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Determinants of Land Use Change Dynamics in the Margins of Protected Forest Areas: Evidence from Central Sulawesi, Indonesia

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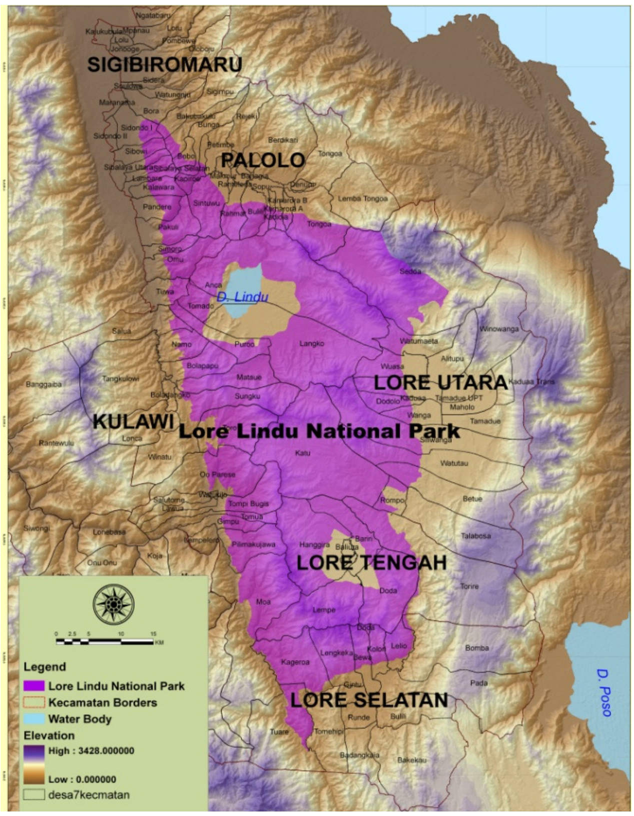
1. Introduction

Land use is defined as the use of land to fulfil human needs that covers a formal economic sense and broader function such as functional relationships among humans, and between humans and the environment (Campbell, 1997 and Latham *et al.,* 2002). Land use that balances trade-off between economic gains of land use and environment is an ideal long term goal. However, many studies show that in recent years, humans have tended to adopt land use patterns that lower the quality of the environment to achieve economic growth through agricultural expansion (Adger and Brown, 1994, Angelsen 1995, Vosti and Reardon 1997, Contreras-Hermosilla, 2000, Fearnside, 2000, Angelsen and Kaimowitz, 2001, and Geist and Lambin, 2002). A similar pattern of land use—causing forest degradation to achieve economic growth—has existed in the study area, namely, Lore Lindu National Park (LLNP) in central Sulawesi, Indonesia. This protected area is very important for biodiversity and conservation since it hosts a unique collection of endemic species besides it functions as water catchments area within the national park (The Nature Conservancy, 2002). However, a previous study of land use in this area found that forestland conversion to agricultural use by rural communities has caused land use to change substantially, leading to forest degradation (Maertens, 2003).

Forest degradation may take place in protected areas in developing countries since the human settlements are not completely restricted to reside in the protected areas. This application is different from the setting of protected areas in most developed countries. The map of the study area (figure 1) illustrates the setting of the LLNP.

Figure 1. Map of study area



Source : The Nature Conservancy, 2002

The map shows that there are different types of nearby villages concerning their locations to the park. The first is villages that are located outside the park have no direct border to the park. The second is villages that have direct border to the park. And the last type is villages that are located inside the park. For the administrative authorization, this park is under two districts (Donggala and Poso) that comprises of eleven sub-districts, which formerly were five sub-districts, and consisting 119 villages A total area of park is 220 thousand hectares which is characterised by complex terrains ranging from low lands to uplands that reach up to 2,600 meter a.s.l., nevertheless, the majority of area is mountainous rainforest.

In these forest margin areas, agricultural activities are very important since 87 per cent of rural communities in surveyed villages depends their income on agricultural lands (Reetz, 2008). A better understanding of the socioeconomic dynamics is beneficial for forest conservation since rural communities at the forest margins should play a significant role in maintaining the stability of the rainforest. It is therefore important to understand determinants of land use change dynamics in the forest margins in order to decelerate forest degradations in these areas.

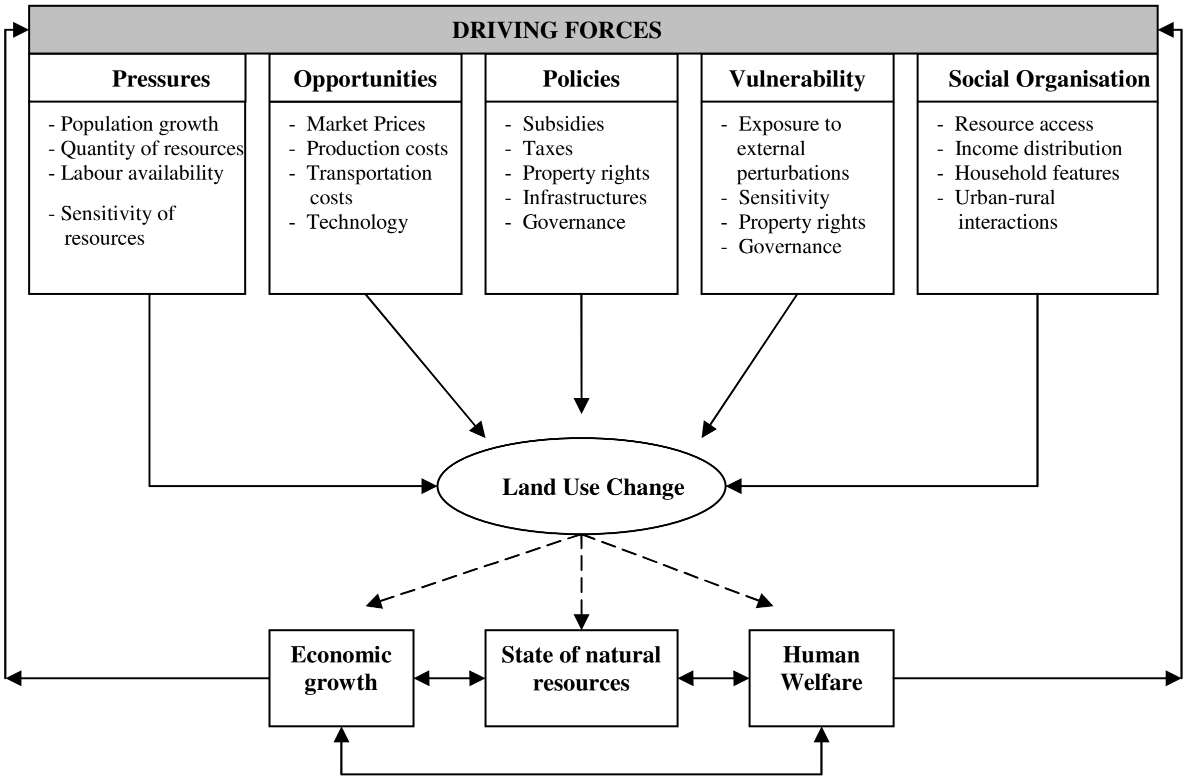
One approach is the use of a spatially explicit model. The usage of spatially explicit modelling allows us to examine land use change in a region, particularly dealing with the locations and patterns of land use, as well as identifying driving forces and characteristic processes of land use change. This knowledge has great importance for supporting land use planning and land allocation that conserve the quality of the environment in the long term. However, the existing models of land use change that accommodate human behavioural components and retain the more fully articulated economic models have not yet been well developed (Irwin and Geoghegan, 2001). Furthermore, although many studies from various countries in Southeast Asia have focused on spatial econometrics of land use change at the village level (e.g. Müller and Zeller, 2002; Maertens, 2003; and Chuong, 2005), they were mainly static models. Less attention has been paid to dynamic analysis. Therefore, this paper aims to extend prior land use studies by assessing the socioeconomic and geophysical factors that drive changes of land use from forest to non-forest applying, for the first time, spatial panel econometric models to the study of land use. The study demonstrates that the use of spatial panel econometric models better perform in estimating factors that determine land use change from forest to non-forest than a dynamic cross section model. The comparison of four panel models of panel models shows that the pooled logit, pooled average (PA) logit, and random effect (RE) led to consistent signs of parameter estimates. In contrast to the other three models, fixed effect (FE) estimation gave a positive sign for the variable "share of irrigated land". Furthermore, factors that were significant to negatively influence changes of land use were: population density, share of irrigated land at the villages, slope, average precipitation, and distance to market. They all have expected coefficient signs except for variables distance to market and slope. This latter finding confirms that deforestation occurred even if the locations were located in remote areas and steeper slope areas.

2. Conceptual Framework

Changes in land use and land cover are not driven by two or three major factors, but involve situation-specific interactions among a large number of factors at different spatial and temporal scales (Lambin *et al.*, 2003). The analysis of land-use/cover changes including human and environmental dynamics requires the integration of various scales and processes of change using complex adaptive systems and transitions. These factors are structural and mainly exogenous in nature in human-environment relations, which are formed by a complex of social, political, demographic, technological, cultural, and biophysical variables. However, some local-scale factors are endogenous to decision makers e.g. the direct regulation of access to land resources, market adjustments, or informal social regulations (Ledec, 1985; Contreras-Hemosilla, 2000; Geist and Lambin, 2002). Since factors causing land use change are complex, it is important to adopt a concept that helps to understand the process of land use change under the scope of study.

To facilitate that purpose, the conceptual framework is illustrated in Figure 1, which combines perspectives from several authors: Scherr *et al.*, 1996; Kaimowitz and Angelsen, 1998; Müller and Zeller, 2002; and Lambin *et al.,* 2003. This figure explains that land use change is determined by driving forces, which are interconnected, but may have different patterns of dominating causes from one area to another. Those forces are distinguished into pressures, opportunities, policies, vulnerability, and social organisation. This classification explains how communities, with their given local endowments, might react differently under the interactions of variables, which are manifested as changes in land use. The responses of communities are not only limited by their local endowments but also influenced by external factors that affect the economic growth, state of natural resources, and human welfare in that region. The aggregate level refers to the attempts of the village community at the forest margins to adapt to their changing environment in a range of time. Their applied livelihood strategies portray the dynamics of land use change in their region. In this framework, livelihood strategies to adapt to a changing environment cover the spatial and temporal issues.

Figure 1. Conceptual Framework of Land-Use Change



Source: Adopted from Scherr *et al.*, 1996; Kaimowitz and Angelsen, 1998; Müller and Zeller, 2002 and Lambin *et al.,* 2003

However, according to theoretical background, previous research findings, and limitation in data collection, this paper only capture selected driving factors of land use change. Based on that consideration, the variables and the expected effects were summarized in table 1.

Table 1. Expected Signs of Independent Variables

Independent variables:	Expected sign	Category of driving force
Socioeconomic factors:		
Population density (person/sq. km)	-	Pressures
Share of bugisnese ethnic (%)	-	Pressures
Share of irrigated land (%)	-	Opportunity
Village Border (1=yes) (0=No)	+	Policies
Distance to village center (000m)	+	Social organisation
Distance to edge (000m)	+	Vulnerability
Distance to river (000m)	+	Vulnerability
Distance to market (000m)	+	Social organisation
Distance to all-year road (000m)	+	Policies
Geophysical factors:		
Elevation (000m)	+	Vulnerability
Temperature (° Celcius)	-	Vulnerability
Average precipitation (ml/day)	+	Vulnerability
Slope (°)	+	Vulnerability
Slope lag (°)	+	Vulnerability
Aspect (°)	+	Vulnerability

3. Methods

a. Data

To analyse land use change in the study area, three types of data have been collected. They are land cover data, geophysical data, and village survey data. Land cover data from satellite imagery were used to provide remotely-sensed data; using aerial photography is another common alternative applied in land use studies. Both techniques are called remote sensing. The usage of remote sensing of vegetative cover and land use helps to provide spatially-explicit data. This is beneficial since data collected on the ground are difficult to obtain, particularly in developing countries. Since some readers might not be familiar with remote sensing, a brief description will explain the data concepts and process. This description is limited to satellite use, since this study only employed this instrument.

Satellites capture the information by detecting and measuring the electromagnetic energy of the sunlight reflected from distant objects of various materials. The information captured by satellite is used to derive the information about characteristics of the earth's surface. Each land use consists of different types of land cover and each land cover reflects individual electromagnetic radiation with different range of energies and wavelength (bands). Inferences derived from satellite remote sensing are made based on the reflectent characteristics of vegetations (Short, 2009). The information of reflected wavelength that is captured by satellite is stored in a regular grid with a specified number of rows and columns. One way to store this information is to use a GIS (*Geographic Information System*). In a GIS, the geographic features over a surface are represented in raster and vector. Vector data store the information as x and y coordinates in a rectangular (planar) coordinate system and usually records the location of discrete geographic features with precise locations. The output of extracted information is represented as satellite images (Agrawal, 2004). In this study, the images of land cover data were derived from the interpretation of a Landsat ETM+ scene. The interpretation yields different colors, structures and patterns that depend on the intensity of light frequency reflected from the earth's surface. By applying a maximum likelihood classification technique with ground-truth data, the interpretation of land cover data in 2001 resulted in ten land use categories with a resolution of 15 by 15 meters. These ten land use categories were distinguished into two forest classes: open and closed forest, and four classes of agricultural land use: coffee and cacao, coconut, paddy and annual crops; grassland; water; settlement areas; clouds and shadow. For the focus of the study which was intended to concentrate on deforestation issues, the ten categories of land use were classified into two classes. The open and closed forests were classified into forest class and the later categories were classified into non-forest class. The similar classification had been applied to obtain a comparable land use map in 2007. In this study, the land cover data were aggregated into 100 by 100 meters as a unit observation at pixel level.

The second type of data is geophysical data. They comprise rainfall, air temperature, slope, and elevation data. Rainfall and air temperature in the daily time series were recorded from ten climate stations, which internally were provided by STORMA (*Stability Rainforest Margin*) project. These data were calculated in annual daily mean and computed at pixel level using the extrapolation method. Slope and elevation were calculated from a digital elevation model (DEM) with 25 meter topographic contour lines. The DEM has a spatial resolution of 70 by 70 meters. This topographic map of the whole study area was digitized from twenty sheets of topographic map based on aerial photographs from the years 1981, 1982, and 1989 and was constructed by Bakosurtanal (National Coordinating Agency for Surveys and Mapping) at a scale of 1: 50,000.

The last type of data is village surveys. The socioeconomic data from 2001 and 2007 were obtained from surveys in 80 randomly selected villages. From both surveys, panel data of socioeconomic variables were obtained with a minimum panel of two time periods.

b. Correcting for Spatial Effects

Two aspects that should be considered in the use of spatial explicit data are spatial dependence (spatial autocorrelation) and spatial heterogeneity (spatial structure). The spatial dependence relates the existence of a functional relationship between one point in space with its nearest neighbourhood in the spatial system. The spatial heterogeneity might rise due to a lack of structural stability across space and non homogeneity of unit observation across space (Anselin, 2001). Furthermore, the issues of spatial autocorrelation and heterogeneity area not exclusively sourced from the interaction of neighbouring agents of pixel data but also result from the integration of different sources of data, from the use of heterogeneous sample designs, or from different aggregation rules (De Pinto and Nelson, 2002). If the presence of spatial dependence and heterogeneity are ignored in a spatial econometric model, the estimated parameters and statistical inferences might be unreliable (Anselin, 2001). There are three ad-hoc techniques that have been applied in the land use study to correct spatial effects—applying regular sampling from a grid, using latitude and longitude index, and introducing spatial lagged variables into a model—(De Pinto and Nelson, 2002). In this study, the regular sampling from a grid and spatially lagged variables have been applied to correct the spatial effects.

c. Binary Panel Outcomes Models

To investigate the dynamics of forest to non-forest movement, mainly for agricultural uses, binary panel outcomes models were applied. The use of panel data is advantageous since there are some attributes attached to panel data that cannot be provided by using cross sectional data or time series only. For instances, panel data models have controls for individual heterogeneity and are able to capture the dynamics of adjustment. Furthermore, it increases the precision of regression estimates, allows one to construct and test more complicated behavioural models, and to be able to identify and measure effects.

Theoretically, it is expected that the panel model captures the dynamics adjustment, providing better analysis of land use change from forests to non-forest use. However, though there are advantages to using panel data, some limitations exist, such as design and data collection problems, distortions of measurement errors, selectivity problems and short time dimensions (Baltagi, 2003 and Kennedy, 2003).

In this study, binary outcomes models as non-linear panel models were applied to analyse the relationship between exogenous variables and dependent variables. The outcomes of panel data takes value yit = 1 if land is devoted for forest and takes value yit = 0 for non-forest. The probability yit = 1 can be stated as (Cameron and Trivedi, 2008):

$$\Pr[y_{it} = 1|x_{it}, \beta, \alpha_i] = \begin{cases} F(\alpha_i + x'_{it}\beta) & \text{in general} \\ \Lambda(\alpha_i + x'_{it}\beta) & \text{for logit model} \\ \Phi(\alpha_i + x'_{it}\beta) & \text{for probit model} \end{cases}$$

Where F(.) is a cumulative distribution function, Λ(.) is the logistic cdf with $\Lambda(z) = e^Z / (1 + e^Z)$, and Φ(.) is the standard normal cdf. Non-linear panel models essentially have similar approaches as in linear models with pooled, population-averaged (PA), random effect (RE) and fixed effects (FE).

c. Marginal Effects

Unlike in a linear model, the information yields from coefficient estimates in a non-linear model are meaningless and have no direct useful information to explain the relationship between the outcome and the independent variables (Long and Freese, 2005). There are several ways to interpret that relationship in a non-linear model. One common approach uses marginal effects. The representation of marginal effects ($\delta p/\delta x_j$) for the logit model is $(\Lambda(x'\beta)/ 1- \Lambda(x'\beta)/ \beta_j$.

Since the marginal effects depend on the point of interest for x, it is common to focus on one or more particular values for which marginal effects are calculated. However, this is not possible for panel logit models. The mean value of regressors is used instead of a specified value in panel logit models. Though the marginal effects of for FE and RE can be obtained, the interpretation of those values is more difficult because of the presence of α_i. As we know that the logit individual-effects model either for FE or RE is $\Pr[y_{it} = 1|x_{it}, \beta, \alpha_i] = \Lambda(\alpha_i + x'_{it}\beta)$, which both include α_i in the models (Cameron and Trivedi, 2008). For these reasons, a computation of marginal effects by using PA logit model is applied in this study rather than RE or FE since the interpretation of marginal effects is more applicable of which is similar to cross-section logit models.

4. Empirical Results and Discussions

4.1. Descriptive Statistics

Table 1 shows the descriptive statistics of the study area within two time periods from 2001 to 2007. As can be seen, forest is the majority of land use with coverage at more than three quarters of the whole study area; non-forest land covers less than one fifth. Population density is considered low, with less than three persons per square kilometre in comparison with sub-districts and provincial level. Most villages have irrigated land at a low percentage; less than ten per cent. More than fifty per cent of villages have a direct border with the national park. The average distance of most villages to central markets is more than seventy kilometers and the average distance required to access all-year roads is more than eight kilometres. Distance to markets and all-year roads were measured by the straight line distance from the sample point to referenced points (central market and the road network) without adjusting road quality. However, because the qualities of most roads were uniformly poor, thus, it can be assumed that, on average, access to markets is difficult. The average topographic conditions are unsuitable for agricultural use since most land is at high elevation—more than thousand meters above a sea level—and have steep slopes of more than fourteen degrees.

Table 1. Descriptive Statistics

Dependent variable:	Frequency		Percent		
Land use:					
Forest Land (1)	50,381.00		85.00		
Non- Forest land (0)	8,892.00		15.00		
Independent variables:	Mean	Std. Dev.	Min	Max	Scale
Socioeconomic factors:					
Population density (person/sq. km)	2.80	1.36	.09	6.36	Survey
Share of bugisnese ethnic (%)	3.66	6.48	.00	41.60	Survey
Share of irrigated land (%)	5.98	9.27	.02	93.74	Survey
Village Border (1=yes) (0=No)	.65	.48	.00	1.00	Survey
Distance to village center (000m)	2.33	2.36		15.11	Pixel
Distance to edge (000m)	0.62	0.65	.00	4.30	Pixel
Distance to river (000m)	1.52	1.69	.00	13.10	Pixel
Distance to market (000m)	70.48	24.85	6.47	122.77	Pixel
Distance to all-year road (000m)	8.64	7.27	.00	34.04	Pixel
Geophysical factors:					
Elevation (000m)	1.23	0.43	30.00	2.45	Pixel
Temperature (° Celcius)	22.03	1.59	16.70	27.65	Pixel
Average precipitation (ml/day)	5.15	.86	2.51	6.77	Pixel
Slope (°)	14.15	9.75	0.00	60.0	Pixel
Slope lag (°)	13.73	8.37	.00	50.00	Pixel
Aspect (°)	182.95	105.39	-1.00	359.00	Pixel

Source : own calculation

Table 2 shows the persistence of land use within two time periods. The results indicate that more than eighty per cent of the land that was not forest before remains as non-forest in the next period, while more than ninety per cent of the land that was forest before remains as forest in the next period. Occasionally, land use change from forest and non-forest and vice versa was taking place in this region. However, the share of land changing from forest to non-forest is higher than from non-forest to forest.

Table 2. Persistence of land use

Land use	Non-forest	Forest	Total
Non-forest	83.70	16.30	100.00
Forest	4.75	95.25	100.00
Total	15.63	84.37	100.00

Source : own calculation

4.1. Dynamics of Land Use Change

4.1.1. Binary Pane Logit Model

To identify the determinants of land use change dynamics, four binary panel models were compared by applying models of pooled logit, pooled-averaged logit (PA), random effect (RE) and fixed effect (FE) in table 3.

Table 3. Binary Panel Logit Estimates of Land Use Change

Dependent variable:				
Forest Land (1) Non- Forest land (0)				
Independent variables:	**Pooled**	**PA**	**RE**	**FE**
Socioeconomic factors:				
Population density (person/sq. km)	-0.057*** (0.019)	-0.057*** (0.019)	-0.067*** (0.024)	-0.239*** (0.086)
Share of bugisnese ethnic (%)	0.005 (0.004)	0.0052 (0.004)	0.006 (0.005)	0.052 (0.035)
Share of irrigated land (%)	-0.007*** (0.002)	-0.007*** (0.005)	-0.008** (0.004)	0.028*** (0.011)
Village Border (1=yes) (0=No)	0.103* (0.059)	0.103* (0.059)	0.124* (0.067)	
Distance to village center (000m)	0.295*** (0.048)	0.295*** (0.048)	0.304*** (0.043)	
Distance to edge (000m)	10.594 *** (0.487)	10.594 *** (0.487)	11.641*** (0.312)	
Distance to river (000m)	0.073 *** (0.023)	0.073*** (0.023)	0.096*** (0.027)	
Distance to market (000m)	-0.011 *** (0.001)	- 0.011 *** (0.001)	-0.013*** (0.001)	
Distance to all-year roads (000m)	0.038*** (0.005)	0.038*** (0.005)	0.048*** (0.005)	
Geophysical factors:				
Elevation (000m)	2.929 *** (0.082)	2.929*** (0.082)	3.648*** (0.122)	
Temperature (° Celcius)	0.111*** (0.021)	0.111*** (0.021)	0.130*** (0.026)	0.730 (0.473)
Average precipitation (ml/day)	-0.202*** (0.020)	-0.202*** (0.020)	-0.260*** (0.028)	-0.338*** (0.054)
Slope (°)	-0.033*** (0.009)	-0.033*** (0.009)	-0.040*** (0.009)	
Slope lag (°)	0.178 *** (0.010)	0.178*** (0.01)	0.217*** (0.011)	
Aspect (°)	- 0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	
_cons	-5.203*** (0.543)	-5.203*** (0.543)	-6.265*** (0.670)	
N observation	54954	54954	54954	3204
Pseudo R^2	0.66			
Wald Chi^2 / LR chi2(5)	4226.09	4225.31	2981.06	168.30
Probability > Wald Chi^2 / Chi^2	0.00	0.00	0.00	0.00

,**, Significant at the 10%, 5%, and 1% level, respectively.**

Source : own calculation

As noted in the methods section, coefficient estimates in non-linear models have no directly useful information to explain the relationship between the outcome and the independent variables. As a consequence, the interpretation of the models was focused on the significance and the direction of signs of the estimated coefficients. As can be seen, coefficients for most geophysical variables in the four models are significant at the 1% level except for the variable aspect. Likewise, coefficients of variables that represent location such as distance to market, distance to all-year road, etc. were also highly significant at 1% level. For socioeconomic variables, apart from the variable share of Bugisnese ethnic group, which was statistically insignificant, most of them were significant but at different levels. The high significance of variables including into the models confirms that the models were able to capture the important factors determining land use from forest to non-forest, which was also indicated by the higher value of Pseudo R^2 (0.6617) in the pooled logit model.

The comparison of four panel models shows that the pooled logit, PA logit, and RE led to consistent signs of parameter estimates. In contrast to the other three models, FE shows that the sign of variable share of irrigated land at the villages changes direction toward the positive. Since FE excludes time-invariant regressors, and this study only covers two periods, the estimation of αi and β to might be inconsistent (Cameron and Trivedi, 2008). Furthermore, factors significant to influence changes of land use negatively were: population density, share of irrigated land at the villages, the slope, mean of average precipitation, and distance to market. They all have expected signs except for variables distance to market and slope. The negative sign of parameter estimates, for instance, for variable population density, can be interpreted as indicating less change in population density making the probability of land become forest greater. Likewise, the same interpretations were applied to variables of share of irrigated land at the villages and the mean of daily rainfalls. The interpretation of variable slope and distance to market in an exception since the sign of coefficients contradict to the existing literatures. The negative coefficient indicates that the further the distance to the central market does not increase the probability of land becoming forest. Nevertheless, this finding confirms that deforestation occurred even in remote areas. Furthermore, the contradict sign of variable slope coefficient indicates that forest was more concentrated in the less steep areas and deforestation was taken place at the steeper slope caused by landslides. Unlike the negative signs of parameter estimates, the positive signs in the estimated models resulted as expected, except for variable temperature.

4.1.2. Marginal Effects of Binary Panel Logit Model

Table 4 describes the marginal effects at sample mean values. Marginal effects express the probability of land becoming forest when there is change in an explanatory variable and everything else being constant. As showed by table 4, most explanatory variables were significant to influence the probability of land becoming forest except for variables: share of Bugisnese ethnic group and aspect. Furthermore, except for the variables of temperature and average precipitation, most explanatory variables have a small probability becoming forest when they change by one point percentage. The relatively higher values of marginal effects of variable temperature and precipitation most likely can arise from a higher aggregation level of climate data, which only consist of ten climate stations to serve about a size of 220 thousand hectares in the whole area.

Table 4. Marginal Effects of Binary Panel Logit Estimation

Dependent variable:	Marginal Effects after logit:		
Forest Land (1) Non- Forest land (0)	y = exp(xb)/(1+exp(xb)) (predict) = .99983356		
Independent variables:	dy/dx(*)	P>|z|	Mean
Socioeconomic factors:			
Population density (person/sq. km)	-9.52e-06	0.007	2.88
Share of bugisnese ethnic (%)	8.65e-07	0.209	3.27
Share of irrigated land (%)	-1.23e-06	0.023	5.98
Village Border (1=yes) (0=No)	1.75e-05	0.067	.68
Distance to village center (000m)	4.91e-05	0.000	2.32
Distance to edge (000m)	1.76e-03	0.000	0.64
Distance to river (000m)	1.22e-05	0.002	1.57
Distance to market (000m)	-1.90e-06	0.000	70.49
Distance to all-year road (000m)	6.28e-06	0.000	8.15
Geophysical factors:			
Elevation (000m)	4.87e-04	0.000	1.26
Temperature (° Celcius)	1.85e-05	0.000	21.92
Average precipitation (ml/day)	-3.37e-05	0.000	5.17
Slope (°)	-5.49e-06	0.000	13.83
Slope lag (°)	2.97e-05	0.000	13.33
Aspect (°)	-2.40e-08	0.451	184.09

Source : own calculation

(*) dy/dx is for discrete change of dummy variable from 0 to 1

5. Conclusions and Policy Implications

The application of spatial panel econometric models to land use study has provided a good basis on how certain key factors significantly influence the dynamic of land use for forest and non-forest. Despite lower population density in the study area, the uses of spatial panel models were able to capture the dynamics of population growth that indicate negative correlation between population growth and forest cover. Besides, the models have confirmed that deforestation was taking placed even in remote areas. The investment in irrigated land in some villages has attracted the expansion of non forest use. This evidence might explain why in some villages the surrounding village were more completely deforested than others. The policy implications that can be derived from this study were: maintaining birth control policy to keep population growth in a low rate, and reducing trade-off between economy gain of non-forest land use and forest degradation by introducing institutional innovation programs such as community forest management.

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