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

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Introduction

Lore Lindu National Park (LLNP) in central Sulawesi, Indonesia is very important for biodiversity and conservation since it hosts a unique collection of endemic species. This park is also essential for water catchments in the surrounding areas. In these forest margin areas, agricultural activities are very important for the livelihood of the communities as 87 per cent of rural communities in the surveyed villages depend on agricultural lands for their income (Reetz, 2008). 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 and has led to forest degradation (Maertens, 2003). Since rural communities, as forest stewards at the forest margins, should play a significant role in maintaining the stability of the rainforest, a better understanding of the socioeconomic dynamics is thus beneficial for forest conservation.

This paper aims to assess the socioeconomic and geophysical factors that drive changes of land use from forest to non-forest using a spatially explicit model. Our analysis presents the dynamics of forest covers using spatial and socioeconomic data from 2001 and 2007 obtained from Landsat images and surveys in 80 randomly selected villages, respectively. Our results indicate that population density, share of irrigated land at the villages, slope, average precipitation, and distance to market were significant factors negatively influencing changes of land use. Furthermore, our finding confirms that deforestation occurred even if the locations were located in remote areas and steeper slope areas.

Data

Three types of data namely: land cover data, geophysical data, and village survey data were used in our analysis. Land cover data were derived from the interpretation of the Landsat ETM+ scene and resulted in ten land use categories with a resolution of 15 by 15 meters. The ten categories of land use were classified into two classes as the focus of this study is the deforestation issue. The land cover data were aggregated into 100 by 100 meters as a unit observation at pixel level. A similar procedure had been applied to obtain a comparable land use map in 2007.

The second type of data is geophysical data comprising 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 the 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.

The last type of data are 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.

Methods

Binary outcomes models as non-linear panel models were applied to analyse the relationship between exogenous variables and dependent variables. The approach of the non-linear panel models is similar to linear models with pooled, population-averaged (PA), random effect (RE) and fixed effects (FE). Furthermore, to correct spatial effects in our model, namely, spatial dependence (spatial autocorrelation) and spatial heterogeneity (spatial structure), the regular sampling from a grid and spatially lagged variables have been applied.

One common approach to interpret that relationship in a non-linear model is through marginal effects. However for panel logit models, the mean value of regressors is used instead of a specified value. Moreover, a computation of marginal effects by using a PA logit model is applied in this study rather than RE or FE. The reason is because the interpretation of marginal effects is more applicable, which is similar to cross-section logit models.

Results and Discussions

The majority of land use is forest with coverage of more than three quarters of the whole study area; non-forest land covers less than one fifth (Table 1).

Table 1. Descriptive Statistics

Dependent variable:		Frequency		Percent	
Land use:	Forest Land (1)	50,381		85	
	Non- Forest land (0)	8,892		15	
Independent variables:	Mean	Std. Dev.	Min	Max	Scale
Socioeconomic factors:					
Population density (person/sq. km)	2.80	1.36	0.09	6.36	Survey
Share of bugisnese ethnic (%)	3.66	6.48	0.00	41.60	Survey
Share of irrigated land (%)	5.98	9.27	0.02	93.74	Survey
Village Border (1=yes) (0=No)	0.65	0.48	0.00	1.00	Survey
Distance to village center (000m)	2.33	2.36	0.00	15.11	Pixel
Distance to edge (000m)	0.62	0.65	0.00	4.30	Pixel
Distance to river (000m)	1.52	1.69	0.00	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	0.00	34.04	Pixel
Geophysical factors:					
Elevation (000m)	1.23	0.43	0.03	2.45	Pixel
Temperature (° Celcius)	22.03	1.59	16.70	27.65	Pixel
Average precipitation (ml/day)	5.15	0.86	2.51	6.77	Pixel
Slope (°)	14.15	9.75	0.00	60.0	Pixel
Slope lag (°)	13.73	8.37	0.00	50.00	Pixel
Aspect (°)	182.95	105.39	-1.00	359.00	Pixel

Source : own calculation

Population density is considered low, with less than three people per square kilometre in comparison to sub-districts and at provincial level. Most villages having irrigated land is 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 kilometres and the average distance required to access all-year roads is more than eight kilometres. The average topographic conditions are unsuitable for agricultural use since most land is at a high elevation—more than a thousand metres above sea level—and have steep slopes of more than fourteen degrees.

Dynamics of Land Use Change

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 2.

Table 2. 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***	-0.057***	-0.067***	-0.239***
	(0.019)	(0.019)	(0.024)	(0.086)
Share of bugisnese ethnic (%)	0.005	0.0052	0.006	0.052
	(0.004)	(0.004)	(0.005)	(0.035)
Share of irrigated land (%)	-0.007***	-0.007***	-0.008**	0.028***
	(0.002)	(0.005)	(0.004)	(0.011)
Village Border (1=yes) (0=No)	0.103*	0.103*	0.124*	
	(0.059)	(0.059)	(0.067)	
Distance to village center (000m)	0.295***	0.295***	0.304***	
	(0.048)	(0.048)	(0.043)	
Distance to edge (000m)	10.594 ***	10.594 ***	11.641***	
	(0.487)	(0.487)	(0.312)	
Distance to river (000m)	0.073 ***	0.073***	0.096***	
	(0.023)	(0.023)	(0.027)	
Distance to market (000m)	-0.011 ***	- 0.011 ***	-0.013***	
	(0.001)	(0.001)	(0.001)	
Distance to all-year roads (000m)	0.038***	0.038***	0.048***	
	(0.005)	(0.005)	(0.005)	
Geophysical factors:				
Elevation (000m)	2.929 ***	2.929***	3.648***	
	(0.082)	(0.082)	(0.122)	
Temperature (° Celcius)	0.111***	0.111***	0.130***	0.730
	(0.021)	(0.021)	(0.026)	(0.473)
Average precipitation (ml/day)	-0.202***	-0.202***	-0.260***	-0.338***
	(0.020)	(0.020)	(0.028)	(0.054)
Slope (°)	-0.033***	-0.033***	-0.040***	
	(0.009)	(0.009)	(0.009)	
Slope lag (°)	0.178 ***	0.178***	0.217***	
	(0.010)	(0.01)	(0.011)	
Aspect (°)	- 0.000	-0.000	-0.000	
	(0.000)	(0.000)	(0.000)	
_cons	-5.203***	-5.203***	-6.265***	
	(0.543)	(0.543)	(0.670)	
N observation	54,954	54,954	54,954	3,204
Pseudo R^2	0.66			
Wald Chi^2 / LR chi2(5)	4,226.09	4,225.31	2,981.06	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

Since 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 focuses on the significance and the direction of signs of the estimated coefficients.

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 might be inconsistent (Cameron and Trivedi, 2008). Furthermore, factors significant in negatively influencing changes of land use were: population density, share of irrigated land at the villages, the slope, mean of average precipitation, and distance to market. 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 becoming 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 is an exception since the sign of coefficients contradicts existing literatures. The negative coefficient indicates that a further distance to the central market does not increase the probability of land becoming forest. Nevertheless, this finding confirms that deforestation did occur even in remote areas. Furthermore, the contradictory sign of variable slope coefficient indicates that forest was more concentrated in the less steep areas and deforestation took place at the steeper slope caused by landslides. Unlike the negative signs of parameter estimates, the positive signs in the estimated models had expected results, except for variable temperature.

Marginal Effects of Binary Panel Logit Model

Marginal effects express the probability of land becoming forest when there is change in an explanatory variable with everything else being constant. Table 3 describes the marginal effects at sample mean values.

Table 3. 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 *	1.75e-05	0.067	0.68
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

As we can see, most explanatory variables were significant in influencing 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 of becoming forest when they change by one point percentage. The relatively higher values of marginal effects of variable temperature and precipitation may arise from a higher aggregation level of climate data, which only consist of ten climate stations serving a size of approximately 220 thousand hectares in the whole area.

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 forest cover dynamics. 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. In addition, 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 the surroundings in some villages 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 at a low rate, and reducing trade-off between economic gain of non-forest land use and forest degradation by introducing institutional innovation programs such as community forest management.

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