growth and development between these areas; this phenomenon has been well explained by the growth pole theory [44].

Fourth, the factors have varying effects on population change from rural to suburban to urban areas. Some factors appear to affect population change more in one area than in others. The effects also depend upon the areal characteristics of the area; for example, urban population change is more constrained by existing land use and policies. Spatial variations of the effects exist because local areas may vary in their growth mechanisms in ways that are not readily captured in traditional global standard regression models [13]. The global estimates of coefficients can only reflect the collective effects but not the local variations of the effects, which would provide misleading information of local dynamics.

Overall, population change is affected by a variety of factors whose effects depend upon population redistribution trends and vary spatially. In addition, population change itself exhibits spatial spillover effects. Therefore, it is important to consider all four elements (factors, temporal, spillover, and spatial) when studying population change, as this would not only make the analysis more methodologically rigorous and provide a more systematic understanding of population change but also offer less biased policy implications to policy and decision makers.

*5.3. Policy Implications.* The findings have important implications for population predictions used for local and regional planning. It is tempting for researchers to seek singular solutions to modeling prediction problems. However, this research suggests that, for population predictions in small areas under dynamic conditions, it may not be possible to accurately predict change from a preselected set of variables. Rather, prediction will require selection of variables from the data, allowing for strong *post priori* evaluation of the influences on population change, while suggesting that prediction of unknown futures is fraught. Accounting for spatial and temporal dynamics will be useful to reduce uncertainty in patterns, but not in selecting variables that are most influential at any given time or place.

Recent planning approaches and policies such as comprehensive planning and the "Smart Growth" law require a comprehensive consideration of population dynamics, housing, economic development, transportation, agricultural and natural and cultural resources, land use planning, utilities and community facilities, and other elements [45]. Planners and decision makers are interested in knowing the variety of results available from "what if" scenarios of their decisions and local and neighboring changes [46]. However, the possible results could be biased if the four elements of population change (factors, temporal, spillover, and spatial) are not systematically considered. A systematic examination of population change through the four elements will provide more robust results for policy and decision makers to help communities understand demographic challenges of deteriorating physical infrastructure, increasing income gaps, threats to environmental quality and natural amenities, housing shortages, traffic congestion, and changes in their neighboring places; look at the variety of results in "what if" scenarios, and suggest strategies to solve potential development problems.

This study examined population change holistically by considering its various driving factors as well as the temporal and spatial variations of the factors' effects. This study builds on existing analyses to examine, specifically and systematically, the ways in which biogeophysical variables and socioeconomic structural variables interact with demographic variables to influence local population growth or decline. Population dynamics should be placed in their historic, spatial, social, economic, and political settings and be linked to environmental constraining/facilitating forces. Population change should be modeled holistically rather than separately within the complex social and economic context.

*5.4. Future Research.* Although this research studied population change spatially and temporally by adopting an integrated spatial approach [5], alternative approaches exist to study population change systematically. Two examples include the recently developed spatial panel approach [47] and the Bayesian spatiotemporal interaction model [48]. These two models are capable of considering a wide range of variables as well as spatial and temporal influences. In addition, the recently rapid development in coupled human and natural systems provides not only sophisticated statistical models for considering the interactions between population change and its driving factors but also an integrated framework for tackling this research topic (e.g., [18]). Recent years have seen increasing emphasis on interdisciplinary research in studies examining human and environment relationships as required by competitive research funding [6], rapid development in spatial statistical methods and software packages [28], and increasing availability of geographically referenced longitudinal data and powerful computing facilities. These provide opportunities for developing theoretical and methodological perspectives of understanding population dynamics and development systematically.

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