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Evaluating natural resource amenities in a human life expectancy production function

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ABSTRACT

This study examined the effect of natural resource amenities on human life expectancy. Extending the existing model of the life expectancy production function, and correcting for spatial dependence, we evaluated the determinants of life expectancy using county level data. Results indicate that after controlling for socio-demographic and economic factors, medical facilities and risk factors, counties with natural amenities such as high proportion of land in forests, farmland, rangeland and water bodies, as well as mild climate such as longer sunlight hours during winter and cooler year around temperature exhibited longer life expectancies at birth. In addition, counties containing state parks and outdoor recreation facilities, and those located near federal wilderness parks were associated with the longer expectancies at birth. Findings from this study have several implications for natural resource economics and management, public health, and human development. An important message of our findings is that the traditional approach of public health should be extended beyond just controlling diseases or treating patients to a more comprehensive approach that also acknowledges the preservation and utilization of natural resources, environmental amenities, and outdoor recreation opportunities in maintaining public health, quality of life, and overall human development.

1. Introduction

Life expectancy has been a major metric in measuring long-term human health, social welfare, and development of our society (Barlow and Vissandjee, 1999; Lomborg, 2002). The human development index, which the United Nations uses to measure human development among countries, depends on life expectancy at birth in addition to other factors such as literacy rate and income (United Nations Development Program, 1997). Some even suggest that it is an important determinant of economic welfare calculus (Anderson, 2005). Life expectancy also influences fertility behavior, human capital investment (Shaw et al., 2005), and public funding on some basic human needs such as education and health care (Gradstein and Kaganovich, 2004), thereby determining the overall quality of life.

The average life expectancy has increased globally in recent years. The rate of increase in life expectancy among developing countries, however, was significantly higher compared to the developed countries (Lomborg, 2002). In the United States, the average life expectancy has steadily increased recently, but there is substantial variation across the nation. Ezzatti et al. (2008) found that life expectancy is decreasing in some parts of the United States, for example, including the deep South and the southern portions of the Midwest and Texas. The very question of what causes this variation cannot be answered unless we adopt a micro approach to examine life expectancy patterns within the United States.

Few studies have been focused on life expectancy (Barlow and Vissandjee, 1999; Shaw et al., 2005). Moreover, most have adopted a macro-approach, using countries as the analysis unit. These studies employed a life expectancy production function in which the socio-demographic factors, risk and safety factors, medical facilities and expenditures, and environmental variables were included as function arguments. The idea of a life expectancy production function is that all of these factors jointly determine the average life longevity of the country's population. Even though there is not a common standard among the studies in using specific factors to describe sociodemographic and economic conditions, factors such as literacy rate and income have been commonly used.

Barlow and Vissandjee (1999) reported that income level, education, fertility, and location are strong predictors of national life expectancy. They also noted that health expenditures and urbanization rates are rather weak determinants. Peltzman (1987) compared the effect of government health expenditures and wealth on life expectancy and reported that only wealth increases expectancy. Hertz et al. (1994) regressed country level life expectancy against literacy rate, availability of medical facilities, dietary factors, gross national

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product, and labor force. Results from their study revealed that literacy rate, animal product consumption, and access to safe water are positively associated to life expectancy.

Some researchers have studied the determinants of life expectancy by breaking down countries according to level of development. Shaw et al. (2005), for example, studied factors affecting life expectancy in developed countries. Their study reveals that pharmaceutical consumption increases life expectancy at various age levels. In another study, Sufian (1989) focused on developing countries and explained life expectancy by literacy rate, energy consumption, per capita gross national product, urban population, access to safe water, and medical resources. He concluded that only literacy rate, family planning efforts, and daily calorie consumption exhibit significant relationships with life expectancy. Rao (1988), in a study using a sample of 51 countries, noted that medical goods and services, literacy rate, and food calories increase life expectancy at birth whereas the amount of meat and poultry in the diet is negatively related to life expectancy.

A number of studies have analyzed the health benefits of landscape quality and environmental resources. Yang et al. (2005) and Nowak et al. (2006) looked at how urban forests help alleviate air pollution. Visiting or being exposed to green space or natural areas has been found to increase the psychological well-being and recovery from illness (Ulrich 1984; Parsons et al., 1998; Frumkin 2001; Kaplan 2001; Grahn and Stigsdotter, 2003). Townsend (2006) analyzed the health and wellbeing benefits of civic engagement in environmental activities. Hansmann et al. (2007) found that performing physical activities in forests and outdoor parks improved health condition of people. Ulrich (1984) observed a faster recovery among surgical patients, who viewed trees than those, who viewed a brick wall from their hospital window. De Vries et al. (2003) reported that people living in neighborhoods with more green spaces enjoyed better health than those living in neighborhoods without. Kaplan (1993) concluded that availability of nature in the view resulted in increase in satisfaction, more patience and enthusiasm and less frustration.

Sugiyama and Thompson (2008) studied the effect of quality of neighborhood open space on walking and active lifestyle of older people. Maas et al. (2006) looked at the effect of amount of green space with a radius of 1 km from residence and found a positive relationship between amount of green space and perceived general health. In an experiment based study, Yamada (2006) found that frequency and waves of sound from different types of forest had recreational and therapeutic values that affected people's health and well being. Maas and Verheij (2007) observed the application of nature-based physical activity for primary health care. Likewise, Sanesi et al. (2006) discussed the psychological and social dimensions of urban green space and analyzed the citizen's perception of environmental quality and health.

Velarde et al. (2007) reviewed more than 30 published journal articles written on the health benefits of environment and landscape elements. They summarized the total health effects of landscape into three categories[1], which included short-term recovery from stress or mental fatigue, faster physical recovery from illness, and long-term improvement on people's health and well being. However, their study also pointed out the fact that most of the existing studies relied on very coarse categories of land use (e.g. natural, urban etc.) to represent landscape element. They also suggested for more research to assess which specific component or characteristic of landscapes are important in providing positive health outcome in a community (Velarde et al., 2007). In addition, nearly all of the paper they revised utilized relatively poor measures of public health such as respondent's self-reported condition of health, frequency of sick-call visits, attention tests etc. To the best of our knowledge, none of the existing studies have used a concrete and reliable measure of public health such as life expectancy at birth, to study the relationship between nature and public health in a society.

The existing literature on life expectancy and health benefit of environment has some other limitations as well. First, most of these studies utilized a macro approach, employing data aggregated at a macroeconomic level (Shaw et al., 2005). This type of model can capture the variation among countries, but understanding local variation in life expectancy within a developed country like United States requires examining differences at a finer scale such as county. With some notable exceptions[2], none of the existing studies examined life expectancy of sub-populations within the United States.

Another limitation is that the life expectancy production function used in previous studies almost ignores environmental factors and natural resource amenities. Ho et al. (2003), however, argued that public health approaches should be holistic and adopt both the medical care and prevention strategies that promote the direct and indirect benefits of natural parks and resources. Nilsson (2006) argued that health issues of modern lifestyles cannot be addressed by medicine alone. With increasing incidences of stress-related diseases, scientist and public health officials are interested to know how landscape and environmental elements affect the health and mitigate or restore mental stress (Velarde et al., 2007). On the other hand, the literature reveals that environmental qualities and recreational resources enhance quality of life (Deller et al., 2001; Nzaku and Bukenya, 2005) and provide a range of health benefits to society (Townsend, 2006; Hansmann et al., 2007; Maas and Verheij, 2007). Abundant natural resources and environmental amenities can maintain clean air and water that are directly associated with human health. In addition, amenities including open space, land use diversity, scenic beauty, and outdoor resources offer a vast potential for leisure activities that might not only enhance recreational satisfaction and personal experience but also help people remain physically fit and maintain good public health (Kruger et al., 2007).

Moreover, areas with a high proportion of farmland, forests, and ranchlands might offer farm produce for daily consumption and engage the local population in physically challenging jobs. All of these could collectively enhance physical health and life longevity. Recent studies also reveal that a significant number of Americans are now moving from urban to naturally rich rural counties for a better quality of life (Deller et al., 2001, Poudyal et al., 2008). Even though earlier studies recognized the role of such resources in life expectancy, they either ignored or failed to properly include them in the production function. Barlow and Vissandjee (1999), for example, utilized a dummy variable to capture whether or not the country is located in tropics to take into account of ecological factors. Shaw et al. (2005) used wealth, education, and safety factors to control for the environmental measures; and Rao (1988) used temperature and precipitation.

This study aims to strengthen our understanding of determinants of life expectancy in a few ways. First, we used a more complete set of natural resources amenities and landscape elements, which as the literature suggests enhance quality of life. Second, in contrast to earlier studies, we used disaggregated data at the county level to explain life expectancy variation at the local level and data for sub-categories of land use (e.g. forest, farm, water) to represent landscape element. It should however be noted that county level data is still macroeconomic but measured at much finer scale than country level. Third, in contrast to previous studies that used cross-sectional data but failed to address spatial dependence, we adopted a more robust econometric model that tests and corrects for any form of spatial autocorrelation in the data.

[1] See Velarde et al. (2007, page 204) for detail summary and comparison of these papers.

[2] A recent study by Singh and Siahpush (2006) however, looked at the effect of socio-economic deprivation on life expectancy among US counties, and concluded that population with higher socioeconomic status experienced an increase in average life expectancy.

2. Methods

2.1. Empirical model

Following Shaw et al. (2005), Sufian (1989), and Barlow and Vissandjee (1999), we used a life expectancy production function, which contains county sociodemographic and economic factors, medical facility and risk factors, and natural resource amenities as factors of production. Eq. (1) summarizes the conceptual model.

$$\text{Life expectancy} = f(\text{sociodemographic factors, medical facility and risk factors, natural resource and environmental amenities}) \quad (1)$$

We began with an ordinary least square (OLS) estimate of this equation. However, since the model uses cross sectional spatial data of counties, residuals from OLS model can exhibit two types of spatial dependence. The first type of spatial dependence is a spatial error, which means the OLS residuals are correlated among counties, which violates the assumption of uncorrelated error terms, leading into inefficient estimates. In such a case, the spatial error model (SEM) as expressed in Eq. (2) is estimated (Anselin and Bera, 1998).

$$\begin{aligned} y &= X\beta + u \\ u &= \rho W u + \varepsilon \quad \text{where} \quad \varepsilon \sim N\left(0, \sigma^2 I_n\right) \end{aligned} \quad (2)$$

Where vector y $(N\times 1)$ contains cross-sectional observations on average life expectancy at birth by county, matrix X $(N\times K)$ contains the observations on a set of independent variables affecting life expectancy. W is a spatial weight matrix[3], whereas β is a vector $(K\times 1)$ of parameters to be estimated. Similarly, μ is a vector $(N\times 1)$ of error terms that are spatially auto- correlated, and ε refers to vector $(N\times 1)$ of error terms with $N(0,s^2I)$, and scalar ρ represent the coefficient of spatial autoregressive error lag term.

The second type of spatial dependence is the spatial lag, which means the dependent variable in a county is affected by independent variables of not only the county itself, but also the surrounding counties. This violates the assumption of uncorrelated error terms as well as independence of individual observations, and can lead to biased and inefficient estimates. In such case, a spatial lag model as expressed in Eq. (3) is estimated (Anselin and Bera, 1998).

$$\begin{aligned} y &= \rho W y + X\beta + \varepsilon \\ \varepsilon &\sim N\left(0, \sigma^2 I_n\right) \end{aligned} \quad (3)$$

Where y again is a vector $(N\times 1)$ of observation on average life expectancy at birth by county, Wy is a spatial lag of dependent variable, and scalar ρ represents the spatial lag autoregressive coefficient. Similarly, β is a vector $(K\times 1)$ of parameters to be estimated, X is a matrix $(N\times K)$ of independent variables, and refers to error terms with $N(0,s^2I)$. We used a spatial regression decision process suggested by Anselin (2005, pp 199) to identify the type of spatial dependence and fit our model to the appropriate form.

2.2. Variables and data sources

The dependent variable in the study was the average life expectancy at birth for county residents in 1999. The definition of this variable is the number of years a newborn is expected to live in a county (Singh and Siahpush, 2006). Data for this variable were obtained from the Harvard School of Public Health. County level expectancy was originally estimated by Ezzatti et al. (2008), using mortality statistics from the National Center for Health Statistics (NCHS) and population data from the US Census Bureau. Mean life expectancy at the birth in 1999 among US counties was 76.32 years, with 66.63 years as the minimum and 81.31 years as the maximum.

The independent variables included three categories including demographic and socioeconomic factors, medical facilities and risk factors, and natural amenity and outdoor recreation resources. The first category included factors that capture the race, literacy rate, income, occupation, housing condition, and type of residence. Since these factors determine the life style, food consumption pattern, and other tastes and preferences of the population, they could eventually determine life longevity. Following Singh and Siahpush (2006), Sufian (1989), and Barlow and Vissandjee (1999), we included the percentage of African-Americans, percentage of college graduates, median household income, population density, median housing value of the house, and a dummy variable indicating whether or not the county was urban.

We included social security benefits per thousand capita and property tax rate in the county to capture any effect of local governmental support and fiscal factors. Average travel time to work was included to capture the effect of commuting pattern and time spent in regular traffic. Data on these variables were obtained from the US Census Bureau City and County data book of 1994. We hypothesized that the variables in this category will have a mixed effect on life expectancy. For example, variables capturing education, income, housing value, will be positively related with life expectancy, whereas those capturing the congestion, county urban status, and proportion of African-American populations will be negatively related to life expectancy (Harper et al., 2007).

We also included medical facilities and risk attributes to control for the factors that are likely to affect life expectancy. Following Rao (1988), we included the number of hospital beds per thousand and the number of physicians per thousand. In addition, the number of community hospitals in the county was also included. Shaw et al. (2005) and Barlow and Vissandjee (1999) used per capita pharmaceutical expenditure to control for these facilities, but found them to be weak determinants. Data on those variables were obtained from the US Census Bureau City and County data book of 1994 as well. We hypothesized that variables capturing the medical facilities will have positive effects on life expectancy.

We also included variables to capture the potential of human life longevity risks. Estimated risks of respiratory disease were obtained from the Environmental Protection Agency (EPA) for 1999. Moreover, we included the percentage of county population in manufacturing jobs, to control for labor or job related life risks (Hertz et al., 1994). Data on manufacturing jobs was obtained from the USDA, Economic Research Service. Crime related effects were controlled, using the number of serious crime incidences per thousand, whereas a distance variable measuring the proximity to interstate and state highways was included to control for traffic and transportation related risks. Crime data were obtained from the US Census Bureau City and County data book of 1994, whereas the distance from each county to major highways was calculated using the Environmental and Scientific Research Service (ESRI)'s county and highway maps in ArcGIS 9.2. Following Rao (1988), we also included the average annual temperature to control for the effect of high temperatures, which favor several pathogens and life threatening disease vectors (Barlow and Vissandjee, 1999). Annual temperature data, which are the average of long-term annual observation, were obtained from the National Climatological Data Center of NOAA. We hypothesized that variables in the risk factor category were negatively related to life expectancy.

The third category included variables describing the county's natural amenities and outdoor recreation resources. These include the percentage of county area in farm, forests, pasture, rangeland, and water bodies. We also included a dummy variable capturing whether or not the county is coastal. Mean sunlight hours in January were also included to capture the availability of sunny days that favor outdoor

[3] Positive and symmetric spatial contiguity weight matrix (NxN), is used to define the first-order adjacency of counties. Each element w_{ij} of W is given 1 when county i and j are adjacent, otherwise 0, and each row in the matrix W are row standardized. Details of weight matrix is found in Anselin and Bera, (1998).

mobility and leisure activities. A topographical index was included to capture general surface terrain. Variables describing outdoor recreation resources included a dummy indicating whether or not the county contains a state recreation park, proximity to the national park, number of outdoor sports attractions in the county, and number of golf courses per thousand. Data on these variables were obtained from the National Outdoor Recreation Supply Information System (NORSIS). As a part of the Renewable Resources Planning Act (RPA), NORSIS compiles periodic data of various outdoor recreation goods and services at the county level (Cordell and Betz, 1997). We hypothesized that variables in natural amenities and outdoor recreation resources category were positively related to life expectancy.

Detailed definitions of the variables, their expected signs in the regression, and sources are summarized in Table 1. Following Barlow and Vissandjee (1999, pp. 17), we treated all variables as exogenous to life expectancy. Multicollinearity, which if present makes precise estimation difficult, was checked using the variance inflation factor (VIF). As a rule of thumb, variables associated with VIF value of 10 is considered to indicate multicollinearity (Freund and Wilson 1998, pp. 194). Even though previous studies with country level data included variables such as calorie consumption per family and percentage of population with access to safe water in the model, we could not do so here due to lack of such data at the county level. However, we believe that the range of demographic and economic variables included in our model control for such factors. This study covers all the states in the conterminous United States and counties are the individual analysis units. Due to data limitations, however, a few independent cities of Virginia and counties from other states were excluded from the analysis, reducing the total number of counties in the analysis to 3064.

3. Results

A Lagrange Multiplier (LM) test confirms the presence of positive spatial autocorrelation in the OLS residuals (Moran's $I = 0.054$, p value < 0.01). Moreover, results from a series of LM tests in spatial regression decision process (Anselin 2005, pp 199) revealed that spatial error dependence was present (LM Statistic for error = 23.16, p value < 0.01), whereas the spatial lag dependence was not (LM Statistic for error = 0.32, p value = 0.32). This indicates the appropriateness of the spatial error model (SEM) to correct for spatially correlated OLS residuals. Maximum likelihood estimates from the SEM model are presented and compared with OLS estimates in Table 2. Even though the R^2, which is a conventional measure of goodness of model fit, does not improve much, comparison of Akaike Info Criteria (AIC) statistics suggests that the spatial error model (9622.79) performed better than OLS (9644.78) on our data. Also, by using SEM model, we substantially reduced the spatial autocorrelation in the residuals (Moran's $I = -0.002$).

The computed VIFs were well below the threshold of 10 (Freund and Wilson, 1998, pp. 194), and suggest that multicollinearity was not a problem. Altogether 22 of the 30 variables were significant at the 10% or better level in OLS model, whereas only 18 of them were significant in the SEM. However, most exhibited the expected sign. It should be noted that our discussion here focuses on estimates from the SEM model, unless mentioned otherwise. Importantly, lambda, which is a coefficient of spatial autoregressive error lag term, was strongly significant and positive, suggesting a positive spatial dependence. A lambda value of 0.13 indicates that a county experienced a 1.3% increase in average life expectancy if expectancy in surrounding

Table 1
Variable definition, mean values, expected signs and data sources.

Variables	Definition	Mean	Expected sign	Data source
Demographic and socioeconomic factors				
African-American	Percentage of African-American in county population	8.427	–	US Census Bureau
College graduate	Percentage of college graduate in county population	7.139	+	US Census Bureau
Household income	Natural log of median household income	10.044	+	US Census Bureau
Population density	Number of people per square mile	187.885	–	US Census Bureau
Median housing value	Natural log of median value of owner occupied housing units	10.766	+	US Census Bureau
Urban	Dummy variable, 1 if the county is urban, 0 otherwise	0.262	–	USDA-ERS
Social security benefit	Social security program beneficiaries per thousand population	188.154	+	US Census Bureau
Tax rate	Natural log of collected property tax per thousand properties	7.057	+/−	US Census Bureau
Travel	Average travel time to work	19.535	+/−	US Census Bureau
Medical facilities and risk factors				
Physicians	Number of active nonfederal physicians per hundred thousand population	94.678	+	US Census Bureau
Hospital beds	Hospital beds per hundred thousand population	376.420	+	US Census Bureau
Community hospitals	Number of community hospitals	1.68	+	US Census Bureau
Respiratory disease risk	Average respiratory disease risk per million population	1.981	–	EPA
Manufacturing jobs	Percentage of county population in manufacturing jobs	5.362	–	USDA-ERS
Crime rate	Number of crime incidence of all kinds per thousand population	28.251	–	FBI, Uniform Crime Report
Proximity to highways	Distance in mile to the nearest state or interstate highways from county centroid	2.536	–	ESRI
Temperature	Average annual temperature in Fahrenheit degrees	54.673	–	NOAA
Natural amenities and outdoor recreation resources				
Farmland	Percentage of county in agriculture cropland	26.513	+	NORSIS
Forestland	Percentage of county in public forestland	29.289	+	NORSIS
Pastureland	Percentage of county area in pastureland	9.932	+	NORSIS
Rangeland	Percentage of county area in rangeland	11.644	+	NORSIS
Water bodies	Percentage of county area in water bodies such as lakes, rivers, streams	5.606	+	NORSIS
Coastal	Dummy variable, 1 if the county is coastal, 0 otherwise	0.099	+	NORSIS
Winter sunlight	Average number of sunlight hours in January	151.510	+	NOAA
Topography	A continuous index measuring topographical steepness of county, starting from 1 for flat plains to 21 for high mountains	8.894	+	USGS
State park	Dummy variable, 1 if county contains a state recreation park, 0 otherwise	0.485	+	NORSIS
Distance to national park	Distance in mile to the nearest entrance of national park from the county centroid	2.573	–	ESRI
Amusement and sports	Number of outdoor sports or amusement attraction in county	0.190	+	NORSIS
Golf course	Number of golf course per thousand populations	0.081	+	NORSIS

Note: Abbreviations include: USDA-ERS, United States Department of Agriculture- Economic Research Service; EPA, Environmental Protection Agency; FBI, Federal Bureau of Investigation; ESRI, Environmental and Scientific Research Institute; NOAA, National Oceanic and Atmospheric Administration; NORSIS, National Outdoor Recreational Survey Information System; USGS; United States Geological Service.

Table 2
Regression estimates from the ordinary least square and spatial error model.

Variables	OLS	SEM	VIF
Intercept	59.928	60.307	–
	(43.612***)	(44.026***)	
Demographic and socioeconomic factors			
African-American	−0.043	−0.044	2.08
	(−20.582***)	(−20.736***)	
College graduate	0.182	0.183	2.23
	(18.610***)	(18.831***)	
ln(household income)	0.927	0.916	5.05
	(4.975***)	(4.955***)	
Population density	−0.000	−0.000	1.18
	(−0.805)	(−0.834)	
ln(median housing value)	0.446	0.916	4.94
	(4.206***)	(4.955***)	
Urban	−0.107	−0.091	1.86
	(−1.649*)	(−1.416)	
Social security benefit	0.000	0.000	1.22
	(0.768)	(0.716)	
Tax rate	0.300	0.298	2.08
	(6.462***)	(6.365***)	
Travel	0.009	0.007	1.33
	(1.910*)	(1.516)	
Medical facilities and risk factors			
Physicians	−0.000	−0.000	1.37
	(−0.761)	(−0.555)	
Hospital beds	0.000	0.000	1.33
	(1.715*)	(1.495)	
Community hospitals	−0.010	−0.008	1.40
	(1.547)	(−1.216)	
Respiratory disease risk	0.013	0.012	1.55
	(1.376)	(1.254)	
Manufacturing jobs	0.003	0.002	1.07
	(0.827)	(0.611)	
Crime rate	−0.005	−0.005	1.53
	(−4.574)	(−4.761***)	
Proximity to highways	0.032	0.029	1.27
	(1.955*)	(1.806*)	
Temperature	−0.047	−0.047	2.51
	(−11.758***)	(−11.546***)	
Natural amenities and outdoor recreation resources			
Farmland	0.015	0.015	2.55
	(12.141***)	(12.127***)	
Forestland	0.001	0.001	1.62
	(2.198**)	(2.280**)	
Pastureland	0.010	0.011	1.63
	(4.387***)	(4.514***)	
Rangeland	0.006	0.006	2.69
	(4.080***)	(3.999***)	
Water bodies	0.006	0.006	1.88
	(2.094**)	(2.049**)	
Coastal	0.335	0.333	1.62
	(3.762***)	(3.721***)	
Winter sunlight	0.005	0.005	1.62
	(6.381***)	(6.535***)	
Topography	0.005	0.006	2.48
	(1.028)	(1.237)	
State park	0.156	0.154	1.13
	(3.506***)	(3.121***)	
Distance to national park	−0.039	−0.039	1.58
	(−4.090***)	(−4.073***)	
Amusement and sports	0.032	0.028	1.08
	(1.849*)	(1.606)	
Golf course	1.052	1.014	1.14
	(5.128***)	(4.995***)	
Spatial autoregressive parameter (Lambda)	–	0.131	
		(4.740***)	
Residual Moran's *I*	0.054***	−0.002	
R Square	0.661	0.665	
AIC	9644.780	9622.790	
N	3064	3064	

Note: Numbers in parenthesis are *t*-ratio for OLS model, and *Z*-value for SEM model. *, **, and *** indicate significance of parameters at the 1%, 5% and 10% respectively.

counties increased by 10%, ceteris paribus. Among demographic and socioeconomic variables, median housing income, percentage of college graduates, and median household income exhibited positive and significant relationships to life expectancy at the 1% level. This is consistent with Singh and Siahpush (2006) who, in a recent study, reported that people in higher socioeconomic groups are likely to have a longer life expectancy.

Similarly, the percentage of African American population was negatively related and significant at the 1% level, corroborating the findings of Harper et al. (2007). Population density, average travel time to work, and the urban status of county possessed the expected signs but were not statistically significant. Travel time was marginally significant at the 10% level in OLS, but appeared insignificant in SEM. Even though the social security benefits per thousand capita exhibited a positive sign, the effect was not statistically significant. Property tax was positive and significant at the 1% level, which may be explained by the fact that high tax revenues might have been invested in public goods and services that enhance health and life resources.

Among medical facility and risk factors, hospital beds were positively and significantly related at the 10% level in OLS Model, but were only marginally significant in SEM model. The number of community hospital and number of physicians per thousand populations were not significant in either model. Even though, a positive effect was expected in those variables, it is not completely surprising given the fact that Barlow and Vissandjee (1999) found little impact of health expenditure on life expectancy. Similarly, Sufian (1989) also did not find significant effect of variables capturing number of hospital beds and number of physicians on life expectancy.

Counter to our expectations, the average risk of respiratory diseases was insignificant. However, there may not have been adequate variation among counties, with regard to risk factors estimated in terms of per million populations. Since none of the previous studies used these variables in the model, we had no precedent for comparison. The percentage of county population in manufacturing jobs was not significant. As expected, crime rate per thousand population and proximity to major highways was negatively related and significant at the 1% and the 10% level, respectively. The effect of temperature was negative and significant at the 1% level, and is consistent with earlier observation of Barlow and Vissandjee (1999).

The difference between this research and previous studies are natural resource amenities and outdoor recreation resources. An *F*-test for the significance of natural resource amenities variables in life expectancy production function rejected the null hypothesis that these variables are not related to life expectancy (F statistic = 24.61, p value < 0.001). In both the OLS and SEM model, variables for mild weather, landuse, and recreation resources were consistently significant and exhibited the expected signs. Percentage of cropland, percentage of pastureland, and percentage of rangeland were positive and significant at the 1% level. These observations suggest that higher proportion of county acres under such land use were related with a higher life expectancy of residents in the county. Similarly, the percentage of area in public forest also was positively related and significant at the 5% level.

The percentage of water bodies in a county was positively related to life expectancy, and significant at the 5% level. Similarly, the dummy variable capturing whether or not the county is in coastal location was also significant at the 1% level, suggesting that counties located in close proximity to water bodies were related with longer life expectancy of its residents. Mean sunlight hours in January were positively and significantly (1% level) related. This might be explained by the fact that an abundance of water resources and clearer days may not only maintain the stability of microclimate but also offer opportunities for outdoor mobility and leisure such as fishing, boating, swimming, and similar activities. Engaging in such activities can be beneficial to human health and quality of life. The effect of the topographical index, measuring the variation in surface terrain, was not statistically significant, however. This is perhaps because the index was too general to properly represent variation in county topography.

As expected, the dummy variable indicating whether or not the county has a state recreation park was significant at the 1% level and exhibited a positive relationship with life expectancy. The number of outdoor sports attractions possessed the expected positive sign, which was significant at the 10% level in the OLS model, but was marginally significant at the 11% level in the SEM model. Similarly, the distance to the nearest national park was negatively related and significant at the 1% level, suggesting that life expectancy in counties closer to national parks is likely to be longer than in those located farther away. Similarly, the number of golf courses in the county was positively and significantly (1% level) related. This is not surprising because golf is a popular physical and sports activity among healthy adults.

4. Conclusion

This study examined the effect of natural resource amenities on human life expectancy in the United States. Extending the existing model of the life expectancy production function with correction for spatial dependence, we assessed the determinants of life expectancy using county level data. The findings from this study have several implications in natural resource economics and management, public health, and economic development. First, we established empirical evidence that life expectancy of human population may well be affected by natural resource amenities. Hence, any life expectancy production function will be incomplete and can result in biased estimates if these amenities are not considered as factors of production.

Additionally, it would be beneficial from a public health and social welfare perspective to preserve existing land resources such as farmland, forests, rangelands, water bodies, and undeveloped open lands. Moreover, agencies may see a benefit in introducing outdoor recreational opportunities such as state parks, golf courses, and municipal parks to maintain active living and enhance public health in their community. By doing so, local agencies could make their communities attractive to retirees (Poudyal et al., 2008) and other amenity demanding population sectors, and help boost their economy because millions of individuals are seeking communities with such amenities for retirement and second home.

Findings from this study could provide a basis for encouraging people to protect our natural resource amenities, because the evidence directly linking these amenities to longevity may be more compelling than other arguments to conserve nature. Very few general practitioners currently advise their patients about the additional benefits of performing their physical activities in natural environments instead of urban or artificial settings (Maas and Verheij, 2007). Efficient use of ecosystem services of our forests and natural resources would require making public-nature interaction a part of preventive medication, and increasing civic environmentalism. For example, Townsend (2006) discussed the idea of 'friends of parks' group to promote civic engagement in preserving and utilizing the health and wellbeing benefits of forest lands. Encouraging people to interact or exercise in natural environment could save significant health expenses in both the public and private sector. Designing voluntary schemes to let urban people participate in tree care etc would achieve this help. Above all, a more compelling message of our findings is that the traditional approach of public health and human development should be extended beyond just controlling diseases or treating patients (Ho et al., 2003), to a more comprehensive approach that also acknowledges natural amenities as well as nature based outdoor recreation resources in maintaining good public health, quality of life, and overall human development.

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