Chapter 5
Modeling the Driving Forces of the Land Use and Land Cover Changes Along the Upper Yangtze River

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Abstract Induced by high population density, rapid but uneven economic growth, and long-time resource exploitation, China's upper Yangtze basin has witnessed remarkable changes in land uses and covers, which have resulted in severe environmental consequences, such as flooding, soil erosion, and habitat loss. This paper examines the causes of the land use and land cover changes (LUCC) along the Jinsha River, one primary section of the upper Yangtze, aiming to better understand the human impact on the dynamic LUCC process and to provide necessary policy actions for sustainable land use and environmental protection. Using a panel dataset covering 31 counties over four time periods from 1975 to 2000, the study develops a fractional logit model to empirically determine the effects of socioeconomic and institutional factors on changes for cropland, forestland, and grassland. It is shown that population expansion, food self-sufficiency, and better market access drove cropland expansion, while industrial development contributed significantly to the increase of forestland and the decrease of other land uses. Similarly, stable tenure had a positive effect on forest protection. Moreover, past land use decisions were less significantly influenced by the distorted market signals. The policy implications of these findings and future directions of research are also discussed.

Keywords Land use and land cover changes · Driving forces · Fractional logit model · Upper Yangtze basin · Policy action

5.1 Introduction

A better understanding of the causes and consequences of land use and land cover changes (LUCC) is essential for global change studies because of their tremendous effects on carbon and water cycles, ecosystem functions, and human

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welfare (Turner, Meyer, & Skole, 1994; Geoghegan et al., 2001; Müller & Zeller, 2002; USGCRP, 2004). With continuous population growth and rapid economy development, China has witnessed substantial changes in land uses over the past several decades, and these changes have resulted in severe environmental consequences, such as flooding, soil erosion, and habitat loss. All of these have led to serious concerns about the sustainability of China's development (Liu, Liu, Zhuang, Zhang, & Deng, 2003). Thus, how to allocate the limited land resources so as to simultaneously satisfy the demands for food, natural resource materials, urban expansion, and quality environment has become a great challenge.

The upper Yangtze basin in China constitutes a great site for the LUCC research. The Yangtze River is the country's longest and the world's third largest river, which starts out from the Tibetan Plateau in the west, courses 6,300 km across 11 provinces (autonomous regions), and finally flows into the East China Sea. The Yangtze basin, with a total area of 180 million ha (19% of the country's area), nurtures around 40% of China's population, possesses 40% of the country's potential hydro-power, and contributes to more than 40% of China's GDP (Du, 2001). However, the development of the whole basin has been threatened by the environmental deterioration in the upper reaches.

The upper reaches of the Yangtze River refer to the vast area west of Yichang, Hubei, with a total area of over 105 million ha. The region is known for its rich biodiversity and complex geography. It features a wide variety of ecosystems that have been recognized as a major biodiversity hotspot (Conservation International, 2002). Accompanying the diverse ecosystems are the extreme fluctuations in topography and landscapes including high mountains and deep gorges in the west to hills and lowlands in the east. Such sharp variations make the region vulnerable, but it is the malpractices of human land use that worsen the situation. Deforestation, farmland expansion, and grassland degradation have seriously damaged native vegetation covers, causing severe environmental problems (Du, 2001; Xu, Katsigris, & White, 2002; Loucks et al., 2001). The deteriorated environment not only reduces land productivity in the region and threatens the lifespan and effectiveness of the Three-Gorges Dam, but also imposes large risks on economic development and people's livelihoods in the middle and lower reaches of the Yangtze. Therefore, it is important and imperative to understand how the regional LUCC are affected by various factors, so that appropriate policy adjustments can be made for more sustainable land use.

However, few rigorous studies have been done on the LUCC driving forces in the upper Yangtze. The existing works are mostly concerned with the long-term food security because of arable land loss that is undermining China's food production capacities. These works either examined cropland changes under different socioeconomic scenarios at the national level (Fischer & Sun, 2001; Verburg, Veldkamp, Espaldon, & Mastura, 2002; Zhang, Mount, & Boisvert, 2003), or analyzed regional arable land losses induced by urbanization and infrastructure or industrial expansion especially in the metropolitan areas (Yeh & Li, 1998; Ji et al., 2001), or looked into the effects of cropland suitability shifts on food production (Li, Peterson, Liu, & Qian, 2001). As stated by Liu et al. (2003), "... In the future, we need to study thoroughly the impact of human social and economic activities on land-use change at regional scales (p. 384)..."

   This paper aims to gain a better understanding of the LUCC process in the upper Yangtze region and thus provide the essential knowledge for taking appropriate policy actions in achieving more sustainable land use. Specifically, we will develop and estimate a sound econometric model to determine the driving forces for changes in cropland, forestland, and grassland in the region; and we will do so by incorporating various socioeconomic and institutional as well as biophysical factors in a spatially explicit way. Our results show the driving forces have different effects on different land uses and the economic growth and institutional change have played important roles in affecting the LUCC. It is expected that the study will provide significant insights concerning the regional land policy, resource management, and environmental protection. Of course, these insights also are of relevance to other regions in China and indeed other developing countries. The paper is organized as follows. A brief description of the study site will be given in the next section, followed by the method and data sections. Then, estimation results will be presented before concluding remarks.

5.2 Study Site

Because of the expansiveness of the upper Yangtze basin, the study site was selected along the Jinsha River, part of the upper Yangtze with a length of 2,290 km. The Jinsha River refers to the section starting from Yushu County in Qinghai province, flowing across Qinghai, Tibet, Yunnan, and Sichuan, and ending in Yibin of Sichuan. The total area of this catchment is about 34 million ha, but included for this study are 31 counties fully located inside it (97.7°–104.8°E, 25.4°–32.7°N) with 14 million ha. Nineteen counties are in Yunnan, with an area of 7.2 million ha; the other 12 in Sichuan have an area of 6.8 million ha (Fig. 5.1).
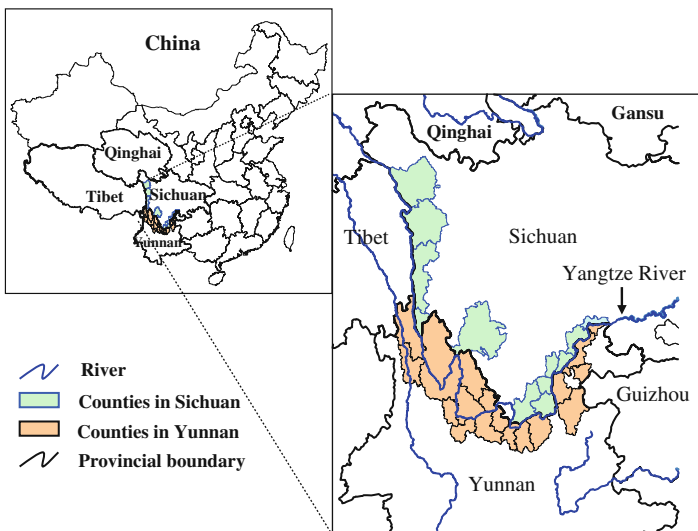

Fig. 5.1 The Study Region in Sichuan and Yunnan of China

The Jinsha River basin is known for its sharp descent, fragile geology, and severe soil erosion. The main stream precipitates by 3,280 m, while the elevation of the basin ranges from 300 to 6,140 m. Among the 31 counties, six have at least 70% of their lands at altitudes higher than 3,000 m, and 21 have at least 50% of their lands at altitudes between 1,500 and 3,000 m. Meanwhile, lands in 13 counties have slopes up to 60°. The geological structure of the lower Jinsha basin is dominated by Triassic shale and sandstone, which weather rapidly in the subtropical monsoon climate and yield soils that are susceptible to erosion (Lu, 2005). The steep slopes and fragile soils make the Jinsha basin a major sediment source to the Yangtze. It is estimated that annual soil loss from the upper Yangtze region averages 1.57 billion ton, accounting for 71.4% of the total soil loss of the whole Yangtze basin. About 45% of soil loss of the upper Yangtze region comes from the Jinsha basin (Pan, 1999).

Unfavorable natural conditions and poor transportation infrastructure make the region relatively isolated from the outside and suffer from a high incidence of poverty. In 2002, for example, the GDP of Ganzi Tibetan prefecture was ranked second to the last in Sichuan and even worse, the net per capita income of rural households (RMB 900/y) ranked the last in the province – less than half of the provincial average (Sichuan Statistics Yearbook, 2003)[1]. Of the 19 counties in Yunnan, 15 are national poverty counties (Wang, 2003), and 31.5% of the rural households had a per capita income lower than RMB 1,000/y (Yunnan Statistics Yearbook, 2003). Nonetheless, farming has long been a major income source in the region. From 1975 to 2000, the average value of annual farming output accounted for at least 55% of the total agricultural output (in addition to farming, official statistics for agriculture include animal husbandry and forestry). However, animal husbandry grew more rapidly than farming and forest sectors: its output share increased from 18% in 1975 to 35% in 2000. The output value from forestry was comparatively small, amounting to about eight percent of the total value of agricultural output, albeit the higher share of forestland.

5.3 Methods

5.3.1 Conceptual Model

Models used to examine the LUCC drivers are mostly derived from the land-rent maximization theory. The land owner is assumed to allocate a parcel of land of quality j at time t to the use that can generate the highest present value of a stream of net returns over time. For example, the net return for a parcel of cropland of certain quality at time t, W_t^a, equals the net present value of a stream of crop revenues minus cultivation costs, plus the present value of the land salvage value (Ahn, Plantinga, & Alig, 2000). The net return for a tract of forestland of certain quality at time t, W_t^f, is the net present value of a series of timber harvest rotations, determined by stumpage

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[1]The Chinese government initially defined the poverty line as per capita income below 200 yuan in 1985. Based on inflation and other considerations, the figure has been adjusted upwards over time, reaching 1067 yuan in 2007 (China State Statistics Bureau 2008). A national poverty county is declared if a majority, but not necessarily all, of the local population lives below the poverty line.

prices and yields by species (Munroe & York, 2003). The land will be allocated to forestry if $W_t^f \geq W_t^a$, otherwise to farming (Plantinga, 1996).

The observed land use shares at the county level are derived by aggregating the land use choices of individuals who attempt to maximize land rents. For each land quality type j across a county, the land is allocated to different uses to maximize the total returns, subject to its availability (Miller & Plantinga, 1999; Ahn et al., 2000). That is:

$$Max \sum_k W_{jkt} \left(X_{kt}, h_{jkt} \right)$$

subject to:

$$\sum_k h_{jkt} = H_{jt} \tag{5.1}$$

where k is the land use choice set, W_{jkt} is the net return function for the kth land use in quality class j at time t, h_{jkt} is the land area for the kth use in quality class j at time t, H_{jt} is the total land area with quality j at time t, and X_{kt} encompasses all the variables that affect the net return to land use k at time t. The solution to the problem is the optimal allocation h_{jkt}^{*}, expressed as:

$$h_{jkt}^{*} = h_{jkt}^{*} \left(H_{jt}, X_t \right) \tag{5.2}$$

If the total land area for a county is $H(t) = \sum_j H_j(t)$, the sum of lands with different quality j, then the optimal share of land use k for this county at time t, p_k, is defined as:

$$p_k^{*}(X, t) = \frac{1}{H(t)} \sum_j h_{jkt}^{*}(H_{jt}, X_t) \tag{5.3}$$

Notably, while a parcel of land with a certain quality can be allocated to different uses, the share of each land use differs across lands with different qualities or land characteristics. What we are interested in here is not only how the land is allocated to different uses at a given time, but also how changes happen to each use over time.

5.3.2 Estimation Method

Following the theoretical model for land allocation, the share of a land use can be defined as (Miller & Plantinga, 1999):

$$y_{it}^k = P_{it}^k (X_{it}) + \varepsilon_{it}^k \tag{5.4}$$

where y_{it}^k and p_{it}^k are the observed and expected shares of land use k in county i at time t, and ε_{it}^k is the independently and identically distributed error term. The sum of y_{it}^k or p_{it}^k equals to unity when the range of k covers each land use in county i at time t.

It should be pointed out that y and p are bounded between zero and one, implying that it is not appropriate to express y or p as a linear function of the explanatory variables and thus to estimate it with a conventional method. A potential problem is that the fitted value of y or p may fall outside the unit interval. To avoid this problem, p can be modeled as a logistic function:

$$E\left(y_{it}^k \mid X_{it}\right) = p_{it}^k = \frac{\exp\left(X_{it}\,\beta_k\right)}{1 + \exp\left(X_{it}\,\beta_k\right)} \tag{5.5}$$

and then the observed land share y for use k is expressed as:

$$y_{it}^k = \frac{\exp\left(X_{it}\,\beta_k\right)}{1 + \exp\left(X_{it}\,\beta_k\right)} + \varepsilon_{it}^k \tag{5.6}$$

where β is the coefficient vector. The above specification, called the fractional logit model, ensures that predicted values for y ranges between zero and one. It is assumed that ε satisfies a logistic distribution. Note that while β_n gives the sign of the partial effect of the nth explanatory variable on a land use, its magnitude cannot represent the partial effect of that explanatory variable on the dependent variable (Wooldridge, 2002).

A popular approach to coefficient estimation is to transform the above model so that the log-odds of the dependent variable have a conditional expectation on the linear form of explanatory variables: E $(\log[y|(1-y)]/X)=X\beta$, which is estimated by the *OLS* method. But such a transformation has certain drawbacks. First, it cannot be used directly if the dependent variable takes on boundary values, zero and one. Second, it is difficult to interpret the coefficients because without further assumptions it is impossible to recover how y is expressed by explanatory variables (Wooldridge, 2002). To address these problems, the fractional logit model is estimated with the quasi-Maximum Likelihood Estimator (MLE), which provides a consistent estimate of β when E($y|x$) is expressed as a logistic form. Meanwhile, the potential problems of heteroskedasticity and serial correlation in variance can be taken care of with the econometrics software.

In principle, the fractional logit Equation (5.6) needs to be established for each type of land use k, and the sum of dependent variables equals to one. To ensure the identification of these equations, only k-1 equations are estimated. Because the total land area is classified into four primary categories in this study, a system of three equations will be estimated. The effects of explanatory variables on the fourth land use type equal to unity minus the sum of the effects on the other three.

5.4 Data Description

The dataset, covering the 31 counties over five time points (mid-1970s, mid-1980s, late 1980s, mid-1990s, and late 1990s), is used in the fractional logit model to elucidate the LUCC drivers from 1975 to 2000. The dataset consists of two parts: the dependent variables – land use shares derived from satellite images, and the

explanatory variables – biophysical and socioeconomic factors gathered from multiple sources.

5.4.1 Land Use Data

The land use data are derived from Landsat Multi-Spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) images. In cases where certain images are missing or of poor quality, those from adjacent years are taken to obtain the information for a given time point. The land use/cover data of the mid-1970s (hereafter referred to as "1975 data") are derived from MSS images of 1973–1977, late 1980s data ("1990 data") are derived from 1988 and 1989 TM images, mid-1990s data ("1995 data") are derived from TM images of the year 1995, and late 1990s data ("2000 data") are derived from TM/ETM+ images for 1999 and 2000.

The data for 1990, 1995, and 2000 are a subset of China's national land cover dataset created by the Chinese Academy of Sciences (CAS). Due to the unavailability of images for the mid-1980s, a land cover map for 1985 was scanned and digitalized to generate the needed data. The classified land use/cover data are re-sampled to form a raster-format dataset with a resolution of 100 m, and then overlapped with a county boundary map to generate the corresponding county-level data (Table 5.1). Tests by CAS (Liu et al., 2003) show that the accuracy rate for 1975 data is 88%; the accuracy rate for 1990, 1995, and 2000 is 92.92, 98.40, and 97.45%, respectively.

Table 5.1   Land Use Patterns in the Study Region from 1975 to 2000

Land uses/ covers (ha)	1975	1985	1990	1995	2000	Changes between 1975 and 2000
Cropland	1,603,687	1,614,621	1,561,700	1,563,426	1,560,719	–42,968
Forests	7,487,370	7,530,783	7,498,984	7,551,545	7,466,451	–20,919
Grassland	4,242,754	4,117,841	4,310,880	4,224,982	4,388,228	145,474
Others	707,821	778,387	670,068	701,679	626,234	–81,587

Note: Data are from the Institute of Geographic Science and Natural Resources, Chinese Academy of Science (Liu et al., 2003).

5.4.2 Explanatory Variables

We use the procurement prices for grain, log, and livestock to represent the economic returns from cropland, forestland, and grassland. Relative to these market signals, however, decisions on land use in China were and still are influenced by government regulation and population pressure. For cropland, farmers sign contracts with local governments to manage it, and contracts are valid for decades and seldom adjusted so as to provide stable "use rights." In principle, cropland expansion on grassland or forestland is prohibited; but in practice, such encroachment does happen due to the necessity for food production and the difficulty in regulation

enforcement. Because of uncertain use rights, however, reclaiming cropland could be induced by contemporary price change, but not by the long-term profitability. Grain procurement prices faced by producers were controlled by the government, and their effects on land use decisions might not be as apparent as expected because they were depressed. In forestry, timber harvest and distribution were largely controlled by the government, and the state-owned enterprises and collective forest entities had little motivation for long-term management. It is thus reasonable to assume that forestland changes were not greatly affected by the limited price movements. Similarly, the modest livestock price changes might not induce significant grassland shifts. Nevertheless, output prices can have significant cross effects.

Costs are not easily identifiable for crop, timber, and livestock production at the county level. As an alternative, we adopt the approach used by Chomitz and Gray (1996) and elaborated by Kaimowitz & Angelsen (1998), who observed that the distance of a parcel of land to roads, reflecting market access, affects both output and input costs and thus land use patterns. The road length in a county is used to capture the transportation cost and market access for that county. And we expect that compared to grassland and forestland, cropland is more likely allocated close to settlement centers.

Industrial development is included as an explanatory variable as well. This is because while industrial development may take away some fertile cropland, it promotes transfer of surplus rural labor to off-farm activities, which reduce pressures on natural resources and help environmental conservation. Off-farm activities also alter the opportunity cost for rural labor, which constrains labor available to extensive farming (McCracken et al., 1999) and improves farmers' income and abilities to adopt new technologies. As a result, enhanced land use productivity can better satisfy livelihood needs and therefore reduce resource overexploitation.

Population expansion is widely used as a determinant of land use changes (Mertens, Sunderlin, Ndoye, & Lambin, 2000), and its main effect is to cause cropland encroachment on forestland and grassland and related resource degradation (Yin & Li, 2001). Soil characteristics influence land allocation by determining land suitability for different land uses and productivity. But measuring soil characteristics for a county is hard because of the large variations of the soil features. So, the average elevation of a county is used to represent soil features as well as temperature and other biophysical conditions that affect land use[2].

The food self-sufficiency policy and forest tenure arrangement are two major political-institutional factors that have affected land use patterns in the study region. The former, reflected in grain procurement quota, encouraged cropland expansion on slopes previously covered by forest or grassland (Xu, Yin, Li, & Liu, 2007). It is thus hypothesized that a decreasing quota, as a sign of relaxing the policy, should benefit the restoration of vegetation covers. The latter, if clearly defined and enforced, forms the basis for at least stable forest management. In the study area, around 30% of the forestland is owned by the state. This forestland was seldom

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[2]Elevation will not be listed in the summary statistics of variables because it is a time-constant variable. It ranges from 295 meters (m) to 6109 m for the study region, with a mean of 3070 m.

Table 5.2 Summary of Variables Used in the Fractional Logit Model

	Measurement	1975	1985	1990	1995	2000
Population	1,000 Persons	6,101	6,815	7,141	7,592	7,908
Population density	Person/km^2	0.66	0.73	0.78	0.82	0.86
Grain price[1]	Index (1990 = 1)	0.587	0.669	0.972	1.619	2.035
Log price[1]	Index (1990 = 1)	0.589	0.531	0.927	1.046	1.294
Livestock price[1]	Index (1990 = 1)	0.860	0.863	1.085	1.873	2.218
Industry output (IO)[2]	1,000 RMB	69,534	141,243	169,494	516,442	698,396
Agricultural output (AO)[2]	1,000 RMB	189,063	329,188	351,141	533,255	729,546
IO/AO		0.320	0.403	0.443	0.768	0.762
Highway	km	6,132	9,836	11,592	14,173	28,059
Highway rate	km/ha	0.0009	0.0014	0.0016	0.0021	0.0031
Grain quota[3]	Ton	170,423	141,292	111,231	115,691	107,481
Per capita quota	Ton/person	0.030	0.028	0.016	0.016	0.014
State forest share		0.338	0.331	0.322	0.319	0.314

Note:
[1] Grain, log, and livestock price indices are provincial aggregates.
[2] Agricultural and industry outputs are output values at 1990 constant price.
[3] Grain quota is from the local grain bureau, and the state forest share is from the local forest bureau. All other data come from local statistics bureaus.

converted to other uses due to its stable and clear tenure, although forest degradation happened because of over-harvesting. In contrast, for sloping lands that belonged to the collectives or those without clear ownership, forestland or grassland loss to cropland often occurred (Xu et al., 2007). Thus, the share of state-owned forest is employed to proximate forest tenure stability. It is not suggested, though, that state ownership is superior and does not need reform.

Table 5.2 summarizes all the variables. Note that a variable's value at a given point of time is the average value from the adjacent years whose range is the same as that of the land cover data. For instance, the land use/cover data in 1975 is derived from the remote sensing images of 1973–1977; so correspondingly, data for each explanatory variable in 1975 is the mean value of 1973–1977. Appendix details the definitions and variations of some of these variables.

5.5 Estimation Results

Including all the explanatory variables, our empirical model becomes:

$$Y_{it} = f\left(GP_{it}, FP_{it}, LP_{it}, IND_{it}, POP_{it}, ROAD_{it}, GQ_{it}, SF_{it}, E_{it}\right) + \varepsilon_{it}$$

where i denotes county and t denotes time. Y represents cropland share, forest share, or grassland share; GP is the price index for grain, FP the price index for

logs, *LP* the price index for livestock; *IND* is the ratio of industry output to gross agricultural output; *POP* denotes population density, *ROAD* denotes the highway rate, *GQ* represents per capita grain quota, *SF* represents the share of state-owned forests, and *E* denotes the elevation. Province and year dummies are also added to control variations across provinces and over time. The model is estimated with STATA software. Endogeneity test indicates that all explanatory variables can be taken as exogenous ones.

Table 5.3 lists the estimated results for the shares of cropland, forestland, and grassland. To save space, coefficients for province and year dummy variables are omitted. It should be noted that the listed coefficients are the corresponding elasticities calculated according to the land use changes, but not *β*. This way of presentation can indicate the extent of driving forces' impacts on each type of land use. In general, signs of most coefficients are as expected and statistically significant, and the effects of explanatory variables are different on different types of land use.

Two price coefficients are statistically significant. First, grain price has a significant negative effect on the change of forestland share; one percent increase of grain prices can reduce the forestland share by 0.37%, holding other variables constant. This indicates that farmers indeed seek short-term farming profits from the increased grain prices by encroaching forestland. Second, the effect of livestock price on cropland share is positively significant at 10% level; one percent increase of livestock price can result in 0.94% increase of the cropland share when controlling other variables. This suggests that some crops are planted for feeding domestic animals, so a higher livestock price drives more feedstock production. The insignificance of most

Table 5.3 Estimation Results of Fractional Logit Model for Primary Land Use

Explanatory variables	Cropland	Forest	Grassland	Others
Grain price	– 0.519 (0.358)	– 0.367 (0.180)**	0.357 (0.342)	– 0.428
Log price	0.011 (0.101)	– 0.087 (0.058)	0.067 (0.089)	– 0.215
Livestock price	0.944 (0.565)*	0.192 (0.368)	0.087 (0.694)	– 4.251
Industry/ agricultural output	– 0.047 (0.011)***	0.068 (0.027)**	– 0.114 (0.059)*	0.919
Highway rate	0.215 (0.077)***	0.018 (0.054)	0.105 (0.140)	– 1.721
Population density	0.480 (0.028)***	– 0.335 (0.082)***	0.157 (0.134)	–0.732
Per Capita Grain quota	0.037 (0.020)*	– 0.005 (0.011)	– 0.015 (0.034)	0.108
Share of state-owned forest	– 0.132 (0.085)	0.116 (0.072)*	– 0.133 (0.107)	1.023
Elevation	– 1.232 (0.128)***	– 0.633 (0.139)***	1.222 (0.335)***	– 6.509

Note:
1. Numbers in parentheses are standard error of the coefficient "*", "**" and "***" represent 10, 5, and 1% significance level, respectively.
2. There were 122 observations used in the estimation, because of some missing values for high way variable. So, the degree of freedom was 107.
3. Result for other lands are derived, thus without significance level.

other price variables partially proves our prior knowledge that the LUCC might not be driven much by price signals, especially for forestland and grassland. On the other hand, the use of a provincial index could have concealed the price variations across counties.

Industrial development significantly reduces the pressures on resource exploitation. The higher the industry output, the lower the shares of cropland and grassland, and the higher the share forestland. A one percent increase of industrial development can result in 0.05% decrease in cropland, 0.11% decrease in grassland, and 0.07% increases in forestland. As discussed earlier, economic development does affect the LUCC by altering land economic returns and labor opportunity costs. Consistent with our assumption, highway construction has significant effects on cropland changes. Holding other variables constant, one percent increase of the highway rate can result in a 0.22% increase in the cropland share. Insignificant effects of highway rate on forestland and grassland changes imply that given other conditions, forestland or grassland share in a county is not closely connected to its highway length. So, road construction has more influence on the changes of cropland use than anything else.

Demography significantly affects land use changes. Counties with higher population density observed higher cropland share and lower forestland share. Increased population resulted in cropland expansion to meet the growing food demand and imposed pressure on forest resources. One percent increase in population density causes the cropland share to grow by 0.48%, while it induces forestland to decline by 0.33%. Although the effect of population growth on grassland changes is statistically insignificant, the positive sign makes sense. Results from the three equations show that the share for other lands declined with the population growth, which suggests that farming encroaches on unused lands or even bodies of water because of limited cropland resource.

Grain procurement quota has significant effects on cropland expansion. One percent increase of per capita grain quota could induce a 0.04% increase of the cropland share. No significant effects of grain quota on forestland and grassland changes are found, but the signs of coefficients are as expected: an increase of grain quota is associated with a decrease in forestland and grassland. So, it can be inferred that eliminating grain quotas will reduce not only burdens on farmers but also cropland expansion at the expense of forestland or grassland. Tenure indeed has a significant influence on forest resource status. The share of forestland increases by 0.12% when the state-ownership is one percent higher, holding other variables constant. Additionally, the share of other lands goes up with the increase of state-owned forestland. Finally, the estimation also proves that land use allocation varies significantly with altitude. The cropland and forestland shares decrease with altitude, but more grassland is found in the high elevation.

5.6 Conclusions and Discussion

This study develops and estimates a fractional logit model to examine the driving forces of the LUCC in the upper Yangtze basin. Results indicate that industrial development had a significant effect on reducing cropland expansion and conserving

forest resources, whereas population growth put pressures on land resources and contributed to deforestation and grassland degradation. In the past, land use decisions were made to capture immediate profits, but they were not significantly influenced by the long-term price signals. In addition, institutional and policy factors played critical roles in shaping the land use patterns: lowering grain quota levied on farmers reduced cropland expansion, and stable forest tenure led to a higher share of forestland.

These and other results carry significant policy implications. First, off-farming opportunities not only increase farmers' income, but also lure them out of rural areas and thus reduce their disturbance to land covers. With the increasing population, development of non-farming sectors has become an important way to alleviate poverty as well as to protect natural resources. Local governments should provide job services to facilitate farmers' pursuit of off-farming activities. Second, market mechanism should be promoted in allocating land resources. That prices did not significantly influence land use decisions in the past is partially because these prices were not real market signals but government-controlled ones, and such distorted prices could not adequately guide long-term land use decisions. For instance, the growth rate of log procurement price was lower than that of livestock price and grain price, and the log price did not reflect higher market demand for forest products and discouraged reforestation and forest management. Reforestation and afforestation will improve if forest managers face higher and more transparent log prices and thus expect to get reasonable returns in the long run.

The food self-sufficiency policy was not conducive to efficient and sustainable land use because the grain procurement quota disrupted the trade and distribution of agricultural products across the nation, and caused more land and other inputs to be used in crop production. It is not necessary to meet food demand with local production for a region like our study site that possesses poor farming conditions and limited cropland. However, with abundant grassland and forestland, farmers should specialize in livestock and forest industries and establish their comparative advantage in the marketplace.

Moreover, clearly defined tenure arrangement encourages long-term planning and protection of forest resources. State ownership represents a stable forest tenure, which has reduced the possibility of forest conversion. However, unclear beneficiaries of collective forests and distorted market prices discouraged farmers from forest management and investment, and consequently the collective forests were more likely to be degraded and even converted to other uses. Results of this study imply that it is important to implement tenure reforms for the collective forests, including the clarification of use and benefit rights, the creation of a well-functioning monitoring and enforcement system, and dissemination of transparent and fair market information to the local forest managers. In doing so, it is expected that the forest conversion to other uses will slow down or even reverse, forest investment will increase, and sustainable forest management will follow.

While the fractional logit model developed well explains the driving forces of the regional LUCC, more needs to be done in order to enhance our understanding

of the complicated land use processes. The logit form of the share functions is ad hoc to some extent. As applied in this study, it does not treat relevant variables as endogenous or account for the feedback effects and thus is insufficient to illuminate the dynamic interactions among different variables. Therefore, future study should develop more sophisticated models that incorporate the interactive processes and environmental consequences into the analysis of the LUCC driving forces (Turner, Lambin, & Reenberg, 2007). Such efforts will shed new light on the fundamental question of how the land use changes have happened and help generate more reliable projections on the future LUCC. Moreover, the effect of technological progress on the LUCC should be considered. Technology progress is a critical solution to sustaining the livelihood of an expanding population on a limited land base (Müller & Zeller, 2002). But technology progress itself is determined by socioeconomic changes and resource endowment (Ruttan, 2001). Thus, incorporating endogenous technology progress into the analytic framework in examining the LUCC driving forces more effectively will be a major research step, which can lend great insights to the quest for sustainable development. Undoubtedly, these tasks will be accomplished only if more comprehensive datasets, particularly those longitudinal ones with long time series and spatially explicit observations, can be built.

Appendix: Definition and Variation of Some Key Variables

Land use is categorized as cropland, forestland, grassland, and other lands. Forestland, grassland, and cropland are major land-use types for the study region. In 2000, these three land-use types accounted for 53, 30, and 11%, respectively. All other lands accounted for about five percent of the total land (Table 5.1). Compared to 1975, areas of cropland, forest, and other lands in 2000 decreased, while grassland increased. Notably, for each of four periods from 1975 to 2000, the percentage change of each land use was not large. Because the study area has 14 million ha, a change even as small as one percent was actually not of small magnitude. On the other hand, the original image processing at the national scale could have obscured the county-level LUCC. Moreover, opposite land conversions (e.g., from cropland to forest and vice versa) always take place, leading to the lack of relative variation for each land use over time.

The land conversion information is insightful for understanding the dynamic LUCC process. The extent of cropland conversion to forestland, grassland, and other lands was larger before 1990 than that thereafter. Between 1975 and 1990, about ten percent of cropland was converted out, whereas from 1990 to 2000 only four percent of cropland was converted out. Similarly, grassland conversion to cropland, forestland, and other lands was at a larger scale before 1990. Except for the period of 1975–1985 when a majority of grassland was converted to other lands, most of the grassland was converted to forestland. Meanwhile, grassland was also the major outlet of forest conversion. In contrast, conversion between grassland and forestland for each period made the total area for forestland and grassland look stable, which

indicates the necessity to examine the causes of the changes for different land uses at a finer scale, such as the county level.

Prices used are the provincial indices, meaning that at each time point the value of each price is the same for all counties of the province. All prices increased continuously from 1975 to 2000. Grain and livestock prices rose at an annual rate of over 12% in the early 1990s, while the late 1980s witnessed the fastest log price increase. Growing livestock price over time partially explains why livestock husbandry is preferred as a means of improving rural income. Log procurement price was more stagnant compared to the other two. This is partly why the farmers have little incentive for long-run forest investment and management, and instead they harvest when the price goes up or when they have access to the forest to capture immediate profits.

Highway mileage in a county is used to represent road length. China's statistics provide a standard definition of highway, so there is no ambiguity or discrepancy for data of highway length across counties over time. Highway rate, the ratio of highway length to county area, is the variable used in the analysis to remove the effect of county size.

Industrial development is defined as the ratio of industry output to gross agricultural output. Despite the dominance of the agricultural sector in the economy, its share declined. In 1975, the ratio of industry output value to the agricultural output was 0.3, and it increased to 0.4 in 1990 and further soared to 0.76 in 2000. Compared to that in 1975, industry output in 1990 more than doubled, and in 2000 increased by nine times. This is because the annual growth rate of industry output was much higher than that of agriculture.

Population density, total population divided by county area, is used in our modeling. Total population kept increasing over time, but at a declining rate. The annual population growth rate was 1.3% between 1975 and 1985, then decreased to 0.83% in the late 1990s. Accordingly, the population density also rose over time at a declining rate.

Grain procurement quota includes a portion for paying agricultural tax and another portion that is mandated to be sold to the state-owned procurement bureau at lower prices. Grain procurement quota declined gradually, and in 2000 it decreased to 60% of the 1975 level. Because of such a large decline, grain quota per rural resident also decreased dramatically, from 30 kg in 1975 to around 14 kg in 2000. The decrease of grain quota over time implies that the food self-sufficiency requirement became gradually out of date as the agricultural produce market became more developed. Since 2003, China has terminated the quota-based agricultural tax nationwide.

Share of state-owned forests in Sichuan is around 50%, while in Yunnan province it is just 20%. The share of state-owned forest decreased slightly over time in both provinces, and there were two reasons for this. First, disputes about land ownership were gradually resolved between local government and communities, with the latter having taken up some forests from the former. Second, afforestation and conversion of sloping cropland to forests increased the total as well as collective forestland gradually, and thus the percentage of the state forest declined.

References

Ahn, S., Plantinga, A. J., & Alig, R. J. (2000). Predicting future forestland area: A comparison of econometric approaches. *Forest Sciences, 46*(3), 363–376.

China State Statistics Bureau. (2008). China Statistics Yearbook. Beijing: China Statistics Press.

Chomitz, K. M., & Gray, D. A. (1996). Roads, land use, and deforestation: A spatial model applied to Belize. *World Bank Economic Review, 10*(3), 487–512.

Conservation International. (2002). *Biodiversity hotspots.* Retrieved from http://www.biodiversity hotspots.org/xp/hotspots/China

Du, S. F. (2001). *Environmental economics.* Beijing: Encyclopedia Press.

Fischer, G., & Sun, L. X. (2001). Model based analysis of future land-use development in China. *Agriculture, Ecosystems and Environment, 85*, 163–176.

Geoghegan, J., Villar, S. C., Klepeis, P., Mendoza, P. M., Himmelberger, Y. O., Chowdhury, R. R., et al. (2001). Modeling tropical deforestation in the southern Yucatán Peninsular region: Comparing survey and satellite data. *Agriculture, Ecosystems and Environment, 85*, 25–46.

Ji, C. Y., Liu, Q., Sun, D., Wang, S., Lin, P., & Li, X. (2001). Monitoring urban expansion with remote sensing in China. *International Journal of Geographical Information System, 22*(8), 1441–1455.

Kaimowitz, D., & Angelsen, A. (1998). *Economic models of tropical deforestation: A review.* Bogor, Indonesia: Center for International Forestry Research.

Li, X., Peterson, J. A., Liu, G., & Qian, L. (2001). Assessing regional sustainability: The case of land use and land cover change in the Middle Yiluo Catchment of the Yellow River Basin, China. *Applied Geography, 21*, 87–106.

Liu, J. Y., Liu, M. L., Zhuang, D. F., Zhang, Z. X., & Deng, X. Z. (2003). Study on spatial pattern of land-use change in China during 1995–2000. *Science in China (Series D), 46*(4), 373–384.

Loucks, C. J., Lü, Z., Dinerstein, E., Wang, H., Olson, D. M., Zhu, C. Q., et al. (2001). Giant pandas in a changing landscape. *Science, 294*, 1465.

Lu, X. X. (2005). Spatial variability and temporal change of water discharge and sediment flux in the lower Jinsha tributary: impact of environmental changes. *River Research and Applications, 21*(2–3), 229–243.

McCracken, S. D., Brondizio, E. S., Nelson, D., Moran, E. F., Siqueira, A. D., & Rodriguez-Pedraza, C. (1999). Remote sensing and GIS at farm property level: Demography an deforestation in the Brazilian Amazon. *Photogrammetric Engineering and Remote Sensing, 65*(11), 1311–1320.

Mertens, B., Sunderlin, W. D., Ndoye, O., & Lambin, E. F. (2000). Impact of macroeconomic change on deforestation in South Cameroon: Integration of household survey and remotely sensed data. *World Development, 28*(6), 983–999.

Miller, J. D., O., & Plantinga, J. A. (1999). Modeling land use decision with aggregated data. *American Journal of Agricultural Economics, 81*, 180–194.

Müller, D., & Zeller, M. (2002). Land use dynamics in the central highlands of Vietnam: A spatial model combining village survey data with satellite imagery interpretation. *Agricultural Economics, 27*, 333–354.

Munroe, D. K., & York, A. M. (2003). Jobs, houses and trees: Changing regional structure, local land-use patterns, and forest cover in Southern Indiana. *Growth and Change, 34*(3), 299–320.

Pan, J. G. (1999). The characteristics of water runoff and suspended sediment along the Jinsha River. *Journal of Sediment Research, 2*, 19–24.

Plantinga, A. J. (1996). The effects of agricultural policies on land use and environmental quality. *American Journal of Agricultural Economics, 78*, 1082–1091.

Ruttan, V. W. (2001). *Technology, growth, and development: An induced innovation perspective.* Oxford, UK: Oxford University Press.

Sichuan Statistics Yearbook. (2003). Chengdu, China: Sichuan Statistics Press.

Turner II, B. L., Lambin, E. F., & Reenberg, A. (2007). The emergence of land change science for global environmental change and sustainability. *PNAS, 104*(52), 20666–20671.

Turner II, B. L., Meyer, B. W., & Skole, D. L. (1994). Global land use/land cover change: towards an integrated study. *AMBIO, 23*(1), 91–94.

USGCRP. (2004). Land use/land cover change: USGCRP program element. Retrieved from http://www.usgcrp.gov/usgcrp/ProgramElements/land.htm.

Verburg, P. H., Veldkamp, W. S. A., Espaldon, R. L. V., & Mastura, S. S. A. (2002). Modeling the spatial dynamics of regional land use: the CLUE-S model. *Environmental Management, 30*(3), 391–405.

Wang, X. T. (2003). *Building an ecological shield along the Upper Yangtze river: Priorities and measures.* Beijing: China Agriculture Publishing House.

Wooldridge, J. M. (2002). *Econometric analysis of cross section and panel data.* Cambridge, MA: The MIT Press.

Xu, J. T., Katsigris, E., & White, A. (Eds.). (2002). *Implementing the natural forest protection program and the sloping land conversion program: Lessons and policy recommendations.* Beijing, China: China Forestry Press.

Xu, J., Yin, R. S., Li, Z., & Liu, C. (2007). China's ecological rehabilitation: Progress and challenges. *Ecological Economics, 57*(4), 595–607.

Yeh, A. G., & Li, X. (1998). Suitable land development model for rapid growth areas Using GIS. *International Journal of Geographical Information System, 12*(2), 169–189.

Yin, H., & Li, C. (2001). Human impact on floods and flood disasters on the Yangtze River, *Geomorphology, 41*(2–3), 105–109.

Yunnan Statistics Yearbook. (2003). Kunming, China: Yunnan Statistics Press.

Zhang, X., Mount, T. D., & Boisvert, R. N. (2003). *Industrialization, urbanization and land use in China.* IFPRI, Environment and Production Technology Division (Discussion Paper No. 58).