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**Modeling Land Use Pattern Change Analysis in the Northern Great Plains: A Novel  
Approach**

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## **Abstract**

The issue of land use/cover (LCLU) change has become a critical field of investigation for economists. This research is designed to present the underlying causes of land use change due to macroeconomic factors and economic growth in Northern Great Plains (NGP) area. This paper introduces a holistic approach that incorporates spatial econometric modeling and geo-spatial modeling to examine the relation between areas of land use change and level of economic activity. The economic component of this study consider panel data sets (both time series and cross section) and the primary sources of data are National Resources Inventory (land use classes), bureau of economic analysis (GDP per capita data), and U.S. census (population density data). A spatial econometric model (Fixed Effect Model) is used to better understand the relationships between areas in land uses and macroeconomic factors influencing change in land use pattern during 1992-2007 time period. The U.S. Geological Survey (USGS) National Land Cover Database (NLCD) is also used here for land use mapping and modeling. The geo-spatial component of this research estimates first-order Markov chain Monte Carlo simulation(MCMC) to calculate transitional probabilities for explaining spatial and temporal patterns of land conversion. The cross sectional analysis reveal the inverse relationship between area of land uses and level of economic activity, as measured by GDP per capita. Also, the fixed effect model indicates the same inverse relation between economic growth and land use change. Key findings also indicate high conversion of urban land and population growth rates have led to an increasingly fragmented land use pattern in the area. Markov chain simulation results for the region also illustrate a change in land use pattern and forest to non-forest conversion over a sixteen year time period.

## 1.0 Introduction

The economic and environmental effect of land use change in the United States is significant. Northern Great Plains (NGP) area (state of Kansas, Nebraska, South Dakota and North Dakota) have experienced major land use pattern change over last sixteen years where conversion appears to be concentrated. The land use (agriculture, crop land and urban use) pattern in Great Plains (GP) play a vital role to maintain ecosystem services and health. However, this region has been experiencing a large reduction of grasslands area over last 50 years (Samson and Knopf, 1994). The grasslands of this region is also defined as most endangered ecosystems in North America (Samson et al., 2004; Cully et al., 2003).

U.S. NGP ecoregions have experienced changes in land use and major suites of land-cover over the last 30 years primarily due to anthropogenic drivers, weather cycles and biophysical conditions. The cropland and agricultural land are the top 2 categories where major changes occur. The NGP are subdivided into different ecoregions. The Northwestern Glaciated Plains ecoregion is experiencing maximum percentage change in land-use between agriculture and grassland (Auch et al., 2011). The ecological resources of the region is quite dependent on changes in land use. Information on future land use is of great importance as it plays a vital role to mitigate adverse potential effects on ecosystem processes.

A simulation approach can be used to predict land cover changes as a result of socio-economic change, by linking land-use change model on the basis of exogenous human-induced drivers (Brown et al., 2000). The economic value of land is often excluded in the market prices of land

conversion and this regulation of land use has of prime importance in this regard. The method of modeling land use change vary in time and spatial dimension. As an example, Terry et al. (2012) designed a scenario based framework to present future land use change in the GP.

Macroeconomic factors can act as an indirect/ underlying causes or driving forces for reduction of wilderness land (Skonhoft and Solem, 2001). Deforestation and expansion of agricultural land are two key issues to discuss regarding land use and economic growth. Most of the empirical studies focuses on these two factors as underlying causes of land use (Cropper and Griffiths, 1994). LCLU change process models can be categorized under two broad categories: regression-based and spatial transition-based approach. Under the regression-based approach, the majority research relates location of LCLU to a set of spatially explicit variables and run logistic regression (Wear et al., 1998) and hedonic price models (Geohegan et al., 1997). On the other hand, cellular automaton simulation models often refer to spatial transition-based models. This approach help predicting future land development based on probabilities using Monte Carlo methods (Clarke et al., 1997).

The primary concentration of this research is to integrate economic analyses into a GIS environment. For this analysis, we consider GIS database of LCLU. The U.S. Geological Survey (USGS) National Land Cover Database (NLCD) is widely used for environmental mapping and modeling (Homer et al., 2007). The NLCD datasets provide a good baseline data layer to use for stratifying nonagricultural lands in satellite imagery prior to classifying specific crop types (Peter et al., 2006). This research will help assess the LCLU relationship and find areas vulnerable to conversion in the NGP. Here, historical patterns of LCLU changes over 15 years (1992-2006) are

examined to establish relationships between land cover and land use. Considering the spatial characteristics of land use of the NGP, the development of an integrated framework to model spatial and temporal patterns of land conversion and understanding the underlying causes of these changes is required. Results from this study should help governmental agencies to locate areas for conservation before initiating other environmental conservation programs. This coupled-modeling approach will provide a holistic framework to policy makers for decision making regarding areas of conversion.

## **1.1 Study area**

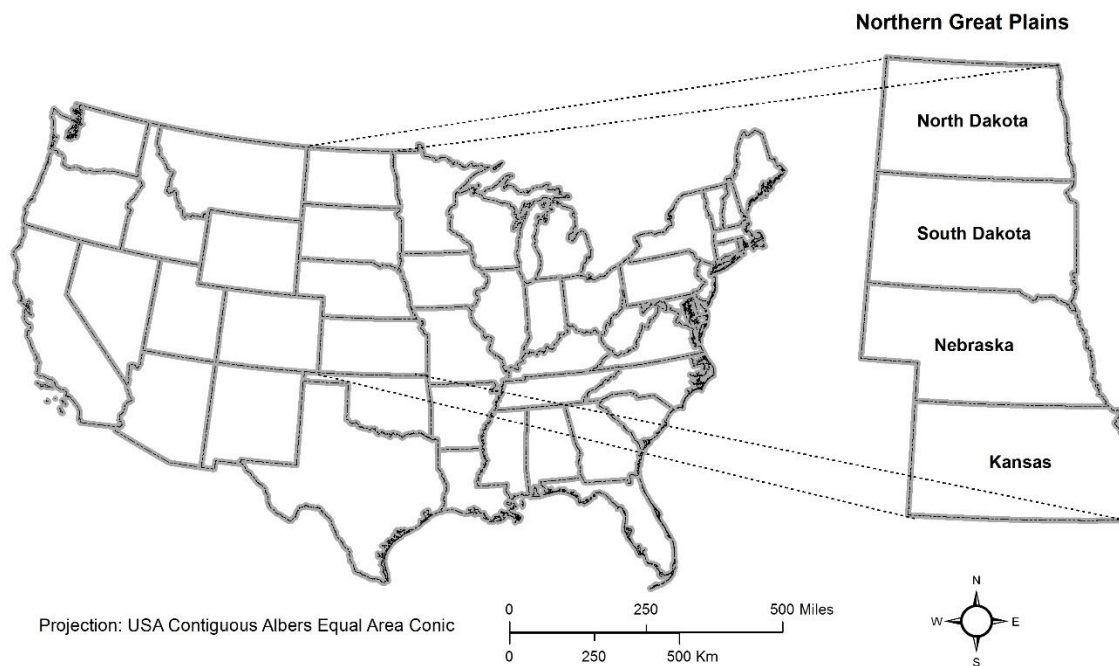


Figure 1. United States Northern Great Plains Map

## 2.0 Materials and methods

The primary objective of this research is to integrate a spatial econometric model (Fixed Effect Model) with geospatial model (Markov chain Monte Carlo Simulation) for better understanding and modeling of land use change and economic growth.

### 2.1 Econometric Modeling

The economic component models macroeconomic variables and land use change. Our data set is a panel that include time series observations from 1992 to 2007 and cross sectional observations by states. The National Resources Inventory (NRI) provides information on land use, land characteristics, and conservation practices on non-federal land in the NGP. We observe land use at each NRI point at two points in time (1992 and 2007). The explanatory variables include GDP per capita, GDP per capita squared and population density. We consider three broad land use classes: (1) agriculture, (2) forest and (3) urban use as dependent variables. This approach has the advantage of comparing land use for different attributes in contrast to earlier studies of land use (Chakir and Gallo, 2012). It would have been worth trying to include more variables like the opportunity cost of preserving land (timber prices) (as in Cropper and Griffiths, 1994). However, this is not taken into consideration for this study due to lack of reliable data and low number of observations in the NGP. Furthermore, there has been little change in timber prices in this region recently. This research is primarily focused on analyzing underlying causes of land use changes like GDP per capital and population density not direct causes like timber prices.

The empirical analysis is at the state level (4 states) and consider three types of land use as dependent variables. Firstly, a simple cross-section regression is performed for the year 1992 and 2007 to examine the relationship between economic activity and change in land use area.

The cross-section model can be written as below

$$\mathbf{L}U_i = \beta_0 + \beta_1 \mathbf{GDPC}_i + \beta_2 (\mathbf{GDPC}_i)^2 + \beta_3 \mathbf{PDN}_i + \epsilon_i \quad (1)$$



Where  $LU_i$  refers to Land use area (three types) in 1992 and 2007 in state  $i$ ,  $Y_i$  refers to real GDP per capita and  $PDN_i$  is the density of population for  $(GDPC_i)^2$   $GDPC_i$  the same time period. Here,  $LU_i$  is calculated as percentage of the total land (in each state),  $GDPC_i$  is calculated as \$1000 per capita in fixed prices, and  $PDN_i$  is presented as the number of people per square miles.  $\beta_0$  is the intercept term and  $\varepsilon_i$  is the white noise error term. The negative  $\beta_1$  sign refers to negative impact on environment, whereas positive  $\beta_2$  indicates a positive relationship between GDP per capital and change in land use area.  $PDN_i$  is a well-known variables in macroeconomic land use analysis and is used here to control for demographic and geographic changes. Equation 1 is regressed separately for each type of land.

To establish the connection between GDP per capital and change in land use area, two cross-section data sets are added to form a pooled sample. Fixed effect model (FEM) is well-suited in this case as it will help determine the relation between impact of changes in per capita income and change in land use area over time. Here, the intercept term is assumed to be correlated with the explanatory variables. The effect of explanatory variables will be time-specific. Here, we consider only two observations in time and this refers to the results only hold for limited time period. Thus, it would be hard to generalized the results.

The FEM model can be expressed as below

$$LUI_{i,t} = \theta_1 GDPC_{i,t} + \theta_2 (GDPC_{i,t})^2 + \theta_3 PDN_{i,t} + \psi_{i,t} \quad (2)$$

Where subscript t presents time (1992 and 2007). Here,  $\psi_{i,t} = \beta_{0i} + Y_{i,t}$ , in this case,  $\beta_{0i}$  is the intercept term specific for state i and  $Y_{i,t}$  is white noise error term. The GDPC sign is assumed to be negative. However,  $(GDPC)^2$  sign is assumed to be positive. This can be interpreted as the effect of economic activity refers a smaller negative impact for state of higher income as compared to lower income. The  $PDN_{i,t}$  refers to impact of demographic changes over time as geographic change effect are represented by intercept terms. Equation (2) is also regressed for each type of land.

## 2.2 Geo-Spatial Modeling

The geo-spatial component of this research estimates first-order MCMC probabilities to model spatial and temporal patterns of land conversion. The U.S. Geological Survey (USGS) National Land Cover Database (NLCD) is used for environmental mapping and modeling. The NLCD provides a baseline to stratify nonagricultural lands in satellite imagery prior to classifying specific crop types. This paper utilizes Landsat Thematic Mapper (TM) images, NLCD and NASS for stochastic modeling and land use change detection analysis to present prioritized areas for land use conversion. An attempt is made to present LCLU patterns within the study area using Landsat 5 TM images, and forest cover data derived from the NLCD for the years 1992, 2001, and 2006. National Agricultural Statistics Service (NASS) data published by USDA for the same time period are also used as preliminary inputs to estimate forest transition. Spatial analyses are performed to prioritize areas critical for planned management. Subsets of NASS data are assessed for maximal variability using crosstab queries in order to determine transition probabilities. The analysis of MCMC simulation has been estimated during the years of 1992-

2006. The framework of National Land Transformation model is also projected using NLCD data. National Land Cover Data is collected for the year 1992, 2001, and 2006. The data is spatially clipped using minimum bounding rectangle (MBR) of the NGP region. Then each data is reclassified using ArcGIS® raster calculator. For example, minor NLCD land-use classes are categorized into six major classes: (1) Water, (2) Urban developed, (3) Forest, (4) Pasture / rangeland, (5) Cultivated Crops, (6) Wetland. We consider only three classes (agriculture, cropland and urban land use) for our analysis. Then each raster data is converted to Ascii data and imported to SemGrid software to generate transition probabilities. The integrated satellite remote sensing and GIS techniques help quantify LULC changes using Landsat TM data. Also, Markov modelling is applied to investigate the stochastic nature of the LULC data. NLCD datasets during period of 1992, 2001, and 2006 have been used. These datasets are derived from classified LandSat TM satellite imagery and then imported into ArcMap-ArcInfo® 10.1. Universal Transverse Mercator (UTM) and North American Datum (NAD) 1983 are set as coordinate system and projection respectively. This system is applied due to its suitability with NLCD datasets. NLCD data are raster datasets with 30 m spatial resolution.

### 2.2.1 Markovian analysis of the land cover/use change process

To model changes in LULC, Markov chains have been used at a variety of spatial scales. These models have several assumptions (Stewart, 1994). One basic assumption is to regard LULC change as a stochastic process, and different categories are the states of a chain. The treatment of Markov chains in this study will be limited to first order homogeneous Markov chains.

$$P \{X_t = a_j / X_{t-1} = a_j\} = P_{ij}$$

The  $P \{X_t = a_j / X_{t-1} = a_j\}$  known as the one-step transitional probability, gives the probability that the process makes the transition from state  $a_i$  to state  $a_j$  in one time period. It might be practical to regard land use/cover change to be reasonably stationary if the time span is not too great. This research establishes Markov process validity by examining statistical independence, Markovian compatibility, and stationarity of the data. According to the Markov hypothesis, the transition probability matrix governing the period 1992–2006 can be obtained by multiplying the 1992–2001, and 2001–2006 matrices.

These transition probabilities can be computed with the aid of the GIS analysis function, and used in the following formula to calculate the expected numbers:

$$N_{ik} = \sum_j \frac{(N_{ij})(N_{jk})}{N_j} (N_j)$$

where:

$N_{ij}$ : is the number of transitions from category  $i$  to  $j$  during the period 1992 to 2001;

$N_{jk}$ : is the number of transitions from category  $j$  to  $k$  during the period 2001 to 2006; and

$N_j$ : is the number of hectares cells in category  $j$  in 2001.

To test for first-order Markovian dependence, a chi-square goodness-of-fit test is used. The statistic is calculated from the relationship:

$$x^2 = \sum \sum (O_{ik} - E_{ik})^2 / E_{ik}$$

Where,  $O_{ik}$  is the observed and  $E_{ik}$  the expected number of transition probability from 1992 to 2006. Moreover, LCLU change is estimated for last 15 years using Markov matrices and regression analyses. The first order Markov Chains (*Aavikso, 1995*) is applied to assess change in land-cover for the periods of 1992-2006. It represent a dynamic system of special classes involving transition probabilities, described as symmetric matrices (*Luenberger, 1979*).

### 3.0 Results and Discussion

#### 3.1 Cross-section analysis for 1992 and 2007

The summary statistics at state level are presented in table 1. The land use data for regression analysis is also mentioned in the descriptive statistics. Key results from Table 1 indicate the amount of urban land varies considerably from 1992 to 2007.

**Table 1. Descriptive statistics land use 1992 and 2007, 4 states**

Land use as a fraction of total states area	Mean	Standard deviation	Minimum	Maximum
LU_cropland92	2.67e+07	5447041	2.04e+07	3.25e+07
LU_forestland92	923250	552984.5	338000	1450000
LU_urbanlnad92	143600	86307.82	61400	264000
LU_cropland07	2.44e+07	43325291	1.00e+07	2.85e+07
LU_forestland07	1419250	597408.5	699000	2104000
LU_urbanlnad07	266000	217967.9	95000	562000

The dispersion is higher in case of Crop land as compared to agriculture and urban land as indicated by the standard deviation. The cross-section analysis results of Eq. (1) are reported in table 2. According to all regression results, GDP per capita has negative sign whereas GDP per capita squared and population density PDN has positive sign as a priori expected.

**Table 2. Cross-section regressions 1992 and 2007<sup>a</sup>**

	LU_cropland92	LU_forestland92	LU_urbanland92	LU_cropland07	LU_forestland07	LU_urbanland07
Intercept	7.39E+07 (1.22)*	3938971 (0.45)	-1330191 (-20.83)**	7.78E+07 (1.73)**	2348415 (0.32)	283475.1 (17.39)**
GDPC	-2370.28 (-0.87)*	-150.05 (-0.38)	68.29 (23.56)**	-2197 (-1.25)*	-61.94 (-0.22)	-13.63 (-21.36)**
PDN	7.26 (1.25)*	0.439 (-0.52)	-0.1245 (-20.17)**	4.81 (1.36)**	0.533 (0.92)	0.246 (190.87)**
R <sup>2</sup>	0.61	0.21	0.99	0.67	0.54	1.00
R <sup>2</sup> adjusted	-0.17	-1.36	0.99	0.02	-0.39	0.99

<sup>a</sup>Dependent variable Land Use

\*Statistically significant at 5% level

\*\*Statistically significant at 1% level. t-statistics in parentheses.

A high degree of significance is observed as suggested by t-statistics. For agricultural and cultivated crop land, the t-values are higher for all variables of the model in the cross-sections for 1992 as compared to 2007. The coefficient in case of urban land is also significantly high for the year 2007 with a positive sign. For the year 1992, this value is also higher with a negative sign. For forest and crop land, the relationship among level of economic activity, population density and change in land use area is evident and statistically significant in 2007 as compared to 1992. According to the findings, the effect of income per capita varies for all three types of land use classes. GDPC has a dominant and robust effect on change in land use area especially in case of urban land. This results continue to hold for different time periods (1992 and 2007). As demonstrated, the effects of PDN are negative and quite substantial in nature. The cross-section

analysis indicates change in land use area is greatly influenced by density of population. The density of population effect is significantly higher in case of agricultural land as compared to crop and urban land.

### 3.2 Pooled regression, fixed effect model

The FEM results as given by Eq. (2) are presented in table 3. The model discuss the relative change in land use area due to level of economic activity for all states for 1992 and 2007. It is assumed that the intercept term is correlated with the explanatory variables. The effect of economic activity is separated from time invariant effects.

Table 3. Pooled regressions, Fixed Effect Model<sup>a</sup>

	LUcropland	LUforestland	LUurbanland
GDPC	-2220.89 (-1.89)*	-16.19 (-0.35)*	-105.68 (-0.61)
(GDPC) <sup>2</sup>	-	-	-
PDN	5.82 (2.39)**	0.09 (0.96)*	0.49 (1.36)

aDependent variable: Land Use

\*Statistically significant at 5% level

\*\*Statistically significant at 1% level. t-statistics in parentheses.

The variable (GDPC)<sup>2</sup> is insignificant and not reported in table 3. The variable GDPC always has a negative sign when ((GDPC)<sup>2</sup> is omitted. However, for urban land, the effect is insignificant. Economic growth and level of economic activity greatly affected urban, agricultural land when controlled for population growth. Here, PDN variable effect is significant which is similar to cross-sectional analysis. This is due to significant changes in this variable over time.

### 3.3 Relative changes in land use over time

For NGP areas, the total area of urban land use decreases from 1,127 thousand acres to 1,063 thousand acres since 1992 to 2007, a decrease of 5.68%. However, total forest land area increases from 3,693 to 5,677 thousand acres during same time period which is an increase of 53.73% in the NGP area (table 4). This high conversion of forest land have led to an increasingly fragmented land use pattern.

In addition, total crop land area decreases from 106,602 to 97,688 thousand acres during 1992-2007 time period which is a reduction of 8.36% in the NGP area (table 4).

**Table 4. Land use pattern of Northern Great Plains from 1992-2007**

<b>Total Land use area, by region and States, United States, 1992-2007</b>					
<b>Total forest-use land</b>					
<b>Regions and States</b>	<b>1992</b>	<b>1997</b>	<b>2002</b>	<b>2007</b>	<b>% change in land use</b>
Northern Plains	3,693	4,318	4,340	5,677	53.73
North Dakota	338	441	441	699	106.77
South Dakota	1,450	1,588	1,511	1,640	13.11
Nebraska	568	797	897	1,234	117.32
Kansas	1,337	1,492	1,490	2,104	57.37
<b>Total urban land</b>					
Northern Plains	1,127	1,266	1,049	1,063	-5.68
North Dakota	111	129	94	95	-14.75
South Dakota	138	150	108	109	-21.15
Nebraska	264	294	293	298	12.82
Kansas	614	693	554	562	-8.53
<b>Total cropland</b>					
Northern Plains	106,602	107,846	101,978	97,688	-8.36
North Dakota	29,622	28,818	27,686	27,676	-6.57
South Dakota	20,382	21,765	21,066	19,853	-2.60
Nebraska	24,103	23,555	22,764	21,612	-10.34
Kansas	32,495	33,708	30,461	28,548	-12.15

Land use areas are in 1000 hectares.

Source: United States Department of Agriculture, Economic Research Service

Results suggest forest land use area have expanded significantly (an increase of 117% during 1992-2007) in the state of Nebraska whereas expansion is quite low (an increase of 13% during



1992-2007) in the state of South Dakota. However, the NGP area display negative growth in terms of total crop land and urban land area over 16 year time period. On the contrary, key findings indicate that the land acreages of urban land use area in state of Nebraska are comparatively higher during 2007 as compared to 1992.

#### **4.0 Concluding remarks**

Finally, the estimated relationships between income per capita and change in land use area over the sixteen year period is not very strong. Markov chain simulation results for the region also illustrate the potential interactions between thresholds in landscape patterns and forest to non-forest conversion. This unique analysis based on a macroeconomic context and GIS platform means that changes in land use are related to different direct and underlying causes. Cross-section analysis indicates that level of economic activity explains between 46 and 65% of the variations of land use change among four states. Thus, the higher level of GPD per capita, the less change in land use area. The fixed effect models indicate a negative, and linear relation between change in land use area and level of economic activity. This holds significant in case of urban land in the region.

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