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## An Econometric Analysis of Causes of Forestry Area Changes in Northeast China

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### Abstract

As one of the areas covered by plenty of primeval forests, Northeast China contributes a lot for the conservation of water and land resources, produces timber production, and provides habitats for a huge number of wild animals and plants. With changes of socio-economic factors as well as the geophysical conditions, there are dramatic shrinkage trends of forestry area. Therefore, it is of significance to find the underlining reasons for the changes of forestry area. To grasp the determinants of forestry area change in Northeast China, an econometric model is developed which is composed of three equations identifying forest production, conversion from open forest to closed forest and conversion from other land uses to closed forest, and then to explore the impacts on the changes of forestry area from demographic, social, economic, location and geophysical factors. The research results provide meaningful decision-making information for conserving and exploiting the forest resources and for making out the planning for forest production in the Northeast China region.

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### 1. Introduction

Northeast China region, an important production base for timber and forestry by-products in China, is also the water conservation area for essential rivers—Heilongjiang river and Songhuajiang river—as well as the ecological barrier of Sanjiang plain, Songnei plain and Hunlunbeier grassland, and bears the important significance to the maintenances of the regional ecological safety and socio-economic development [1-3]. After half a century of exploitation, forestry area in the Northeast China region has been shrinking dramatically, the age structure of forests has tended to be monotonous and juvenile, and the forest resources suitable for exploitation decrease gradually. According to the national survey of forest resources, ripe forestry area reduced by 49.0% in the period between 1981

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and 1988, then in the next ten years, 0.61 million ha of forestry area will further disappear, accounting for about 60.0% of the total ripe forestry area of whole country [4,5]. Therefore, protection of forest quality has been the significant challenge for the environmental conservation and ecological engineering construction, which would restrict the development of local forestry production seriously [6].

As is known, forestry area changes are closely related to many factors, such as economic growth, social development and the changes of geophysical conditions [7-9]. Logging out of plan, forest fire, extreme weather events and man-made destroy activities for forestry area all promote the shrinkage of forestry area to some extent. Although Northeast China is the pilot region for the Grain for Green project, Logging Ban Program, and other ecological restoration projects have achieved success to some extent, the shrinking trends of forestry area and forest degradation still exist [10-13]. In addition, forestry area changes in Northeast China not only refer to conversions between forestry area and other land uses, but also the conversions among the sub-classes of forests consisting of closed forest, shrub, open forest and other forest [14-16], which has drawn more and more attentions from the scholars as well as the decision-makers. Therefore, it is of significance to explore the causes of forestry area changes in Northeast China for improving the management of the forests and understanding the causes and possible effects of deforestation at the regional extent and even for the entire China.

## 2. Data and processing

Before building the Structural Equation Models (SEM) for exploring the causes of the forestry area changes in the Northeast China region, detailed information needs to be gathered and integrated. The first step of the methodological design is to build a database which includes relevant data related to the attributes of the influencing forces and data to describe the changes of land uses from 1988 to 2005 to provide parameters for the SEM model. Parameters for the SEM can be generically categorized into three categories: land use information, geophysical variables and socio-economic variables (Table 1).

Table 1. Variables for exploring the causes of forestry area changes in Northeast China

Definition of Variables	Variables
Population density	Popden
Agricultural population proportion at one stage lag	Ap
GDP	Gdp
Average elevation	Dem
Square term of average elevation	dem2
Average terrain slope	Slope
Square term of average terrain slope	slope2
Soil organic matter	Organic
Annual precipitation	Pa
Square term of annual precipitation	pa2
Annual temperature	Ta
Distance to the provincial capital	d2pvc
Distance to the nearest port city	d2port
Distance to the nearest road	d2road
Distance to the nearest water area	d2water
Gross output value of forestry section	Y
Forest production	Prod
Forest product price index	Value
Is natural reserve (=1) or not (=0)	Fpark
Is major grain production area (=1) or not (=0)	Grain
Gets involved in the state-owned forest and nursery financial system regulation (=1) or not (=0)	Mng
Area of other land use categories converted into closed forest	cvother21
Area of open forest	ld22
Have implemented natural forest protection project (=1) or not (=0)	Tbp
Have implemented policy of returning cropland to forestland (=1) or not (=0)	Tghl
Forestry coverage rate	Forcover

† The land use data in 1988, 1995, 2000 and 2005 is derived from Data Center of the Chinese Academy of Sciences; Variables at one stage lag are substituted by the average values of each of the variables for the last three years.

### 2.1. Land use data

Land use data set is derived from the Data Center of the Chinese Academy of Sciences, which is composed of six kinds of land use categories: cultivated land, forestry area, grassland, water area, built-up area and unused land. In this study, the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) remote sensing data of late 1980s and late 1990s was chosen and used as the basic information, because the use of satellite remote sensing has been proven to be a good choice for detecting and monitoring forestry area changes. Landsat TM/ETM images in 1988, 1995, 2000 and 2005 were interpreted at a scale of 1:100,000, and its interpretation accuracy reached 92.7% by field survey and random sampling check conducted by the Data Center of the Chinese Academy of Sciences (CAS) [17]. In order to identify the spatial variability of forest quality, forestry area was further disaggregated into four sub-classes: closed forest, open forest, shrub, and other forest. Closed forest is defined as natural or man-made forest with canopy cover over 30%, open forest refers to land covered by trees with canopy cover between 10% and 30%, shrub is land covered by trees less than 2 meters high and with the canopy cover over 40%, and other forest refers to land covered by tea-garden, orchid, and/or non-grownup forest [18].

### 2.2. 2.2 Geophysical data

Geophysical data include measurements on climatic change, information on terrain slope, information on soil property variability, and so on. The original meteorological data, consisting of annual temperature and annual precipitation, were derived from China Meteorological Bureau, which was originally filed in the form of text, and then we interpolated the text information into 1km×1km grid pixel data using the method of Kriging. Information on the terrain slope and the proportion of plain area were derived from DEM data at a scale of 1:250,000 covering the Northeast China. Information on the soil property comes from the second national soil survey of China, and is finally interpreted into 1km×1km grid pixel data using the Kriging method [19].

Location data is to measure the distance to the nearest expressway, the nearest provincial capital, the nearest water area and the nearest port city, and these measurements are calculated by using measure tools based on the road network, provincial capital map, water area map and the port city maps, which are derived from the topographic map at a scale of 1:250,000 for the Northeast China region.

### 2.3. Socio-economic data

Socio-economic data set consist of variables such as population density, agricultural production, agricultural population proportion, GDP, timber production, forest product price index, gross output value of forest production, and those binary values, e.g., if it is major grain production area, if it is natural reserve, and so on. Those continuous data including population density, agricultural population proportion, GDP, are derived from provincial statistics, and forest production data are derived from the forest products yearbook of China [20].

The policy variables involved in this study include the involvement of Grain for Green project and Logging Ban program which have been unfolded in the national level. Logging Ban program was put forward after the devastating flood in 1998 summer, and is designed to achieve restorative development of forest, control water and soil loss and preserve ecological environment [21]. Grain for Green project, an ecological environment protection engineering, is organized and implemented in 1999, and protect the ecological environment in Northeast China to some extent [22].

## 3. Methodology

Based on the process selection of forestry area change in Northeast China, we develop an econometric approach of structural equations model to explore the causes of forestry area change. In this model, the forestry area changes were set as explained variables and the driving factors were set as explanatory variables. By using the method of stepwise estimation, we explored the driving mechanism of all factors driving forestry area changes in Northeast China.

The structural equations model (SEM) for the causes of forestry area change in Northeast China are composed of three regression equations, the process of forest production (1), the conversion of open forest to closed forest (2) and the conversion of other land uses to closed forest (3). This model takes into account the causality among various variables, that is, some explained variables in the left side of the equation can be regarded as explanatory variables to present in the right side of another equation. To be described in mathematical language, some dependent variable  $y_i$  can be taken as independent variable to influence other dependent variable  $y_j$ , which force the estimation error transferred from  $y_i$  to  $y_j$ . In this way, the causes of forestry area change can be described in detailed. As for the variables, we can distinguish exogenous ones from endogenous ones. The main variables needed for structural equation model are presented in Table 1.

When establishing the structural equations model, we diagnosed the collinearity between each two variables to eliminate the non-linear influences on estimation results; and then we took the natural logarithm for each variable in 1988, 1995, 2000 and 2005 to eliminate dimension differences on estimation results. In this way, the influences from the scales of variable on the estimates of the magnitude of the variables were avoided. After preparing the databases, the structural equations model used to explore the causes of forestry area change in Northeast China is in the following form, among which involves three explained variables including forest production ( $y_{it}$ ), conversion of open forest to closed forest ( $sy_{it}$ ) and the conversion of other land uses to closed forest ( $oy_{it}$ ):

$$\begin{aligned}
y_{it} = & \alpha_0 + \alpha_1 \text{popden}_{it-1} + \alpha_2 \ln(\text{gdp}_{it-1}) + \alpha_3 \ln(\text{dem}_i) + \alpha_4 \ln(\text{dem2}_i) + \alpha_5 \ln(\text{slope}_i) + \alpha_6 \ln(\text{slope2}_i) + \alpha_7 \text{splain}_i \\
& + \alpha_8 \ln(\text{organic}_i) + \alpha_9 \ln(\text{pa}_i) + \alpha_{10} \ln(\text{ta}_i) + \alpha_{11} \ln(\text{d2pvcp}_i) + \alpha_{12} \ln(\text{d2port}_i) + \alpha_{13} \ln(\text{d2road}_i) \\
& + \alpha_{14} \ln(\text{d2water}_i) + \alpha_{15} \ln(\text{prod}_{it}) + \alpha_{16} \ln(\text{value}_{it}) + \alpha_{17} \text{fpark}_{it-1} + \alpha_{18} \text{tbp}_{it-1} + \alpha_{19} \text{grain}_{it} + \alpha_{20} \text{mng}_{it-1}
\end{aligned} \quad (1)$$

$$\begin{aligned}
sy_{it} = & \beta_0 + \beta_1 \ln(y_{it-1}) + \beta_2 \text{popden}_{it-1} + \beta_3 \text{ap}_{it-1} + \beta_4 \ln(\text{gdp}_{it-1}) + \beta_5 \ln(\text{dem}_i) + \beta_6 \ln(\text{dem2}_i) + \beta_7 \ln(\text{slope}_i) + \beta_8 \ln(\text{slope2}_i) \\
& + \beta_9 \ln(\text{organic}_i) + \beta_{10} \ln(\text{pa}_i) + \beta_{11} \ln(\text{pa2}_i) + \beta_{12} \ln(\text{ta}_i) + \beta_{13} \ln(\text{d2pvcp}_i) + \beta_{14} \ln(\text{d2port}_i) + \beta_{15} \ln(\text{d2road}_i) \\
& + \beta_{16} \ln(\text{d2water}_i) + \beta_{17} \ln(\text{prod}_{it-1}) + \beta_{18} \text{tbp}_{it-1} + \beta_{19} \ln(\text{cvother21}_{it-1}) + \beta_{20} \text{foreserve}_{it-1} + \beta_{21} \ln(\text{ld22}_{it-1})
\end{aligned} \quad (2)$$

$$\begin{aligned}
oy_{it} = & \rho_0 + \rho_1 \ln(y_{it-1}) + \rho_2 \text{popden}_{it-1} + \rho_3 \text{ap}_{it-1} + \rho_4 \ln(\text{gdp}_{it-1}) + \rho_5 \ln(\text{dem}_i) + \rho_6 \ln(\text{dem2}_i) + \rho_7 \ln(\text{slope}_i) + \rho_8 \ln(\text{slope2}_i) \\
& + \rho_9 \ln(\text{organic}_i) + \rho_{10} \ln(\text{pa}_i) + \rho_{11} \ln(\text{ta}_i) + \rho_{12} \ln(\text{d2pvcp}_i) + \rho_{13} \ln(\text{d2port}_i) + \rho_{14} \ln(\text{d2road}_i) + \rho_{15} \ln(\text{d2water}_i) \\
& + \rho_{16} \ln(\text{prod}_{it-1}) + \rho_{17} \ln(\text{value}_{it-1}) + \rho_{18} \text{fpark}_{it-1} + \rho_{19} \text{tbp}_{it-1} + \rho_{20} \text{grain}_{it-1} + \rho_{21} \text{tghl}_{it-1} + \rho_{22} \text{for cover}_{it-1}
\end{aligned} \quad (3)$$

where,  $i$  identifies the basic analysis unit, county or municipality;  $t$  is to identify the year, 1988, 1995, 2000 and 2005;  $t-1$  refers to the first stage lagged variables.

#### 4. Results

It is of importance to understand the causes of forestry area change in Northeast China from 1988 to 2005 for the best management of forestry resources, because it can not only help us recognize and represent the pattern of forestry area change and it can deepen the understanding for the driving mechanism of forestry area change in Northeast China. Table 2 displays the quantitative relationship between endogenous variables and exogenous variables in the process of forestry production, open forest converted to closed forest, and other land uses converted to closed forest. In order to clearly explain the driving mechanism of forestry area change, we will elaborate the driving factors by dividing them into geophysical conditions and socio-economic variables.

Table 2 Estimation results for the causes of forestry area change in Northeast China

Variables	Equation(1)	Equation(2)	Equation(3)
popden	-0.009 (1.88)*	-0.025 (0.89)	-0.010 (1.69)*
ap	—	0.383 (0.47)	0.294 (1.85)*
ln(gdp)	0.034 (1.34)	0.247 (1.19)	-0.043 (0.92)
ln(dem)	0.379 (2.45)**	0.945 (1.52)**	0.564 (2.05)**
ln(dem2)	-0.095 (5.56)***	-0.725 (3.16)***	-0.063 (2.07)**
ln(slope)	0.522 (10.25)***	1.188 (2.57)**	0.397 (3.58)***
ln(slope2)	0.059 (3.90)***	0.407 (3.09)***	0.097 (2.99)***
ln(organic)	-0.551 (11.61)***	0.051 (0.11)	-0.148 (1.74)*
ln(pa)	0.686 (4.52)***	1.787 (1.49)	0.323 (1.21)
ln(pa2)	—	-2.223 (0.81)	—
ln(ta)	-30.42 (6.54)***	-43.693 (0.95)	-26.519 (0.86)
ln(d2pvcp)	-0.025 (0.76)	-0.055 (0.2)	0.083 (1.46)
ln(d2port)	-0.737 (10.44)***	0.589 (0.93)	0.100 (0.97)
ln(d2road)	-0.340 (5.90)***	0.660 (1.39)	0.142 (1.44)
ln(d2water)	-0.066 (1.73)*	0.426 (1.19)	-0.022 (0.35)
ln(y)	—	0.776 (2.16)**	0.412 (6.18)***
ln(prod)	0.162 (1.89)*	-0.528 (1.56)	-0.330 (4.59)***
value	0.003 (2.48)**	—	0.001 (0.92)
fpark	-0.004 (0.05)	—	0.156 (0.99)
grain	-0.010 (0.21)	—	0.167 (1.96)*
mng	1.300 (20.12)***	—	—

ln(cvother21)	—	0.218 (2.09)**	—
ln(ld22)	—	0.932 (7.05)***	—
tbp	0.282 (4.64)***	1.142 (2.67)***	0.362 (2.49)**
tghl	—	—	0.207 (2.56)**
forcover	—	—	-0.018 (3.67)***
Constant	4.848 (8.53)***	-3.576 (3.88)***	5.117 (7.02)***
Observations	645	365	398

† Absolute value of t statistics in parentheses; † † † \*\*\*, \*\*, \* is the significant level of 1%, 5% and 10%, respectively; † † † (t-1) identifies one stage lagged variables; † † † † Observations of 258 in 86 county/municipalities corresponds the counties of Jiangxi province (86 times 3 years).

#### 4.1. Impacts of geophysical conditions

Geophysical conditions are the controlling factors for forestry production and forestry area changes. Among them, average terrain slope and elevation exert an obvious influence on the forestry production and forest conversion. The steeper the terrain slope is and/or the higher the elevation is, the larger the forestry area is, and the higher the forestry production is. In addition, these areas, with poor condition for habitat, are not suitable for cultivation, and the levels of urbanization and industrialization are low, so it provides the positive conditions to make open forest and other land uses converted to closed forest in a certain extent. Similarly, when the altitude surpasses a certain height, the further development of forestry sector is limited, and area of other land uses can be converted to forestry area decrease. Variables such as annual temperature and annual precipitation were chosen to analyze and illustrate the influence of climate changes on forestry area. Estimation results show that annual temperature and annual precipitation are only obvious to the forestry production, but not obvious to forest conversion. The coefficients of annual precipitation on the forestry production is around 0.686 and its significance is at 1% level, which indicates that forestry production would increase by 68.6% while annual precipitation increase by 10%. However, temperature has somewhat constrains on the forestry production because that the forestry area of Northeast China is mainly distributed in northern part of Northeast China.

Variables to measure the effects of distances to the nearest port city, the nearest water area and nearest main road can not be ignored, especially their functions for the conversion of land use cover. The estimated coefficients from these variables of distances to the nearest port city and nearest main road are 0.278 and 0.340, respectively. Variable on the distance to nearest water area is also the important factors to promote forest production, because a close distance to the water resource can not only provide conditions for forest conversion, but also provide the possibility for the timber shipping. Although the location conditions have dramatic influence on the forest production, however, they have no obvious influence on the conversion of other land uses to closed forest.

#### 4.2. Impacts from socio-economic variables

Socio-economic variables are the major factors affecting forest production and the spatial pattern of forestry area. Population density, agricultural population proportion (one stage lagged terms), GDP are taken to identify and characterize the statistic relationship between economic or population growth and forestry area change. In populated area, the damage to forest is usually more dramatic, so gross output value of forest production is relatively lower, and the conversion of other land uses to closed forest is restricted. However, the increase of agricultural population could promote more area of other kinds of land uses converted into closed forest. The expansion of gross output value of forest production stimulates the development of forestry sectors, promotes the closed forest expansion, and

the coefficients for the conversion of open forest to closed forest and the conversion of other land uses to closed forest is up to 0.776 and 0.412, respectively. Although in natural reserve area and main grain production county forest production will be influenced, the magnitude is marginal. In main grain production area, the conversion of forestry area is dramatic, the elasticity coefficient is 0.167, and its significance is at 10%. Open forest provide the resources for the conversion of open forest to the closed forest, the more area the open forest, the bigger the conversion area of open forest to closed forest.

By analyzing polices of Grain for Green project and Logging Ban program, the influences of forestry management policies and the elasticity coefficients were measured. Research results show that the implementation of Grain for Green project and Logging Ban program have obvious influences on forest production and the conversions from open forest to closed forest, and the estimated coefficients of the Logging Ban program are 0.282 and 1.142, respectively. The effect of Grain for Green project is to promote the conversion of other land uses to closed forest, and its elasticity coefficient is 0.207.

In a word, forestry area in Northeast China is affected by both geographical conditions and socio-economic environment. Geographical conditions of forestry area constitute the basis of its spatial distribution changes, and determine its changing trend at large scale. On the contrary, socio-economic environment would influence the direction and intensity of forestry area changes. Therefore, forestry area change is the result of interaction of a variety of factors.

## 5. Conclusion

It is of great significance to explore the causes of forestry area changes to reveal the macro-structure and spatial heterogeneity of land system. In this paper, we developed a model to analyze the causes of forestry area change in the Northeast China region. In this model, we build three equations, set explanatory variables associated with forestry area change, and then estimate the relationship between forestry area change and influencing factors including geophysical conditions, socio-economic environment and forest management policies in Northeast China from 1988 to 2005. The research results show that terrain slope, elevation and climate conditions are crucial factors to determine the forest production and forest conversions. Location conditions, as the socio-economic factors, have obvious influence on forest production. At the same time, population density, gross output value of forest production, polices of Grain for Green project and Logging Ban program will have different influence on the forestry area changes. In general, it can be concluded that the socio-economic factors play a decisive role for the changes of forestry area in the short term, while the geophysical conditions factors play an important role in the long term.



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## References

- [1] Dai LM, Zheng BF, Guo FH. The roles of a decision support system in applying forest ecosystem management in Northeast China. *Science in China Series E-Technological Sciences*, 2006, **49**: 9-18.
- [2] Yuan CY. Superiority of Forest Resources in Northeast China. *Journal of Northeast Forestry University*, 2007, **35**(12):65-67.
- [3] Chen XW. Tree diversity, carbon storage, and soil nutrient in an old-growth forest at Changbai Mountain, Northeast China. *Communications in Soil Science and Plant Analysis*. 2006, **37**(3-4): 363-375.
- [4] Hao ZQ, Wang QL, Dai LM. Significance of Natural Forest Protection Project on biodiversity conservation in the northeastern forest areas/Biodiversity Committee of Chinese Academy of Sciences. 21 century for biodiversity conservation in China – 3rd Symposium for National Biodiversity Conservation and Sustainable Use. Beijing: Chinese Forestry Press, 2000:21-26.
- [5] Xiao XM, Boles S, Liu JY, Zhuang DF, Liu Mingliang. Characterization of forest types in Northeastern China, using multi-temporal SPOT-4 VEGETATION sensor data. *Remote Sensing of Environment*, 2002, **82**(2-3): 335-348.
- [6] Ge QS, Zhao MC, Zheng JY. Land Use Change of China during the 20th Century. *Acta Geographica Sinica*, 2000, **55**(6):698-706.
- [7] Zhu JJ, Mao ZH, Hu LL, Zhang JX. Plant diversity of secondary forests in response to anthropogenic disturbance levels in montane regions of northeastern China. *Journal of Forest Research*. 2007, **12**(6): 403-416.
- [8] Zhang YF, Tachibana S; Nagata S. Impact of socio-economic factors on the changes in forest areas in China. *Forest Policy and Economics*, 2006, **9**(1): 63-76.
- [9] Wang XG; He HS; Li XZ. The long-term effects of fire suppression and reforestation on a forest landscape in Northeastern China after a catastrophic wildfire. *Landscape and Urban Planning*. 2007, **79**(1): 84-95.
- [10] Wang TM, Wang XC, Guo QX, Sun L, Gui GD. Forest landscape diversity changes in Heilongjiang Province. *Biodiversity Science*, 2004, **12**(4):396-402.
- [11] Zhao BZ, Jia WW, Li FR. Effect evaluation of Natural Forest Protection Project for forestry enterprises in Daxing' anling of Inner Mongolia. *Journal of Northeast Forestry University*, 2006, **34**(2): 84-86.
- [12] Shen YQ, Liao XC, Yin RS. Measuring the socioeconomic impacts of China's Natural Forest Protection Program. *Environment and Development Economics*, 2006, **11**: 769-788.
- [13] Peng H, Cheng G, Xu, Z, Yin Y, Xu W. Social, economic, and ecological impacts of the "Grain for Green" project in China: A preliminary case in Zhangye, Northwest China. *Journal of Environmental Management*, 2007, **85**(5): 774-784.
- [14] Zhang GP, Liu JY, Zhang ZX. Analysis of deforested-land reclamation during the late 20th century in China based on remote sensing and GIS. *Geographical Research*, 2003, **22**(2): 221-228.
- [15] Chen LZ. Biodiversity in China. Beijing: Science Press. 1993.
- [16] Ge QS, Dai JH. Farming and forestry land use changes in China and their driving forces from 1900 to 1980. *Science in China Series D-Earth Sciences*. 2005, **48**(10): 1747-1757.
- [17] Liu JY, Zhang ZX, Zhuang DF, et al. *Geographical Research*, 2003, **22**(1):1-12.
- [18] Xu XL, Liu JY, Zhuang DF, Zhang SW. Spatial-temporal characteristics and driving forces of woodland resources changes in China. *Journal of Beijing Forestry University*, 2004, **26**(1):41-46.
- [19] Deng XZ. *Simulation of Land System Dynamics*. Beijing: China Land Press. 2008a.
- [20] Deng XZ. *Analysis of Land Use Conversions*. Beijing: China Land Press. 2008b.
- [21] State Natural Protection Project, 1998.
- [22] Uchida E, Xu JT, Rozelle S. Grain for green: cost-effectiveness and sustainability of China's conservation set-aside program. *Land Economics*, 2005, **81**(18): 247-264.