Land-use Changes, Forest Type Changes, and Related Environmental Concerns in the Southern U.S.

by

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Abstract

The U.S. South covers roughly 24 percent of the total land area and 30 percent of the unreserved forest area of the United States. During the past few decades, the region has experienced dramatic land use as well as forest type changes due to rapid economic and population growth, and different returns in land uses. These kinds of changes, though meeting the needs of economic development, may result in severe environmental degradation such as air and water pollution, loss of biodiversity, wildlife habitat fragmentation, and increased flooding, which will threaten the environment. This dissertation includes three essays to address these kinds of land use and environmental changes from economic perspectives.

The first essay (chapter 2) presents an empirical analysis of the contributing factors that driven land use and land use changes in the South by applying a random parameter logit (RPL) model using the USDA National Resources Inventory (NRI) 1982-1997 five-year interval land use and land quality data. Results indicate that land use and land use changes in the US South follow the classic land-use theory that higher economic returns cause lands to transit to or to remain in a certain use. Human disturbance is another main factor that results in the loss of rural lands. However, land use transition probabilities with respect to economic returns and population density are both inelastic. The importance of each driving factor and the policy implications are addressed and discussed as well.

The second essay (chapter 3) projects the future distribution of forest types in the South by examining the factors that directly or indirectly influence historical forest type changes using a two-stage discrete choice model, and explores the environmental consequences caused by forest type transition in terms of carbon sequestration on forest lands. Projection results indicate that the area of pine plantation will keep increasing, with a total increase rate of 58 percent during 1997-2047, and the areas of natural pine and hardwoods will decline. Comparing the projections of carbon stocks on forest lands with and without forest type transition, carbon storage from the dramatic change of increase of planted pine, and decline of other forest types are not significantly different from that without forest type transition.

The third essay (chapter 4) explores how land use change decisions are determined by private landowners when property taxes are involved in land use management strategy. Taking North Georgia as the empirical study area, a random parameter logit model is applied to examine how property tax, especially the current use valuation property tax policy influences landowners' land use change decisions. Results indicate that property taxes have a negative impact on landowner's land use and land use change decisions, which means that the higher the property tax for a land use, the lower the probability of lands converting to or remaining in that use. It is inelastic and varies among plots. Without the current use valuation assessment property tax policy, there would be an extra 8,000 acres croplands, an extra 10,000 acres pasture lands, and an extra 10,000 acres of forest decrease in North Georgia, which is about 0.25 % of the total area of rural lands of North Georgia.

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List of Abbreviations

APT	Agricultural Preferential Taxation
CH_4	Methane
CL	Conditional Logit
CO_2	Carbon Oxide
CRP	Conservation Reserve Program
CUVA	Current Use Valuation Assessment
DC	Discrete choice
EQIP	Environmental Quality Incentive Program
FIA	Forest Inventory and Analysis
IIA	Independence of Irrelevant Alternatives
LCC	Land Capability Class
NRCS	National Resources Conversion Service
NRI	National Resources Inventory
N_2O	Nitrous oxide
PII	Population interaction index
REIS	Regional Economic Information System
RPL	Random Parameters Logit
TMS	Timber Mart South
WRP	Wetland Reserve Program

Chapter 1. Introduction[1]

The area of U.S. 13 southern states covers roughly 24 percent of the total land area of the United States. Forests of the region account for 30 percent of the unreserved forest area of the country and 27 percent of all forest lands (Smith et al. 2009). It is the most important timber production region, and it holds about two-fifths of the timberland, and produces about 58 percent of U.S. industrial roundwood and three-fourths of total U.S. pulpwood in 2002 (Smith et al. 2004, Zhang and Polyakov 2010). In the past few decades, the U.S. South has experienced dramatic land use and forest type changes. Six of the top ten states that lost cropland, forests, and other types of rural open space to urban development were in the South in 1992-1997 (Alig and Ahearn 2006).[2] Pine plantations have increased by around 12 million hectares over the past 40 years within afforestation from agricultural lands as well as internal forest type transitions (Haynes 2003).

Land use and land use changes are considered to be closely linked to public policy and environmental conditions and have significantly impacted local residential living conditions, economic development and social welfare (Lubowski et al. 2006a). Figure 1 shows the link between land use, public policy and environment effects. Land use and management strategies are determined by external factors, public policy, and land attributes. External factors such as product demands of society, landowners' individual preferences, technology, and trade laws could influence land use management behavior directly or indirectly which is from reflections of

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[1] This dissertation uses the official format required by the journal *forest Science*

[2] They are Texas, Georgia, Florida, North Carolina, Tennessee, and South Carolina in a descending order.

market responses. Land use and management decisions based on public policy and land attributes have environmental consequences. However, environmental and social costs and benefits associated with different land use and land use changes are seldom considered by individual landowners when they make land use decisions (Lubowski 2002). Thus a private landowner's motivation to maximize profits or utilities from a specific land use could result in pervasively aggregated externalities, which may not be readily observed in a short term.

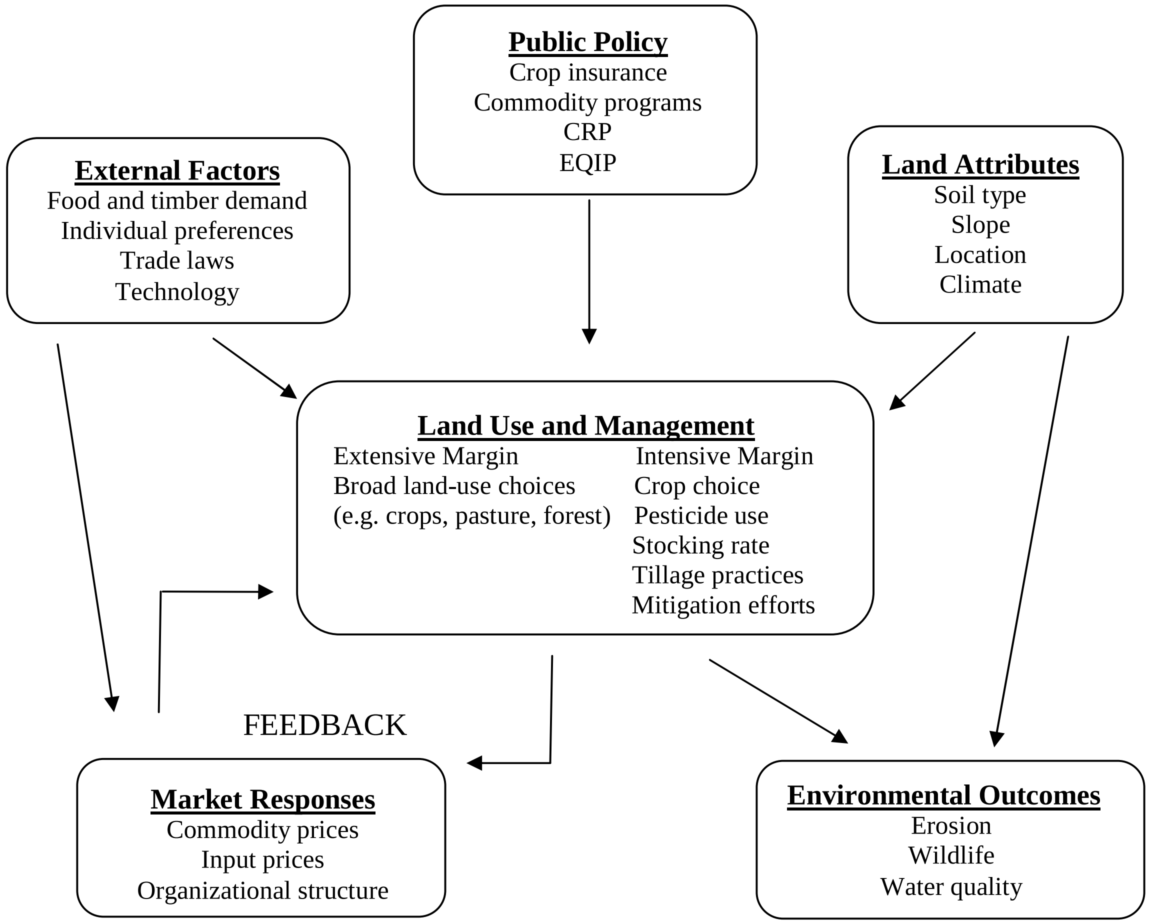

Figure 1. Link between policy, land use, and the environment.
Source: Lubowski et al. 2006a.

In the Southern U.S., about 90 percent of the land is under the control of private individuals (Forest Service 2002). Though driven by maximizing profits or utilities to landowners, final decisions on land use and land use conversions are influenced by public policy, market conditions, and demographics.

Public policy often puts a judicious limit on production and consumption of the goods and services in the society. The goal of public policy with regard to land use is to protect the public's interests in sustainably managing private land resources through a complex mix of information, education, regulation, technical assistance, fiscal and tax incentive programs, and to narrow the divergence between privately and socially optimal land allocations by modifying the economic incentives faced by private landowners (Plantinga and Ahn 2002). It can affect land use decisions in a variety of ways.

In the United States, property tax is one of the most often used public programs used by government to manage private lands through increasing the relative net returns to landowners, thus to encourage them to convert lands to or retain lands in a desired use. Property tax deduction has been ranked as the top preference for government−sponsored programs for nonindustrial private forest landowners in the Midwest and the second top in the Southeast (Hibbard et al. 2000, Megalos and Cubbage 2000). The primary mechanism to accomplish property tax deduction is preferential assessment with a use value assessment methodology (Anderson 2003). This method uses current use instead of market to assess values of property for tax purpose in order to restore balance between taxable value of rural properties and individual landowners' potential producing income, and to provide tax relief for rural landowners to retain lands in traditional uses.

Table 1. Current use property tax policy in the southern United States

State	Property Tax Programs	Qualifications	Administration	Withdraw penalties
Alabama	Current use value		File application with county tax assessor; application must include soil type	Tax based on fair market value or sale price are due for the three proceeding years
Arkansas	Special timberland tax			
Florida	Agricultural classification	Length of time land has been utilized; Whether lands has been continuous ; Purchase price; size; management practice; is there a lease	Must apply with property appraiser	
Georgia	Conversion use assessment for timberland	Maximum 2000 acres; property must remain devoted o qualifying use; owner must be natural or naturalized citizen; must have certified soil map.	must apply with county assessor; 10 years agreement	
	Conversion use assessment for environmentally sensitive lands	Maximum 2000 acres; owner must be natural or naturalized citizen; types of eligible land.	10 years agreement	
Kentucky	Growing timber is classified as an agricultural use	Parcel must be 1 minimum of 10 acres		
Louisiana	Timberland classification	must be at least 3 acres or produce at least $2000/yr in avg. annual income	must apply with parish assessor; apply every four years	
	Forest protection tax		To aid in fire protection	
Mississippi	Forest land classified as agricultural land use			
North Carolina	Forest land classification	minimum of 20 acres; current owner must own parcel for past 4 years	must file with county assessor	deferred taxes, interest, and penalties
Oklahoma	Managed timberland is assessed at its current value for use			
South Carolina	Agricultural classification	At least 5 acres or land produces $1000 of income in 3 of every 5 years.	must apply with assessor	difference in taxes for previous 5 years
Tennessee	Farm property classification	Greater than 15 acres with quality and quantity to signify a forest; no more than 1500 acres.	to assessor; one time application	Roll back taxes
Texas	Open space land devoted to timber production	devoted to timber production 5 of past 7 years	File application with chief appraiser.	difference in taxes for past 5years at 7% interest
	Restricted use timberland	Parcel must be in aesthetic management zone, critical wildlife habitat zone, or streamside management zone.		
Virginia	Forest use classification	Minimum 20 acres; growing commercial crop or parcel is in a planned timber management program.	must submit application	difference in taxes for pervious 5 years

Source: Hibbard et al. 2001.

Every state in the U.S. South provides some sort of preferential property tax treatments for rural lands. Table 1 presents the current use property tax policy in this region based on special property tax classification or property tax programs. Landowners with eligible lands can enroll the program by signing contracts with the government or county tax assessors with a restriction of minimum or maximum tract size, minimum annual production, and minimum period of continuous forest cover, ownership, and zoning (Hibbard et al. 2001, Polyakov and Zhang 2008). The simplest goals of these property tax programs are to mitigate the higher tax burden of landowners, to compensate them for improving land management and increasing agricultural or wood fiber production, and to provide them more leeway to keep lands in their rural uses.

The overall objectives of this dissertation are to systematically document the determinants of land use and land use transitions and forest type changes in U.S. South, and to predict the effects of the future forest type changes on carbon stocks on forest lands. The main part of this dissertation has three essays.

Essay 1 (Chapter 2) investigates the observed determinants of land use and land use changes in the Southern U.S. for six major land use categories by applying a Random Parameter Logit model using panel data of USDA National Resources Inventory (NRI) sample plots. The model is used not only to fully relax the Independence of Irrelevant Alternatives (IIA) assumption of logit models, but also to capture the temporal correlation between observations of the same sample plot, heterogeneity of marginal utility of economic factors among landowners, and complex substitution patterns between alternative land uses. Results indicate that economic return, population density, and land quality are key factors driving lands from rural use to developed purpose. Economic returns positively affect land use change decisions and land conversions are more likely to happen among the ones with similar land quality.

Essay 2 (Chapter 3) presents an empirical analysis to explore how forest type changes in the U.S. South conditional on changes in land use, timber market, and demographic conditions using USDA Forest Service Forest Inventory and Analysis (FIA) periodic data, and to compare carbon sequestrations potential under forest type projected from the estimation results with a non-transition strategy that eliminates forest type conversion. Results indicate that the trends of increase of planted pine and decrease of natural pine and hardwoods will continue in the coming half century. Planted pine will increase by 58 percent, from 10.2 million hectares to 16.1 million hectares, and natural pine, mixed hardwoods, bottomland hardwoods, and upland hardwoods will decrease by 30 percent, 23 percent, 18 percent and 5 percent respectively. The transition among forest types ends to a 1.23Gg Carbon (C) decrease of carbon stocks on standing forests, and 0.5 Gg C increase of carbon stocks on both forests and forest products in 2047. Considering carbon emission by energy recapture, there will be a 1.30 Gg C decrease of carbon sequestration in total caused by forest type transition.

Essay 3 (Chapter 4) examines how the public policy-current use valuation property tax policy influences land use change decisions in Georgia. North Georgia is taken as an empirical study area to quantify the influence of Current Use Valuation (CUV) property taxes policy on land use change decisions. The simulation results indicate that without this program, there will be an extra 8,000 acres croplands, an extra 10,000 acres pasture lands, and an extra 10,000 acres forests decrease in the North Georgia.

Chapter 5 draws the main conclusions of this dissertation and discusses future works.

Chapter 2. A Random Parameters Logit Study on Land Use and Land Use Transition Patterns in the Southern U.S.

1. Introduction

Land use change has become an inevitable environmental change in the twenty-first century. The trends of decline in rural lands and expansion of urban or developed lands have produced observed negative externalities such as air and water pollution, loss of biodiversity, wildlife habitat fragmentation, and increased flooding. The causes and consequences of changes in land use have been examined by a growing number of economists and environmentalists through using various methods.

As a whole, the 13 Southern states in the U.S. cover roughly 24 percent of the land area of the United States, about 93 percent of which belongs to private landowners (Forest Service 2002, NRI 2007). Land use statistics for four major land use categories in the South from 1945 to 2007 show a decline in cropland and forest, a slight increase in pastureland, and a significant expansion in developed areas (Figure 2.1). From 1982 to 2007, U.S. South has experienced more land use transition than any other U.S. region—cropland acreage dropped by 26.2 percent, from 107 million to 79 million acres, while developed land use increased by 72.0 percent from 25 million to 43 million acres (NRI 2007). The main trends in land use change include land use conversion from forestry and agricultural lands to more intensive uses; transition between marginal agricultural lands and forestry; and transition within agricultural uses under different land quality (Rudel 2001, Wear and Greis 2002, Polyakov and Zhang 2008).

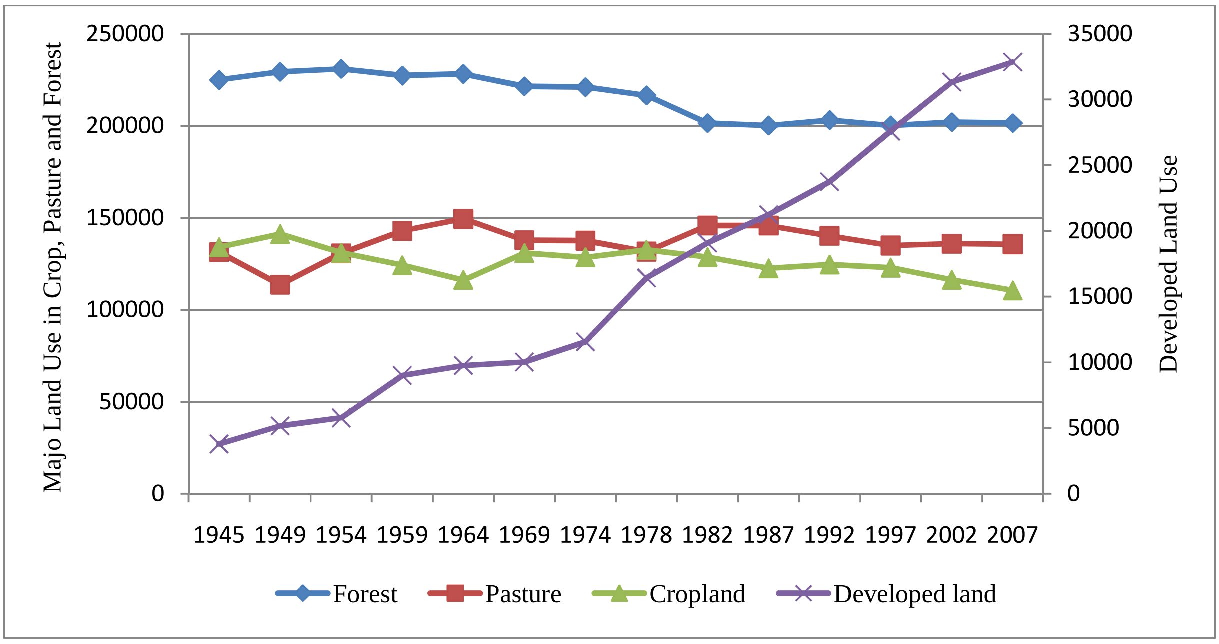

Figure 2. U.S. South major land use changes from 1945 to 2007

Economic growth, urbanization, and decentralization of the population are found to cause the conversion of rural lands to urban uses (Nelson 1990, Plantinga 1996, Nagubadi and Zhang 2005, Polyakov and Zhang 2008), and much of the urbanization occurring in the South is found to be driven by population growth and migration (Snider 2002). The loss of rural lands and negative impacts on environmental change by human disturbance could be more severe in the South in the coming decades due to the rapid population growth. Based on the latest Census Bureau statistics, the South is the fastest growing region in the U.S. in terms of growth rates of population. Among the top 100 fastest growing counties in the country, 64 counties belong to this region (http://www.census.gov/popest/counties/CO-EST2004-09.html).[3] The rapid growth of population calls for more home sites, roads, commercial and industrial lots and other non-rural intensive uses, and thus increases the competition of rural lands, particularly lands in rural-urban interface.

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[3] Among the 64 fasted growth counties, FL, GA, TX, VT, NC, KY, TN, SC account for 15, 12, 11, 9, 5, 3, 3, 2 counties, respectively, and one county each for AL, AK, LA, MS.

The objective of this essay is to explore the major factors contributing to land use and land use conversions regarding economic and population features in the South using the National Resources Inventory (NRI) sample plot land use and land quality data. It differs from previous studies in terms of methodology, data structure, and land use categories. First, it expands the existing studies of the determinants of land use changes in the South by using a more realistic and appropriate discrete choice model—Random Parameters Logit (RPL) model, which could not be applied in earlier studies due to software limitations and computation capability. This model fully relaxes the restriction of independence of irrelevant alternatives (IIA) limitation of discrete choice models, and allows variation among land use alternatives. Second, we fully consider the data structure of NRI and examine the RPL model with plot-level panel data to capture land use transition probabilities, and to capture both time variant and invariant explanations. Third, we decompose regional private lands into more specific categories—crop, pasture, range, forest, lands in CRP, and developed lands—to fully reflect the demands of landowners' multiple choices, and to examine the transition patterns in internal and external agricultural lands simultaneously without separately estimating land use transition probabilities from each initial land use. Some of these aspects are not considered in previous studies. Specifically, Lubowski et al (2002, 2006a) used the national NRI land use data, six land use categories as in this essay, and a nested logit model to partially relax IIA. However, they did not treat data as panel, and the estimated transitions are examined from each land use separately. Polyakov and Zhang (2008) used RPL, panel data, and all initial land uses simultaneously, but with smaller scale and few land uses. To the best of our knowledge, this study is the first one to apply a panel RPL model to examine land use transition driving factors in such a large scale as well as a broad set of categories using the entire NRI land use dataset without random-selected sampling, which could lessen the uncertainty of existed data and provide more precise model estimates and simulation results.

The next section of this chapter reviews the existing literature for land use changes based on data collection and applied discrete choice models. Section 3 introduces the RPL model. Section 4 provides a data description. Section 5 presents results of the RPL model and elasticity analysis. Section 6 provides historical simulations based on the results of RPL model and Section 7 concludes and discusses.

2. Literature Review

Land use and land use change studies in economics can be traced to as early as 1755 (Cantillon 1755), and the classic land use theory developed by David Ricardo and Johann von Thunen is the foundation for most existing land use models. This theory explains land use patterns in terms of the relative rents to the alternative uses, which depends on land quality and distance on a "featureless plain". The models explore the relationship between land-use choices and explicit or proxy measures for land rents, including land quality, location, transportation costs and so on.[4] The analyses reveal significant economic and environmental effects with implications for a wide range of policy issues.

One of the most common data sources for land use and land use change studies in the US is the National Resources Inventory (NRI) land use data. The NRI is a longitudinal panel survey conducted by the Natural Resources Conversion Service (NRCS), which can be used to assess the conditions and trends of the nation's soil, water, and related resources through analyzing national, regional, state, or sub-state sample sites information of land use, land cover, soil characteristics, erosion, and conservation practices on a sample of non-federal lands. It proves to

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[4] More empirical methods discussion can be found from Plantinga and Irwin (2006).

be useful for developing statistical estimates of natural resource conditions, and for conducting geospatial and temporal analyses of these conditions at many geographical levels (NRI 1997).

Recent econometric studies of land use and land use change using NRI data can be classified into two groups. County-level aggregated NRI land characteristics data (Parker and Kramer. 1995, Wu and Segerson 1995, Hardie and Parks 1997, Miller and Plantinga 1999, Maudlin and Plantinga 1999a, Maudlin et al. 1999b, Hardie et al. 2000, Hsieh et al. 2000, Nagubadi and Zhang 2005) and plot-level NRI land characteristics data (Claassen 1993, Schataki 1998, Claassen and Tegene 1999, Lubowski 2002, Lubowski et al. 2003, Lubowski et al. 2006b, Lubowski et al. 2006c, Polyakov and Zhang 2008). The most common aggregate data model is the share model (Plantinga and Irwin 2006). The disadvantage of this model is that the model examines factors affecting levels in shares or net changes rather than transitions among particular uses, thus the model cannot account for heterogeneous features of land parcels within the county or region (Lubowski 2002).[5]

Studies examined direct land use transitions emerged in the early 1990s (e.g. Claassen 1993, Claassen and Tegene 1999, Schatzki 1998). These studies are limited to analyze land use changes with a small number of transitions and in small geographic regions. Recent studies by Lubowski et al. (2003, 2006b) extend them to the whole United States using a full set of non-federal land use categories (crop, pasture, range, forest, lands in Conservation Reserve Programs (CRP), and urban lands), using a nested logit model to capture not only the probability of land use transition from one land use category to another, but also the possibilities of different substitution patterns among land use categories. Lubowski et al. (2003, 2006b) are the first to study national comprehensive land use and land use change using NRI plot-level data.

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[5] With the exception of Plantinga (1996) and Miller and Plantinga (1999), in their works, they use maximum likelihood procedure and maximum entropy procedure, respectively, to model the effect of unobserved parcel-level variation on aggregate land-use decisions (Lubowski 2002).

Additionally, carbon sequestration and other public land use policies can be examined by using plot-level observations (Lubowski et al. 2006c).

Discrete choice models are usually used to directly measure land use transition probabilities based on plot-level observations. Binomial probit models are used for cases with two land use choices (Bockstael 1996, Bockstael and Bell 1997, Kline and Alig 1999, Hite et al. 2001, Irwin and Bockstael 2002), and multinomial and conditional logit models are for cases within more than two choices (Claassen 1993, Landis and Zhang 1998, Munn and Cleaves 1999). To partially or fully relax the logit model assumption of independence of irrelevant alternatives (IIA), Lubowski (2002) and Polyakov and Zhang (2008) respectively used nested logit and mixed logit specifications.

As noted earlier, NRI data is a longitudinal panel dataset. It provides plot-level land use information from 1982 to 1997 at five year intervals. Using the panel structure, some unobserved parcel-specific characteristics can be accounted for using either a fixed or random effects specification. Land parcels with the same value of explanatory variables could have different land use probabilities (Lubowski 2002). Thus, individual behavior over time can be captured instead of average behavior in the population (Hsiao 1999). Fixed effects models have been proposed (Chamberlain 1980, 1985), but they are incapable of explaining individual characteristics that do not vary over time, such that the relationship between land use choices and time invariant features cannot be captured even when individual attributes among observations exist. For example, two parcels with the same land quality may experience different transition patterns within the same period, due to the differences in spatial attributes that have not been accounted for in the model. Holding land quality constant ignores some of these differences and will lead to misleading estimates of transition probability (Lubowski 2002). Under this condition, the random effects model is the most advantageous model, because it allows parameters to vary randomly across individual observations. However, random effects versions of logit models were previously considered infeasible due to computational intractability (Greene 2001). A new module in Limdep econometric software provides random parameter versions of logit model, with application to panel data (Greene 2002). To our knowledge, Polyakov and Zhang (2008) is the only known recent study that uses the panel structure of the NRI plot-level data to explore factors influencing land use and land use transitions. In their work, they explore a random parameter logit (RPL) model using the NRI plot-level panel data to examine how property tax policy affects land use changes between agricultural, forestry, lands in CRP, and developed uses in Louisiana. The RPL model takes the temporal correlation between observation of the same sample plot in the panel data into consideration, and accounts for heterogeneity of the marginal utility of property tax among landowners, as well as complex substitution patterns between land use alternatives (Polyakov and Zhang 2008).

3. Random Parameters Logit (RPL) Model

The Random Parameters Logit (PRL) model (also called Mixed Logit, Kernel Logit or Mixed Multinomial Logit model) is the most general model form in the multinomial logit toolkit for discrete choices studies in terms of the flexibility of model specifications and the range of behavior that it can model (Greene 2007). It can approximate any random utility model (McFadden and Train 2000), and allow the parameters to vary randomly over individual observations, and thus fully releases the well-known limitation of logit models-independence of irrelevant alternatives (IIA) assumption.

The RPL model has been known for many years, while its full implementation can only be traced to the advent of simulation. Now, studies using an RPL model include alternativefueled vehicle choice (Brownstone et al. 2000, McFadden and Train 2000), residential customers' choice of energy supplier (Train 1999), and multiparty elections (Glasgow 2001). Its capability to accommodate many sources of individual variability, like random heterogeneity around the mean, different forms of correlation among alternatives (Akiva et al. 2001, Gopinath et al. 2005), correlation among different parameters in the same alternative and choice situation and auto-correlation of the same parameter over choice situations (Gopinath et al. 2005), and observed heterogeneity around the standard deviation of random parameters and error components (Greene and Hensher 2006), have made this model theoretically and empirically appealing.

Following Greene (2007), the RPL model can be derived from the basic form of the multinomial logit model,[6]

$$prob(y_i = j) = \frac{\exp\,(\alpha_{ji}+\boldsymbol{\beta}_i'\boldsymbol{X}_{ji})}{\sum_{q=1}^{J}\exp\,(\alpha_{qi}+\boldsymbol{\beta}_i'\boldsymbol{X}_{qi})} \tag{1}$$

Where "j" indexes the choice, y_i is the index of the choice made for individual i , α_{ji} is the alternative specific constant term for individual *i*, and $\boldsymbol{\beta}_i$ is a vector of individual-specific parameters. The most familiar, simplest version of the model is specified as

$$\beta_{ki} = \beta_k + \sigma_k v_{ki} \tag{2}$$

and

$$\alpha_{ji} = \alpha_j + \sigma_j v_{ji} \tag{3}$$

where β_k is the population mean for attribute k , v_{ki} is the individual specific heterogeneity of individual *i* under attribute *k*, with mean zero and standard deviation one, and σ_k is the standard deviation of the distribution of β_{ki}s around β_k. The choice specific constants α_{ji} and the elements of β_i are distributed randomly across individuals with fixed means. To allow the means of the parameter distribution to be heterogeneous with observed data $\boldsymbol{z}_i$ (which does not include

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[6] For detailed explanation of model derivation, see Greene 2007, Nlogit Version 4.0 Reference Guide.

one), the specification of β_k can be redefined with a set of choice invariant characteristics δ_k' to produce individual heterogeneity in the means of the randomly distributed coefficients so that

$$\beta_{ki} = \beta_k + \delta_k' \boldsymbol{z}_i + \sigma_k v_{ki} \tag{4}$$

Distribution of the model is not limited to be normal. Lognormal distribution is appealing particularly when the dependent variable of interest is in the non-negative domain. The triangular distribution is widely specified in “willingness to pay” studies to make sure that the empirical amount of money you have to pay related to a policy or a situation change is positive, and without a very long right-hand tail (Hensher et al. 2005). When the distribution is specified as log-normal,

$$\beta_{ki} = \exp(\rho_k + \delta_k' \boldsymbol{z}_i + \sigma_k v_{ki}) \tag{5}$$

and $$\alpha_{ji} \text{ or } \beta_{ki} \sim \text{Lognormal}\left[\rho_{j\ or\ k} + \delta_{j\ or\ k}' \boldsymbol{z}_i, \sigma_{j\ or\ k}^2\right]$$

For the full vector of K random coefficients in the model, the set of random parameters are written as

$$\boldsymbol{\rho}_i = \boldsymbol{\rho} + \Delta \boldsymbol{z}_i + \Gamma \boldsymbol{v}_i \tag{6}$$

where Γ is a diagonal matrix which contains σ_k on its diagonal. The treatment for panel data can be specified as an extension of Equation (5) with subscript “t” to index observations over time for each individual,

$$\boldsymbol{\rho}_i = \boldsymbol{\rho} + \Delta \boldsymbol{z}_{it} + \Gamma \boldsymbol{v}_i \tag{7}$$

To apply the RPL model to a land use and land use transition study, we assume that a risk neutral landowner chooses to allocate a parcel of land with homogenous quality to a specific land use from a set of potential uses by seeking the maximization of net present value of future returns from different potential land uses (Polyakov and Zhang 2008). We examine observed characteristics such as land quality, land location and economic conditions related to land net returns and conversion costs to capture their relationship to land use decisions. To explain a landowner's behavior, let $U_{ntj|i}$ represent the utility of converting a parcel n to a new land use j conditional on current land use i at time t. The utility in terms of net returns and conversion costs can be specified as

$$U_{nt+1j|i} = f(R_{ntj}, R_{nti}, C_{ntj|i}) = R_{ntj} - R_{nti} - C_{ntj|i} \tag{8}$$

where R_{nti} is the net returns for parcel n in land use i at time t, and $C_{ntj|i}$ is a one-time cost to convert land use from i to j. Land use transition happens when $U_{nt+1j|i}$ is positive, and the best choice j will be chosen when

$$U_{nt+1j|i} > U_{nt+1k|i}, \forall\, k \neq j \tag{9}$$

The utility function, $U_{nt+1j|i}$ is divided into $V_{nt+1j|\,i}$, the observable characteristics of land such as quality and rents, and ε_{nti}, a non-observable random part that represents factors influencing the utility function, but cannot be quantitatively collected from the real world. The utility function can then be written as

$$U_{it+1j|i} = V_{nt+1j|\,i} + \varepsilon_{ntj} \tag{10}$$

The probability of converting parcel n from land use i to land use j from potential land use alternatives is

$$\begin{aligned} P_{nt+1j|i} &= prob\left(U_{nt+1j|\,i} > U_{nt+1k|\,i}\right) \\ &= prob\left(V_{nt+1j|\,i} + \varepsilon_{ntj} > V_{nt+1k|\,i} + \varepsilon_{ntk}\ (\forall\ k \neq j)\right) \end{aligned} \tag{11}$$

Assuming the random unobservable components ε_{nti} are independently and identically distributed with a type I extreme value distribution, and following McFadden's (1973) conditional logit model, we specify the empirical model as

$$P_{nt+1j|i} = \frac{\exp\left(V_{nt+1j|\,i}\right)}{\sum_{k=1}^{J} \exp\left(V_{nt+1k|\,i}\right)}$$

$$= \frac{\exp(\alpha_{ij}+\boldsymbol{\beta}'\boldsymbol{X}_{ntj}-\boldsymbol{\beta}'\boldsymbol{X}_{nti}+\boldsymbol{\gamma}_j'\boldsymbol{S}_{nt}-\boldsymbol{\gamma}_i'\boldsymbol{S}_{nt})}{\sum_{k=1}^{J}\exp(\alpha_{ik}+\boldsymbol{\beta}'\boldsymbol{X}_{ntk}-\boldsymbol{\beta}'\boldsymbol{X}_{nti}+\boldsymbol{\gamma}_k'\boldsymbol{S}_{nt}-\boldsymbol{\gamma}_i'\boldsymbol{S}_{nt})} \tag{12}$$

where α_{ij} is the conversion-specific constant ($\alpha_{ij} = 0\ \forall i = j$), $\boldsymbol{\beta}$ is a vector of coefficients of the attributes characterizing alternative land uses, and γ_j is a vector of coefficients of the plot-specific attributes for land use j ($\gamma_J = 0$ to prevent an indeterminacy in the model, where J represents developed use). Components of representative utility specific to initial land use ($\boldsymbol{\beta}'\boldsymbol{X}_{nti}$ and $\boldsymbol{\gamma}_i'\boldsymbol{S}_{nt}$) cancel out due to appearance in both numerator and denominator. So the final form of the empirical model is

$$P_{nt+1j|i} = \frac{\exp(\alpha_{ij}+\boldsymbol{\beta}'\boldsymbol{X}_{ntj}+\boldsymbol{\gamma}_j'\boldsymbol{S}_{nt})}{\sum_{k=1}^{J}\exp(\alpha_{ik}+\boldsymbol{\beta}'\boldsymbol{X}_{ntk}+\boldsymbol{\gamma}_k'\boldsymbol{S}_{nt})} \tag{13}$$

When the $\boldsymbol{\beta}$ parameters of attributes of alternative land uses are assumed to randomly vary among sample points, and there is no observed personal specific characteristics $\boldsymbol{z}_i$, combining Equation 6 with Equation 12, the panel form of RPL model is specified as

$$P_{nt+1j|i}(\boldsymbol{\beta}_n) = \frac{\exp\left(\alpha_{ij}+\boldsymbol{\beta}_n'\boldsymbol{X}_{ntj}+\boldsymbol{\gamma}_j'\boldsymbol{S}_{nt}\right)}{\sum_{k=1}^{J}\exp\left(\alpha_{ik}+\boldsymbol{\beta}_n'\boldsymbol{X}_{ntk}+\boldsymbol{\gamma}_k'\boldsymbol{S}_{nt}\right)} \tag{14}$$

where

$$\boldsymbol{\beta}_n = \boldsymbol{\beta} + \Gamma\boldsymbol{v}_n \tag{15}$$

4. Data

The NRI dataset for the southern US includes 436,324 points, covering 526.91 million acres surface area. Plots used in this study are selected from privately owned properties, belonging to any of the six land use categories: croplands, pasture, range lands, forests, lands in CRP and developed lands. Lands in CRP are classified into an independent type in NRI. Since the program is established, there are relatively higher percentages of land use transition from other major land use compared to changes in other land-use categories. Land use transition data

Table 2. Changes in major non-federal land uses between 1982 and 1997 in the southern U.S. from National Resources Inventory (NRI) (in thousands of acres)

		Final Land Use						
Initial Land Use	Period	Crop	Pasture	Range	CRP	Forest	Developed	Total
Crop	1982-87	95,755	4,551	456	3,353	1,412	679	106,207
	1987-92	88,076	4,103	363	4,856	983	742	99,123
	1992-97	82,517	4,127	794	476	1,369	973	90,255
Pasture	1982-87	2,418	57,882	659	218	2,794	580	64,551
	1987-92	1,910	59,443	255	230	1,711	798	64,347
	1992-97	2,595	56,279	1,091	27	3,344	1,185	64,520
Range	1982-87	778	925	113,511	115	305	408	116,043
	1987-92	478	504	112,584	44	298	441	114,348
	1992-97	598	446	111,061	14	228	527	112,873
CRP	1982-87	0	0	0	0	0	0	0
	1987-92	13	0	0	3,720	0	0	3,733
	1992-97	294	240	102	8,074	170	4	8,884
Forest	1982-87	650	1,146	53	39	175,766	1,420	179,074
	1987-92	289	696	30	34	177,325	1,689	180,063
	1992-97	478	1,359	141	16	175,528	2,629	180,151
Developed	1982-87	18	10	4	0	28	26,829	26,889
	1987-92	13	14	4	0	39	29,904	29,974
	1992-97	10	10	24	0	35	33,581	33,660
Total	1982-87	99,619	64,514	114,684	3,725	180,306	29,917	492,764
	1987-92	90,779	64,760	113,237	8,883	180,355	33,573	491,587
	1992-97	86,492	62,461	113,213	8,607	180,673	38,899	490,344

Note:

1. Lands transited to uses other than the six categories are excluded from the table.
2. Read the table horizontally to see how land that was under a particular land use at the beginning of cited period was subsequently allocated in terms of land use at the end of the cited period. Read the table vertically to see how land that was under a particular land use at a cited period was subsequently allocated in terms of land use at the previous five years.

were structured into initial and final land use types respectively according to land information at the beginning and the end of each five-year period from 1982 to 1997, covering 259,681 points, representing 456.43 million acres, approximately 86.62 percent of the total land area, and 94.10 percent of non-federal lands in the South.

Table 2 shows the flow of land among major land-use categories considered in this study at five year increments from 1982 to 1997. “Total” in the last column represents the area of land that is under a particular use at the beginning of a cited period, and “Total” in the last three rows shows the area of land in a particular use at the end of the cited period. For example, total cropland was 106,207 thousand acres in 1982 and 99,619 thousand acres in 1987. Lands in CRP did not exist during 1982 to 1987, because CRP programs were first established and contracts were signed by landowners in the southern U.S. in 1986, and no land is in CRP at the beginning of this period.

Two factors, prime farmland (prime) and Land Capability Class (LCC) are included in NRI to show land quality of an observable plot. These factors have a major influence on use of lands for agricultural purposes and forests (Hardie and Parks 1997, Ahn et al. 2000, Ahn et al. 2002), and are used to control for land heterogeneity. Prime farmland is a binary variable. Land classified as a prime farmland indicates that crops can be produced on the plot for the least cost and with the least damage to the resource base. LCC is a categorical variable classified by the U.S. Department of Agriculture (USDA) to summarily measure the suitability of land for crop production, and to demonstrate the erosion, conservation practices, and cultivation conditions of a plot by taking values from I to VIII. It is limited only to crop, pasture, range, forests, or wildlife food and cover (NRI 2003). The number represents the limitation of lands that restrict their uses, where I is the most productive and VIII is the least productive land. Lands in LCC V or greater are marginal for agricultural crops or have severe limitations that restrict choice of crops to be grown. In this study, we create a dummy variable of LCC to measure land quality. LCC dummy=0 for LCC I to IV, 1 otherwise.

Spatial information on NRI sample sites is confidential, and it is impossible to obtain economic information for every plot, county-level net returns are used as proxies for plot attribute measurements. Data are taken from Lubowski (2002) and discussed in great details in Lubowski (2006). Crop net returns are annual county-level weighted average of the gross returns per acre from different varieties of crops from 1982 to 1997 plus the value of direct government payments per acre (excluding payments to the CRP) less seed, fertilizer, and petroleum products costs, farm labor expenses, and other related costs. Annual net returns to land under pasture are calculated based on the county-level average of pasture yields for different soil types, weighted by soil type acreage less pasture management costs in each county. Forestry returns are weighted county-level net present value of sawtimber revenue from different forest types. Net returns to developed use are proxy for county-level annual measure of developed lot prices, back calculated from county-level data on single-family home price, which includes the values of both the house and of the land. [7]

Population expansion usually precipitates land use transition. It increases developed land use in order to provide public facilities or non-private services. Population density, the ratio of population to total land area, determines the share of land devoted to urban use and explains population effects on land use change decisions. Total population for each county is obtained

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[7] We would like to thank Ruben N. Lubowski for providing county-level net return data. More details of return data collection can be found in Lubowski (2002).

Table 3. Descriptive statistics of the variables

plot_Level Variable	Number of Plots	Mean	Median	Std. Dev.	Minimum	Maximum
Plot in Land Capability Class 1-4	744470	0.36	0.00	0.48	0.00	1.00
NRI Sampling Weight (acres/plot)	744470	1000.00	889.81	747.15	55.61	30587.27

County level Variables (in US$ 1990)	Number of Counties	Mean	Median	Std. Dev.	Minimum	Maximum
Annual crop profit/acre (1978-1982)	1212	44.32	31.53	55.62	-141.52	926.23
Annual crop profit/acre (1983-1987)	1209	13.83	12.51	46.97	-547.36	476.54
Annual crop profit/acre (1987-1992)	1176	17.30	21.76	75.74	-811.88	329.07
Annual pasture profit/acre (1978-1982)	1208	25.43	29.31	39.30	-88.17	133.31
Annual pasture profit/acre (1983-1987)	1204	-44.36	-32.21	65.07	-206.97	159.61
Annual pasture profit/acre (1988-1992)	1209	9.04	-6.04	52.39	-111.13	200.33
Annual range profit/acre (1978-1982)	351	14.45	13.72	6.85	0.00	52.98
Annual range profit/acre (1983-1987)	348	17.18	14.82	8.88	0.00	64.17
Annual range profit/acre (1988-1992)	346	18.23	17.39	8.73	0.00	51.84
Annual forest profit/acre (1978-1982)	1093	6.29	4.44	4.54	0.19	23.57
Annual forest profit/acre (1982-1987)	1094	6.33	4.42	4.34	0.39	23.79
Annual forest profit/acre (1987-1992)	1092	9.18	8.53	3.93	2.48	26.04
Annual CRP profit/acre (1978-1982)	1306	0.00	0.00	0.00	0.00	0.00
Annual CRP profit/acre (1982-1987)	1307	34.59	28.67	13.53	20.21	65.46
Annual CRP profit/acre (1987-1992)	1306	45.18	43.43	5.52	39.38	57.43
Annual developed profit/acre (1978-1982)	1306	875.27	572.02	722.17	168.88	4633.83
Annual developed profit/acre (1982-1987)	1307	1176.73	777.95	986.62	217.74	6316.35
Annual developed profit/acre (1987-1992)	1306	1280.76	787.97	1123.08	266.02	7895.67
Annual Government Payment/acre (1978-1982)	1212	19.59	16.90	12.57	0.98	137.59
Annual Government Payment/acre (1982-1987)	1209	10.64	9.19	7.16	1.25	58.48
Annual Government Payment/acre (1988-1992)	1176	9.58	7.75	7.12	0.12	49.58

from the Regional Economic Information System (REIS) of the Bureau of Economic Analysis (BEA).

Table 3 presents summary statistics of explanatory variables. NRI land use data from 1982 to 1997 are pooled together. Missing values for each variable are replaced by county-average data. Merging county-level data with NRI plot-level data yields 744,470 points that are used in this study.

5. Estimation Results and Additional Empirical Analysis

5.1. Parameter Estimates

The study area is separated into two subregions based on the presence or absence of range lands. The subregion with rangelands includes Alabama, Arkansas, Florida, Louisiana, Oklahoma, and Texas. The subregion without rangelands includes Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. Parameters are estimated using both conditional logit (CL) and RPL panel models. The dependent variable in each subregion is the land use type in year t at each NRI plot. Explanatory variables are lagged one period and take the values of the previous five-year average. We use the first-order Markov transition matrix to simultaneously model land use transition probabilities among five major land use categories (crop, pasture, forestry, CRP and developed) for states without rangelands. The transition terms α_{ij} are for three initial land uses i (crop, pasture, and forestry) and five final uses j. For the subregion with rangelands, range land is added as an initial and a final choice, such that α_{ij} terms are for four initial and six final uses. CRP lands are excluded from initial land use, because the number of parcels converted from CRP to other land use types is relatively small. Land transition from CRP occurred only in the 1992-1997 period, when the first signups began to expire. Conversion to developed use is considered irreversible,[8] and lands in urban use remained in that status during the study period. We use Nlogit 4.0 to estimate both the CL and RPL model. Scaled NRI expansion factors whose sum equals to the total number of actual observations used in the model are created as weights to obtain correct values of standard errors (Greene 2002).

Tables 4 and 5 report the estimation results for CL and RPL models for subregions with and without rangelands, respectively. The CL model is estimated using maximum likelihood method while the RPL model is estimated using maximum simulated log-likelihood with 1000 Halton draws.[9] The coefficient of county-level net return in RPL model is treated as a random parameter to account for plot-level variation, and is specified as a log-normal distribution. For both subregions, the estimation results from CL and RPL indicate good model fits as indicated high Mcfadden R^2 values. The estimated coefficients are generally highly significant with intuitive interpretations. Likelihood ratio tests reject the hypothesis that all of the coefficients are simultaneously equal to zero at the 0.01 level. And likelihood ratio tests for model preference indicate that RPL models are preferred in both subregions at the 0.01 level.[10] All McFadden's likelihood ratio indices (Pseudo R^2) are around 0.85, indicating that the explanatory variables are good predictors of the transition probabilities p_{jk}. Comparison of CL model and RPL models in each subregion shows that, except for return, the coefficients do not differ significantly, hence the explanation for RPL model should also hold for the CL model.

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[8] Small figures in Table 2 shows land use transition from developed to other types are considered as marginal errors when collecting land use data in NRI.

[9] Halton draws are contained in the unit interval, and well spaced in the interval. A small number of Halton draws is as effective as or more effective than a large number of Pseudo random draws (Hensher et al. 2005)

[10] The value of the likelihood ratio statistic is 8.15 and 26.52 for the subregion with and without rangelands respectively, with 99% critical value of $\chi_1^2 = 6.635$.

Table 4. CL and RPL model estimation results for subregion with rangelands

		Conditional Logit	Random Parameter Logit
Transition Specific Constants (α_{ij})			
Crop→ Pasture		-3.4027***(0.0212)	-3.4065***(0.0211)
Crop→ Range		-4.8197***(0.0396)	-4.8272***(0.0399)
Crop→ Forest		-5.3208***(0.0496)	-3.6056***(0.0257)
Crop→ CRP		-3.1007***(0.0255)	-3.1013***(0.0214)
Crop→ Developed		-6.7320***(0.0637)	-6.6911***(0.0684)
Pasture→ Crop		-3.5179***(0.0293)	-3.5147***(0.0296)
Pasture→ Range		-4.2231***(0.0369)	-4.2276***(0.0357)
Pasture→ Forest		-3.4771***(0.0266)	-3.4773***(0.0273)
Pasture→CRP		-5.9226***(0.1026)	-5.9185 ***(0.1010)
Pasture→ Developed		-5.9354***(0.0573)	-5.8067***(0.0994)
Range→ Crop		-4.5554***(0.0368)	-4.5485***(0.0363)
Range→ Pasture		-4.7746***(0.0378)	-4.7690***(0.0365)
Range→ Forest		-5.9112***(0.0574)	-5.9046***(0.0570)
Range→ CRP		-6.9453***(0.1173)	-6.9369***(0.1147)
Range→ Developed		-6.4230***(0.0568)	-6.4110***(0.0682)
Forest→ Crop		-6.0042***(0.0814)	-6.0004***(0.0814)
Forest→ Pasture		-4.6971***(0.0396)	-4.6942***(0.0401)
Forest→ Range		-7.0115***(0.1025)	-7.0177***(0.1012)
Forest→ CRP		-8.7651***(0.3357)	-8.7592***(0.3348)
Forest→ Developed		-5.9546***(0.0525)	-5.8854***(0.0568)
Attributes of Land Uses (β)			
Return	Mean of Coefficient	0.0008***(0.0002)	0.0006
	Mean of ln(coefficient)		-7.5164***(0.0504)
	Std.Dev. of ln(coefficient)		0.5345*** (0.0355)
Attributes of Plots (γ_j)			
Crop	Population density	-0.0013*** (0.0001)	-0.0012***(0.0001)
	Land quality	-0.7868***(0.0623)	-0.7691***(0.0735)
Pasture	Population density	-0.0005*** (0.0001)	-0.0004***(0.0001)
	Land quality	-0.1397***(0.0541)	-0.1147**(0.0632)
Range	Population density	-0.0010*** (0.0001)	-0.0009***(0.0001)
	Land quality	0.8159*** (0.0553)	0.8513***(0.0650)
Forest	Population density	-0.0001***(0.0000)	-0.0001***(0.0000)
	Land quality	0.5302***(0.0532)	0.5604***(0.0614)
CRP	Population density	-0.0061*** (0.0004)	-0.0061***(0.0002)
	Land quality	-0.0721 (0.0883)	-0.0521 (0.0973)
Number of Observations		397,491	397,491
McFadden R^2		0.85	0.89
Log Likelihood		-81700.26	-81703.11

** * significant at the 1% level, ** significant at the 5% level

Table 5. CL and RPL model estimation results for subregion without rangelands

		Conditional Logit	Random Parameter Logit
Transition Specific Constants (α_{ij})			
Crop→ Pasture		-2.8256*** (0.0516)	-2.8287***(0.0186)
Crop→ Forest		-3.6067***(0.0880)	-3.6056***(0.0257)
Crop→ CRP		-3.3942***(0.0568)	-3.3942***(0.0279)
Crop→ Developed		-5.2570***(0.0965)	-5.2650***(0.0439)
Pasture→ Crop		-2.6220***(0.0559)	-2.6191***(0.0209)
Pasture→ Forest		-2.9214***(0.0668)	-2.9187***(0.0234)
Pasture→CRP		-5.3670***(0.1220)	-5.3640***(0.0750)
Pasture→ Developed		-4.9686***(0.0888)	-4.9708***(0.0454)
Forest→ Crop		-5.2720***(0.1085)	-5.2730***(0.0376)
Forest→ Pasture		-5.0641***(0.0743)	-5.0685***(0.0326)
Forest→ CRP		-8.0385***(0.3072)	-8.0379***(0.1451)
Forest→ Developed		-5.1428***(0.0975)	-5.1550***(0.0344)
Attributes of Land Uses (β)			
Return	Mean of Coefficient	0.0006***(0.0001)	0.00056
	Mean of ln(coefficient)		-7.5923***(0.0518)
	Std.Dev. of ln(coefficient)		0.4394*** (0.0489)
Attributes of Plots (γ_j)			
Crop	Population density	-0.0005*** (0.0001)	-0.0006***(0.0001)
	Land quality	-0.6099***(0.0476)	-0.5945***(0.5012)
Pasture	Population density	-0.0005*** (0.0001)	-0.0006***(0.0001)
	Land quality	-0.1070**(0.0426)	0.1244***(0.0452)
Forest	Population density	-0.0006***(0.0001)	-0.0008***(0.0001)
	Land quality	0.4460***(0.0365)	0.4661***(0.0389)
CRP	Population density	-0.0019*** (0.0002)	-0.0020***(0.0002)
	Land quality	-0.0499 (0.0838)	-0.0342 (0.0857)
Number of Observations		346,979	346,979
McFadden R^2		0.87	0.842
Log Likelihood		-88512.66	-88486.14

** * significant at the 1% level, ** significant at the 5% level

5.1.1. Transition Specific Constants (α_{ij})

As defined in the model, the main explanatory variables include three components. Conversion specific constants of α_{ij}, which determine land use transition probabilities in the first-order Markov transition matrix, can be used to compare the transition priority of lands horizontally (transition probabilities from an initial land use) and vertically (transition probabilities to a specific land use). Since lands that are initially in rural use have a high probability of remaining in this use, i.e., α_{ij} is smaller than α_{ii}, restricting α_{ii} to zeros will lead to negative estimates of land use transition terms. The interpretation of the value of α_{ij} is self explanatory—the greater the value, the higher transition probability of that land use conversion.

Comparing all 20 of the transition terms α_{ij} in the RPL model in Table 4 for the region with rangelands, the lowest α_{ij} from forest to CRP (-8.7651) and the highest α_{ij} from crop to CRP (-3.1007) indicate that forests have the lowest, and croplands have the highest probabilities to convert to CRP. For lands enrolled into CRP program, the transition probabilities for the four initial rural lands, in descending order, are cropland, pasture, rangeland and forest, consistent with CRP policy that croplands are the first to qualify for enrollment into CRP. Besides, the weighted values of LCC for the four initial land uses show the same descending order of transition patterns to the CRP program. The value of weighted LCC for CRP lands is between cropland and pasture, which indicates that correct land use transition patterns are obtained from using RPL model. Lands initially under crop, pasture or range use are likely to remain in their initial use or convert to another agricultural use, rather than to a non-agricultural use. Transitions from agriculture to forests and vice versa happen at the same time, while transitions within pasture and forests have higher probabilities compared to transitions among other land use categories within forests. Urbanization is the primary reason for loss of rural lands. Higher transition coefficients of pasture and forests to developed use indicate that pasture and forest lands are usually developed for urban expansion.

The α_{ij}s in Table 5 for the subregion without rangelands do not vary much across the different transition patterns. Lands in CRP are mainly derived from croplands. Conversions within pasture and forests have higher probabilities than within croplands and forests. Developed lands are more likely to be converted from pastures. Among the three initial rural land use types, pasture lands have the highest probability of being converted to other uses, except to CRP.

5.1.2. Attributes of Land Uses (β)

Economic forces drive landowner's decisions and management strategies. The coefficient of return is the mean of coefficient for the CL model, while the mean and standard deviation of log-coefficient are both shown for the RPL model. A significant standard deviation of the log-coefficient would indicate high variation among observations. The coefficient mean of return in the RPL model is calculated from the estimated means and standard errors of log-normal distributed returns using the formula $\beta_i = exp(b_i + \frac{s_i^2}{2})$. In Table 4 and 5, the coefficient of return in CL model is positive and significant at the 0.01 level, and the calculated coefficient of return from the mean and standard deviation of log-coefficients in the RPL models are positive as well. This demonstrates the classic land use theory that the higher the economic return obtained from a land use choice, the higher the probability a private landowner will choose that use.

To further investigate if the RPL model can be replaced by the CL model, we use a likelihood ratio test to determine which model is more appropriate. The likelihood ratio statistic at the 99% critical value with $\chi_1^2 = 6.635$ is 8.15 (26.52) for subregion with (without) rangelands, which implies that RPL model is the preferred model. For each subregion, the mean of coefficient of return in RPL models is slightly less than that in CL model.

5.1.3. Attributes of Plots (γ_j)

Attributes of plots refer to land quality and population density. They vary among plots, not among land use alternatives. The former reflects the suitability of lands for crop production, and the latter reflects land use pressures due to human disturbances.

To examine how land quality influences landowner's final land use decision, we create a series of dummy variables by interacting land quality dummy and land use alternatives. The signs of the coefficients indicate the effects of land quality on the probability of choosing a certain type of land use from any other potential land use alternatives, and the magnitude of the coefficient can be used to compare the propensity of land use transitions to that type use. By choosing developed lands as the reference land use, the coefficients of interactions of land quality dummy and land use alternatives in the subregion with rangelands can be ranked as crop—pasture—CRP—developed—forest—range, which means that high quality land is most likely to be converted to croplands, a little bit less likely to pasture, a little bit less likely to CRP, a little bit less likely to developed use, little bit less likely to forests, and least likely to be converted to rangelands from any initial use and vice verse. The subregion without rangelands presents the same land use transition propensity. In the absence of rangeland as a choice, low quality lands are more likely to convert to forests, and least likely to convert to croplands.

The relationship between population growth and land use change has been well documented in the literature (Plantinga 1996, Nagubadi and Zhang 2005, Polyakov and Zhang 2008). Population growth puts tremendous pressures on lands and promotes rapid development forcing lands converted to non-rural uses. Interaction between population density and land use alternatives is expected to have negative effects on land transition probabilities for rural use. Interactions of population density with rural land use for both subregions is negative and significant at the 0.01 level in the RPL model, which confirms the role of population growth in speeding up land conversing to more intensive uses.

5.2. Further Empirical Analysis

Though the parameter estimates provide an intuitive interpretation of the effects of each explanatory variable on land use transitions, the relative and absolute impacts of each independent variable and the predicted power of the different sets of estimates are hard to tell. It is even harder to evaluate the magnitudes of the estimated transition effects because a change of economic return in a particular land choice could affect 25 (5×5 for subregion without rangelands) or 36 (6×6 for subregion with rangelands) conversion specific constant terms. To understand the estimated importance of each explanatory variable in driving land use conversions, we have conducted further empirical analysis to explore the estimated effects of them on the estimated probabilities with the parameters from the RPL model at the means of the explanatory variables.

5.2.1 Probabilities and Effects with Respect to Land Quality

Table 6 and Table 7 show the estimated probabilities of land use transitions at the means of explanatory variables by land quality dummy with the parameters from RPL models for the two subregions, respectively. Standard errors are computed using the Delta Method. From Table 6, the probabilities of lands remaining their initial uses in crop, pasture and forests reveal higher probabilities when lands are in higher quality. For example, the probability of remaining lands in crops was about 91.15% in LCC 1 from 4, but was only 77.47% in LCC from 5 to 8. It could be explained that transition probabilities from cropland to pasture, forest or other potential use increase as land quality declines.

Table 6. Land use transition probabilities at the means of explanatory variables by different land quality for subregion with rangelands

Transition Terms	**Probability for All LCC**	**Probability for Lqua=0 (LCC=1 to 4)**	**Probability for Lqua=1 (LCC=5 to 8)**
Crop → Crop	0.9054**(0.0919)	0.9115**(0.0926)	0.7747**(0.0775)
Crop → Pasture	0.0326**(0.0028)	0.0315**(0.0027)	0.0500**(0.0044)
Crop → Range	0.0082**(0.0011)	0.0074**(0.0011)	0.0321**(0.0034)
Crop → CRP	0.0479**(0.0043)	0.0441**(0.0040)	0.1338**(0.0124)
Crop → Forest	0.0033**(0.0012)	0.0031**(0.0011)	0.0067* (0.0031)
Crop → Develop	0.0026**(0.0012)	0.0025**(0.0011)	0.0035 (0.0033)
Pasture → Crop	0.0227**(0.0023)	0.0260**(0.0028)	0.0138**(0.0013)
Pasture → Pasture	0.9340**(0.1237)	0.9357**(0.1240)	0.9165**(0.1210)
Pasture → Range	0.0161**(0.0015)	0.0130**(0.0013)	0.0346**(0.0037)
Pasture → CRP	0.0030**(0.0010)	0.0026**(0.0011)	0.0050**(0.0014)
Pasture → Forest	0.0175**(0.0017)	0.0163**(0.0016)	0.0225**(0.0021)
Pasture → Develop	0.0067**(0.0009)	0.0064**(0.0009)	0.0076**(0.0012)
Range → Crop	0.0047**(0.0005)	0.0101**(0.0013)	0.0021**(0.0002)
Range → Pasture	0.0054**(0.0006)	0.0086**(0.0011)	0.0033**(0.0004)
Range → Range	0.9855**(0.1603)	0.9750**(0.1584)	0.9916**(0.1614)
Range → CRP	0.0009**(0.0003)	0.0010*(0.0005)	0.0008**(0.0002)
Range → Forest	0.0012**(0.0002)	0.0017**(0.0005)	0.0008**(0.0001)
Range → Develop	0.0024**(0.0003)	0.0036**(0.0005)	0.0015**(0.0002)
Forest → Crop	0.0036**(0.0014)	0.0048**(0.0017)	0.0026*(0.0012)
Forest → Pasture	0.0203**(0.0070)	0.0196**(0.0069)	0.0208**(0.0071)
Forest → Range	0.0029**(0.0013)	0.0018 (0.0011)	0.0049**(0.0017)
Forest → CRP	0.0005 (0.0012)	0.0004 (0.0011)	0.0007 (0.0013)
Forest → Forest	0.9595**(0.3537)	0.9613**(0.3544)	0.9565**(0.3524)
Forest → Develop	0.0133**(0.0045)	0.0122**(0.0042)	0.0145**(0.0049)

** significant at 1% level, * significant at 5% level

Opposite patterns can be observed in rangelands. Lands remaining in their initial range use have relatively high probabilities as land quality declines. Probabilities of transition terms among land use alternatives indicates that land use transitions are more likely to happen among land use alternatives in closer quality to the extensive margin. For example, for lands converting from crop to range, the change will occur to low land quality plots with a high probability, while for lands initially in forests, high probabilities of conversion to agricultural uses are more likely to happen when land qualities are high.

The standard errors in parentheses provide intuition for identifying when estimated probabilities are statistically different from zero at a certain level. For the 24 examined land use transition types in Table 6, only 1 out of 24 in all LCC, and 2 out of 24 in LCC from 5 to 8, and 2 out of 24 in LCC from 1 to 4 are statistically insignificant at the 5% level. With implications of statistically significant level of each transition probability, CRP lands can't be transited from lands initial in forests no matter how rich the land is. This is consistent with the requirements of CRP program. Lands initial in forests under low quality are more likely to convert to range, and almost a zero probability of transition from forests to range in high land quality. Another transition term in Table 6 that should be mentioned is the crop-developed transition term. The insignificant probability of low quality lands transitioning from crop to developed suggests that croplands in high quality have characteristics that make them more attractive to developed use though high productivity of crop products can be obtained on these lands. The same conclusion has been drawn from previous studies (Hite et al. 2000, Lubowski 2002, Hite et al. 2003, Templeton et al. 2006, Hite and Sohngen 2006,), and could be explained by the theory of efficient allocation of lands among different land use alternative in Zhang and Pearse (2011). High quality lands are usual flatter, closer to market, cheaper to develop and lower transaction cost to need, thus it is possible that no trade will be cut down after land use transitions.

Table 7 presents a similar land use transition probability pattern to Table 6. Lands initially croped are more likely to keep their initial use in high land quality, while pasture and forests transited more to other uses as land quality is high. The primary differences between these two subregions come from lands initial use in forests. In the subregion without rangelands, there are zero probabilities of lands in forests to convert to agricultural uses due to insignificant probabilities of transition terms from forests to crop and pasture. Statistics from NRI that forests in this subregion have not experienced observed loses from 1982 to 1997 make the insignificant transition probabilities more convincible. The gain of forests from agricultural uses is quantitatively equal to the loss of forests to developed uses.

Elasticity is the ratio of the percent change in one variable to the percent change in another variable, used to measure the responsiveness of a function to changes in the interested variable in a unit-less way. Due to the binary definition of land quality, it is impossible to estimate traditional elasticities of the transition probabilities with respect to a percentage change of land quality. Thus, we compare percentage changes of land use transition probabilities between the land quality dummy rather than calculating elasiticities. Two probabilities with lands all in high quality or all in low quality of each land use transition type are evaluated using the RPL model estimated at the overall means of all observed explanatory variables. Therefore,

Table 7. Land use transition probabilities at the means of explanatory variables by different land quality for subregion without rangelands

Transition Terms	**Probability for All LCC**	**Probability for Lqua=0 (LCC=1 to 4)**	**Probability for Lqua=1 (LCC=5 to 8)**
Crop → Crop	0.8886***(0.0570)	0.8913***(0.0572)	0.7916***(0.0496)
Crop → Pasture	0.0526***(0.0023)	0.0514***(0.0023)	0.0947***(0.0043)
Crop → CRP	0.0255***(0.0011)	0.0249***(0.0011)	0.0419***(0.0027)
Crop → Forest	0.0244***(0.0010)	0.0235***(0.0010)	0.0611***(0.0017)
Crop → Develop	0.0089***(0.0012)	0.0088***(0.0011)	0.0106***(0.0025)
Pasture → Crop	0.0553***(0.0045)	0.0646***(0.0053)	0.0320***(0.0026)
Pasture → Pasture	0.8790***(0.0846)	0.8725***(0.0839)	0.8913***(0.0860)
Pasture → CRP	0.0032* (0.0018)	0.0036**(0.0018)	0.0023 (0.0017)
Pasture → Forest	0.0500***(0.0040)	0.0464***(0.0037)	0.0639***(0.0054)
Pasture → Develop	0.0124***(0.0016)	0.0129***(0.0017)	0.0105** (0.0016)
Forest → Crop	0.0030 (0.1422)	0.0051 (0.1410)	0.0018 (0.1430)
Forest → Pasture	0.0053 (0.1419)	0.0062 (0.1409)	0.0045 (0.1426)
Forest → CRP	0.0002 (0.0004)	0.0003 (0.0005)	0.0002 (0.0003)
Forest → Forest	0.9827***(0.1574)	0.9768***(0.1564)	0.9869***(0.1581)
Forest → Develop	0.0088***(0.0013)	0.0116***(0.0017)	0.0066***(0.0010)

*** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level the difference between transition probabilities of each transition term is caused by land quality dummy only.

Table 8. Impact of land quality on land use transition probabilities

	Subregion with rangelands				**Subregion without rangelands**			
Transition	all LCC	lqua=0 (LCC=1 to 4)	Lqua=1 (LCC=5 to 8)	percentage change	all LCC	lqua=0 (LCC=1 to 4)	Lqua=1 (LCC=5 to 8)	percentage change
Crop_Crop	0.9054	0.9117	0.7679	-14.38%	0.8886	0.8913	0.7927	-9.86%
Crop_Pasture	0.0326	0.0315	0.0509	1.95%	0.0526	0.0514	0.0938	4.24%
Crop_Range	0.0082	0.0074	0.0314	2.40%	-	-	-	-
Crop_CRP	0.0479	0.0440	0.1400	9.60%	0.0244	0.0236	0.0605	3.69%
Crop_Forest	0.0033	0.0032	0.0054	0.23%	0.0255	0.0250	0.0389	1.39%
Crop_Developed	0.0026	0.0025	0.0045	0.20%	0.0089	0.0087	0.0140	0.53%
Pasture_Crop	0.0227	0.0262	0.0134	-1.27%	0.0553	0.0646	0.0320	-3.26%
Pasture_Pasture	0.9340	0.9344	0.9222	-1.21%	0.8790	0.8734	0.8879	1.45%
Pasture_Range	0.0161	0.0131	0.0340	2.09%	-	-	-	-
Pasture_CRP	0.0030	0.0026	0.0051	0.24%	0.0500	0.0460	0.0659	1.98%
Pasture_Forest	0.0175	0.0172	0.0181	0.09%	0.0032	0.0033	0.0029	-0.04%
Pasture_Developed	0.0067	0.0065	0.0072	0.07%	0.0124	0.0126	0.0113	-0.13%
Range_Crop	0.0047	0.0101	0.0020	-0.81%	-	-	-	-
Range_Pasture	0.0054	0.0085	0.0033	-0.52%	-	-	-	-
Range_Range	0.9855	0.9750	0.9916	1.66%	-	-	-	-
Range_CRP	0.0009	0.0010	0.0008	-0.02%	-	-	-	-
Range_Forest	0.0012	0.0018	0.0007	-0.11%	-	-	-	-
Range_Developed	0.0024	0.0035	0.0015	-0.20%	-	-	-	-
Forest_Crop	0.0036	0.0050	0.0025	-0.26%	0.0030	0.0051	0.0018	-0.33%
Forest_Pasture	0.0203	0.0208	0.0196	-0.13%	0.0053	0.0062	0.0044	-0.18%
Forest_Range	0.0029	0.0019	0.0046	0.28%	-	-	-	-
Forest_CRP	0.0005	0.0004	0.0007	0.03%	0.9827	0.9774	0.9866	0.92%
Forest_Forest	0.9595	0.9589	0.9590	0.01%	0.0002	0.0003	0.0002	-0.01%
Forest_Developed	0.0133	0.0129	0.0136	0.07%	0.0088	0.0110	0.0070	-0.40%

As is revealed on the left side of Table 8, probabilities of land use remaining in croplands decrease as land quality declines, and probabilities of transitions from crop to other alternatives increase as land quality declines. Lands initially in forests display an opposite pattern, regardless of insignificant conversions from forest to CRP. Deviations of transition probabilities for pasture and range between land quality in high and low have positive (negative) figures when final land use types relatively require lower (higher) land quality than that of the initial transited lands. Overall, land quality plays a more important role on lands whose initial uses are in crops. The probability of staying in crops is 14.38 percent lower on low quality compared to high quality. The probability of land use transition from crop to CRP at lower quality is approximately three times larger relative to croplands in high quality. It is reasonable since lands enrolled into CRP are not required to be in high land quality because they are not used for crop production any more. They can be used for planting trees, or providing space for wildlife habitats. Percentage changes in probabilities of land use transitions initially in croplands by land quality revealed in the right part of Table 8 have relatively higher magnitudes than lands initially in pasture and forests, which indicates that land quality for crops plays a more important role than that for pasture and forests when land conversion happens.

5.2.2 Probabilities and Elasticities with Respect to Economic Return

Table 9 and Table 10 report the land use transition probabilites and elasticities of probabilities with respect to the mean of economic returns for subregion with and without rangelands, respectively. The transition probabilities are evaluated at the mean of the explanatory variables, and are the same in magnitudes with the probabilities of Table 6 and Table 7 under all LCC. The probabilities in the second column of Table 9 (Table 10) reveal that crop (pasture) lands are the most competitive lands by showing a relatively low probability of remaining lands in their initial use and higher probabilities of converting lands to other alternatives. The general conclusion derived from comparing the probabilities of lands remaining in their initial uses is that high quality lands are more likely to convert to other land use alternatives. Land use transition probabilities follow the extensive margin theory and can be interpreted in the same way as in Table 6 and Table 7.

Table 9. Land use transition probabilities and elasticities of probabilities with respect to economic return for subregion with rangelands

Transition (Retention)	Predicted Probabilities	Elasticities of Transition Probabilities with respect economic return per acre on					
		Crop	**Pasture**	**Range**	**Forest**	**CRP**	**Developed**
Crop→ Crop	0.9054	**0.0017**	-0.0001	-0.0001	0.0000	-0.0004	-0.0028
Crop→ Pasture	0.0326	-0.0190	**0.0033**	-0.0001	0.0000	-0.0004	-0.0027
Crop→ Range	0.0082	-0.0191	-0.0001	**0.0089**	0.0000	-0.0004	-0.0027
Crop→ CRP	0.0479	-0.0190	-0.0001	-0.0001	**0.0034**	-0.0004	-0.0027
Crop→ Forest	0.0033	-0.0191	-0.0001	-0.0001	0.0000	**0.0128**	-0.0027
Crop→ Developed	0.0026	-0.0250	-0.0001	-0.0001	0.0000	-0.0005	**0.9512**
Pasture→ Crop	0.0227	**0.0190**	-0.0064	-0.0002	-0.0001	0.0000	-0.0082
Pasture→ Pasture	0.9340	-0.0004	**0.0006**	-0.0002	-0.0001	0.0000	-0.0081
Pasture→ Range	0.0161	-0.0004	-0.0063	**0.0104**	-0.0001	0.0000	-0.0081
Pasture→ CRP	0.0030	-0.0004	-0.0063	-0.0002	**0.0032**	0.0000	-0.0081
Pasture→ Forest	0.0175	-0.0004	-0.0063	-0.0002	-0.0001	**0.0140**	-0.0082
Pasture→ Developed	0.0067	-0.0006	-0.0086	-0.0002	-0.0001	0.0000	**1.0845**
Range→ Crop	0.0047	**0.0165**	0.0000	-0.0092	0.0000	0.0000	-0.0022
Range→ Pasture	0.0054	-0.0001	**0.0034**	-0.0091	0.0000	0.0000	-0.0021
Range→ Range	0.9855	-0.0001	0.0000	**0.0001**	0.0000	0.0000	-0.0021
Range→ CRP	0.0009	-0.0001	0.0000	-0.0091	**0.0035**	0.0000	-0.0021
Range→ Forest	0.0012	-0.0001	0.0000	-0.0092	0.0000	**0.0133**	-0.0022
Range→ Developed	0.0024	-0.0001	0.0000	-0.0118	0.0000	0.0000	**0.8965**
Forest→ Crop	0.0036	**0.0199**	-0.0001	0.0000	-0.0041	0.0000	-0.0047
Forest→ Pasture	0.0203	0.0000	**0.0151**	0.0000	-0.0041	0.0000	-0.0047
Forest→ Range	0.0029	0.0000	-0.0001	**0.0081**	-0.0041	0.0000	-0.0047
Forest→ CRP	0.0005	0.0000	-0.0001	0.0000	**0.0001**	0.0000	-0.0046
Forest→ Forest	0.9595	0.0000	-0.0001	0.0000	-0.0041	**0.0145**	-0.0047
Forest→ Developed	0.0133	0.0000	-0.0001	0.0000	-0.0054	0.0000	**0.9462**

Elasticities are used to examine the sensitivity of land use transition probabilities with respect to economic returns under different land use alternatives. The diagonal elements of the elasticity sub-table represent the own elasticities, indicating the percentage change of conversion probability to certain land use with 1% change of economic return on this land use, and the off-diagonal elements are cross elasticities showing how much the percentage of land use transits to a different type when economic return increases 1 % on a certain land use.

Table 10. Land use transition probabilities and elasticities of probabilities with respect toeconomic return for subregion without rangelands

Transition (Retention)	Predicted Probabilities	Elasticities of Transition Probabilities with respect to economic return per acre on				
		Crop	**Pasture**	**Forest**	**CRP**	**Developed**
Crop→ Crop	0.8886	**0.0015**	0.0006	-0.0001	-0.0004	-0.0045
Crop→ Pasture	0.0526	-.0116	**-0.0107**	-0.0001	-0.0004	-0.0044
Crop→ Forest	0.0255	-0.0116	0.0006	**0.0042**	-0.0004	-0.0045
Crop→ CRP	0.0244	-0.0116	0.0006	-0.0001	**0.0146**	-0.0045
Crop→ Developed	0.0089	-0.0129	0.0007	-0.0001	-0.0005	**0.5332**
Pasture→ Crop	0.0553	**0.0160**	0.0032	-0.0002	-0.0001	-0.0080
Pasture→ Pasture	0.8790	-0.0009	**-0.0004**	-0.0002	-0.0001	-0.0079
Pasture→ Forest	0.0032	-0.0009	0.0032	**0.0032**	-0.0001	-0.0079
Pasture→ CRP	0.0500	-0.0009	0.0032	-0.0002	**0.0172**	-0.0080
Pasture→ Developed	0.0124	-0.0010	0.0036	-0.0002	-0.0001	**0.6614**
Forest→ Crop	0.0030	**0.0121**	0.0001	-0.0045	0.0000	-0.0060
Forest→ Pasture	0.0053	0.0000	**-0.0147**	-0.0044	0.0000	-0.0059
Forest→ Forest	0.9827	0.0000	0.0001	**0.0001**	0.0000	-0.0060
Forest→ CRP	0.0002	0.0000	0.0001	-0.0045	**0.0158**	-0.0060
Forest→ Developed	0.0088	0.0000	0.0001	-0.0051	0.0000	**0.6498**

The expected positive own-elasticities on the diagonals and negative cross-elasticities on the off-diagonals confirm the role of net returns on land use transitions. High economic return on a certain type of land is associated with high probability of remaining in or converting lands to that use, and decrease the competitiveness of other land use alternatives. Take croplands as an example, for lands in the subregion with rangeland, a 1% increase of economic return of croplands will increase the probability of lands remaining in this use by 0.0017%, and will cause a 0.0190%, 0.0139%, and 0.0164% increase on land use transition probabilities from pasture, range and forests to croplands, respectively. The same change of crop returns will decrease the probability of land converted to forestry by 0.0190%, 0.0004% and 0.0001% from lands initially use for crop, pasture and range, respectively.

For all the own and cross elasticities in Table 9 and Table 10, the magnitudes are quite small, indicating an inelastic relationship between land use transition probabilities and economic returns. In Table 9, the cross responses of land use transition probabilities with respect to CRP earnings are negligible according to the zero cross-elasticities of land use transitions from pasture, range and forests. Economic return for CRP lands is derived from government subsidies for conservation purposes rather than driven by markets. Its increase does promote lands to enroll this program, but does not affect transitions among other alternatives except itself. Some other zero cross-elasticities are observed as economic return changes. For example, an increase in pasture returns will not influence land use transitions from range to other alternatives except use in pasture. And transition probabilities of lands from forests to other types except cropland (rangeland) do not change as economic profit of cropland (rangeland) changes. One point of interest is that the means of return to pasture for subregion without rangelands for the 1978-1982 and 1983-1987 are negative, thus the own and cross-elasticities of land use transition probabilities with respect to pastures return in Table 10 are opposite to our expectation.

One of the goal for use of the RPL model is to fully relax the IIA assumption of standard logit models by achieving different cross-elasticities of land use transition probabilities among land use alternatives from one initial use with respect to change of economic returns of a certain use. Unfortunately, there is no strong evidence to say that IIA is not a reasonable assumption either by presenting some equal cross-elasticities of transition probabilities from one initial land use category with respect to changes of economic returns of a kind of land. The quite small magnitudes of cross-elasitcities with only four-digit round decimal might be one of the reasons to negelet the insignificant differences.

5.2.3 Probabilities and Elasticities with Respect to Population Density

Table 11 presents the elasticities of land use transition probabilities with respect to the mean of population density by subregion. Under the definition of population density−the ratio of

Table 11. Land use transition probabilities and elasticities of probabilities with respect to population density

Subregion with Rangelands			**Subregion without Rangelands**		
Transiton	Predicted Probabilities	Elasticity	Transiton	Predicted Probabilities	Elasticity
Crop_Crop**	0.9054	-0.0046	Crop_Crop**	0.8886	-0.0041
Crop_Pasture**	0.0326	0.0481	Crop_Pasture**	0.0526	0.0091
Crop_Range**	0.0082	0.0147	Crop_Range	-	-
Crop_CRP**	0.0479	0.0701	Crop_CRP**	0.0244	-0.0147
Crop_Forest**	0.0033	-0.3332	Crop_Forest**	0.0255	-0.1770
Crop_Developed**	0.0026	0.0779	Crop_Developed**	0.0089	0.0848
Pasture_Crop**	0.0227	-0.0599	Pasture_Crop**	0.0553	-0.0046
Pasture_Pasture**	0.9340	0.0109	Pasture_Pasture**	0.8790	0.0013
Pasture_Range**	0.0161	-0.0339	Pasture_Range	-	-
Pasture_CRP**	0.0030	0.0405	Pasture_CRP**	0.0500	-0.0269
Pasture_Forest**	0.0175	-0.5014	Pasture_Forest**	0.0032	-0.2203
Pasture_Developed**	0.0067	0.0510	Pasture_Developed**	0.0124	0.0916
Range_Crop**	0.0047	-0.0207	Range_Crop	-	-
Range_Pasture**	0.0054	0.0362	Range_Pasture	-	-
Range_Range**	0.9855	0.0001	Range_Range	-	-
Range_CRP**	0.0009	0.0600	Range_CRP	-	-
Range_Forest**	0.0012	-0.3757	Range_Forest	-	-
Range_Developed**	0.0024	0.0684	Range_Developed	-	-
Forest_Crop**	0.0036	0.7017	Forest_Crop	0.0030	0.0173
Forest_Pasture**	0.0203	0.8198	Forest_Pasture	0.0053	0.0222
Forest_Range**	0.0029	0.7451	Forest_Range	0.0000	0.0962
Forest_CRP	0.0005	0.8693	Forest_CRP	0.0002	-0.0010
Forest_Forest**	0.9595	-0.0349	Forest_Forest**	0.9827	-0.1596
Forest_Developed**	0.0133	0.8867	Forest_Developed**	0.0088	0.0962

** significant at the 1% level

total population to county land area, it varies only among observations, not among land use alternatives. The own and cross elasticities of each transition probabilities with respect to population density are even in magnitudes, thus we only report the own elasiticities. For both of the subregions, the elasticity of any transition probability to pasture or developed uses with respect to population density is positive, indicating that no matter what kind of land it is initially, population growth or urbanization stimulates lands to convert to pasture lands or to urban use. Probabilities of lands staying in crops or transiting to crops decrease as population increase with the exception of lands initial in forests.

Lands initially in forests respond more drastically with respect to population density in the subregion with rangelands. The negative elasticities of the probabilities of lands remaining their original use in forests or the probabilities of new forests transiting from other rural uses imply that population growth make the forests lose their competitiveness with other rural lands. Lands are not likely to convert to forests when population rises.

Keeping all other factors equal, a 1% increase in population density will result in a 0.08%, 0.05%, 0.07% and 0.89% increase of land transition probabilities from crop, pasture, range, and forest to developed use respectively in the subregion with rangelands, and 0.08%, 0.09% and 0.10% increase of that from crop, pasture, and forests in the subregion without rangelands. The same change of population density will cause 0.33%, 0.50%, 0.38%, and 0.04% decrease of land use transition probabilities from crop, pasture, range, and forest to forests respectively in the subregion with rangelands, and 0.18%, 0.22% and 0.16% increase of that from crop, pasture, and forests in the subregion without rangelands. The role of population density on rangelands is bilateral. A 1% increase of population density increase the land use transition probabilities from crop, range and forests to range by 0.01%, 0.04%, and 0.74%, respectively, while decrease the transition probability of lands from pasture to range by 0.04%.

Comparing the magnitudes of elasticities of the transition probability with respect to the mean of economic returns and the mean of population density, though both of them are inelastic, the magnitudes of the elasticities with respect to population density are relatively larger, which means that land use transition probabilities are more sensitive to the change of population density. It contributes more on rural land use reduction and on urbanization.

6. Simulations

The previous analysis provides quantitative effects of economic returns and land quality on land use transition probabilities by estimating the parameters, probabilities and elasticities of each variable. While it is not easy to tell the relative importance of the different effects since both own and cross elasticities are estimated at the means of the economic profits, and could affect lands on 25 or 36 terms simultaneously. Analysis based on the plot level data could examine land use transition behavior more accurately, however, it cannot reflect the aggregate behavior of the key factors on land use transitions, and could not provide enough information for comparing the explanatory power of different variables.

Simulations provide a way to explore the aggregate changes among different land-use categories driven by different economic returns. Here we examine two types of simulations: factual and counterfactual simulation. In this section, we first present a “factual” simulation to check the predictive accuracy of the RPL model, and then we present a series of “counterfactual” simulations directly related to changes of economic returns to explore the importance of the various economic return levels on return variable.

6.1. “Factual” Simulation

The “factual” simulation is designed to use the historically observed values of all variables to simulate land use changes among the six major land use categories. Using the parcel simulated transition probability derived from the RPL model, and its corresponding acreage factor from NRI, estimations of acres of land at that parcel transiting from one starting use to another use can be calculated. Summation of the simulated acreages of all parcels for each particular land use category presents the aggregate estimated acreages of that certain use. The aggregate estimated acreages of a certain land use type are compared with factual land use from the NRI reports to check the predictive accuracy of the RPL model as well as to provide a baseline for comparing the historically observed land use change against some hypothetical scenarios.

Table 12 presents the factual simulation results in terms of the approach described above and the comparison of the simulated and actual acreages. The RPL models are generally powerful for predicting aggregate land use acreage since most of the percentages of predicted deviation between factual simulated and actual land use status are fairly small in both subregions. The greatest predicted deviations for both subregions come from lands for CRP and lands for developed purpose for each transition period. For example, in the subregion with rangelands, lands in CRP use from factual simulation during the period 1982 to 1987 are underestimated by 0.3 million acres (11.56%) compared to the actual use. Lands in developed use are overestimated by 38.06 percent between 1987 and 1992 in the factual simulation. The most serious deviation for the subregion with rangelands is the CRP lands in the period of 1992-1997. The factual simulated acreage overestimates the actual acreage by about 5 times. The same situation is observed in the subregion without rangelands as well. One possible reason for the large deviations could be the relatively small areas of CRP and developed lands compared to other land use categories. Generally, the total acreage of lands is fixed. Any small deviation from crop, pasture, range or forest could cause a large absolute acreage difference to CRP or to developed use. The trade-off between the fixed area and four or three large rural land bases goes to CRP and non-rural use, thus aggregate the deviation of these two kinds of lands.

Table 12. Comparison of "factual" simulated areas and actual areas

Scenarios	Period	Crop	Pasture	Range	Forest	CRP	Developed
Subregion with Rangelands							
Actual Acreages	1982-87	59977.2	39561.8	113818.6	78070.7	2589.6	1403.8
Factual Simulated Acreages		59670.23	39406.22	114516.7	78172.39	2290.14	1366.04
Percentage Deviation		-0.51%	-0.39%	0.61%	0.13%	-11.56%	-2.69%
Actual Acreages	1987-92	55178.8	39938.8	112733.5	78583.1	3551.7	1647.7
Factual Simulated Acreages		56376.03	39148.4	113049.9	78672.72	2199.86	2186.73
Percentage Deviation		2.17%	-1.98%	0.28%	0.11%	-38.06%	32.71%
Actual Acreages	1992-97	52482.7	38697.9	112953.4	79380.5	320.1	2225.2
Factual Simulated Acreages		51498.15	39484.65	111869.4	79012.8	1967.63	2227.12
Percentage Deviation		-1.88%	2.03%	-0.96%	-0.46%	514.69%	0.09%
Subregion without Rangelands							
Actual Acreages	1982-87	32000.1	23414.3	---	100506.9	1075.9	1449.6
Factual Simulated Acreages		32053.96	23612.09	---	100282	1028.92	1469.74
Percentage Deviation		0.17%	0.84%	---	-0.22%	-4.37%	1.40%
Actual Acreages	1987-92	28429	23601.9	---	100361	1561.4	1694.6
Factual Simulated Acreages		29314.30	22853.76	---	100477.6	968.07	2034.25
Percentage Deviation		3.11%	-3.17%	---	0.12%	-38.00%	20.04%
Actual Acreages	1992-97	26519.7	22262.7	---	99844.8	204.9	2614.5
Factual Simulated Acreages		25553.35	22766.58	---	99837.85	844.41	2444.60
Percentage Deviation		-3.64%	2.26%	---	-0.01%	312.11%	-6.50%

6.2 “Counterfactual” Simulations

Following Lubowski (2002), the counterfactual simulations regarding to variables of economic return variable are pursued to examine the importance of return variables on aggregate land use transition behaviors between different land use categories by keeping the return of one land use category at the early period’s value, while allowing the profit values of all the other land use categories to take their actual historical values. Because the return variable in our RPL model specification is with a period lag and the values of return before 1978 is not available, we only examine the simulations from 1987 to 1997.

From Table 3, the values of land economic returns for the six major categories change into different directions for the periods for 1978-1982, 1983-1987 and 1988-1992. Except for the average negative pasture return where is observed in the U.S. South for the 1983-1987 period, in general, between the 1978-1982 and 1988-1992 periods, the total real increases of annual per acre economic return for range, forest, CRP and developed use are \$3.78 (26.16%), \$2.89 (45.95%), \$45.18, and \$405.49 (46.33%), respectively. Real per acre crop return decreased from \$44.32 to \$13.83 from 1978-1982 to 1983-1997, then increased slightly to \$17.30 in 1988-1992. Table 13 reports the simulation results of area changes of the six major land use categories under different scenarios. The change in the acreage of each land use type for factual simulation is based on the historical values of all variables used in the estimation. Counterfactual simulations trace land use situations under different assumptions on economic values. The difference between the counterfactual simulation and factual simulation results divided by the factual simulation results measures the percentage change caused by the constant economic returns. Positive (negative) values indicate that the acreage change in the counterfactual simulation is

Table 13. Simulated changes of land use categories in the southern U.S. under alternative scenarios

Simulation Scenario	Subregion with rangelands		Subregion without rangelands		U.S. South	
	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant
Crop Lands						
Factual Simulation	-8172.07	0.00%	-6500.61	0.00%	-14672.68	0.00%
No Change in any return	-8006.53	-2.03%	-6266.88	-3.60%	-14273.41	-2.72%
No Change in Crop Return	-8131.77	-0.49%	-6411.32	-1.37%	-14543.09	-0.88%
No Change in Pasture Return	-8222.40	0.62%	-6515.45	0.23%	-14737.85	0.44%
No Change in Range Return	-8169.94	-0.03%	-6500.61	0.00%	-14670.56	-0.01%
No Change in Forest Return	-8171.55	-0.01%	-6498.82	-0.03%	-14670.37	-0.02%
No Change in CRP Return	-8129.33	-0.52%	-6483.85	-0.26%	-14613.18	-0.41%
No Change in Developed Return	-8041.73	-1.59%	-6358.2	-2.19%	-14399.93	-1.86%
No change in Govt. payment	-7849.39	-3.95%	-6046.38	-6.99%	-13895.77	-5.29%
No Change in Crop excluded govt. Return	-8130.57	-0.51%	-6410.47	-1.39%	-14541.04	-0.90%
No Change in Population Density	-8151.20	-0.26%	-6429.07	-1.10%	-14580.27	-0.63%
Pasture Lands						
Factual Simulation	78.43	0.00%	-845.51	0.00%	-767.08	0.00%
No Change in any return	408.64	421.05%	-659.35	-22.02%	-250.71	-67.32%
No Change in Crop Return	60.47	-22.90%	-892.87	5.60%	-832.40	8.52%
No Change in Pasture Return	191.83	144.60%	-821.97	-2.78%	-630.14	-17.85%
No Change in Range Return	81.08	3.38%	-845.51	0.00%	-764.43	-0.35%
No Change in Forest Return	80.40	2.51%	-842.35	-0.37%	-761.95	-0.67%
No Change in CRP Return	81.70	4.17%	-842.51	-0.35%	-760.81	-0.82%
No Change in Developed Return	306.86	291.27%	-640.66	-24.24%	-333.80	-56.48%
No change in Govt. payment	-55.11	-170.26%	-1090.24	28.94%	-1145.35	49.31%
No Change in Crop excluded govt. Return	59.77	-23.78%	-893.39	5.66%	-833.62	8.67%
No Change in Population Density	19.92	-74.60%	-909.61	7.58%	-889.69	15.98%

Table 13. (Continued) Simulated changes of land use categories in the southern U.S. under alternative scenarios

Simulation Scenario	**Subregion with rangelands**		**Subregion without rangelands**		**U.S. South**	
	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant
RangeLands						
Factual Simulation	-2647.30	0.00%	---		-2647.30	0.00%
No Change in any return	-2482.12	-6.24%	---		-2482.12	-6.24%
No Change in Crop Return	-2653.20	6.89%	---		-2653.20	6.89%
No Change in Pasture Return	-2665.02	0.45%	---		-2665.02	0.45%
No Change in Range Return	-2654.59	-0.39%	---		-2654.59	-0.39%
No Change in Forest Return	-2646.96	-0.29%	---		-2646.96	-0.29%
No Change in CRP Return	-2645.53	-0.05%	---		-2645.53	-0.05%
No Change in Developed Return	-2453.71	-7.25%	---		-2453.71	-7.25%
No change in Govt. payment	-2699.22	10.01%	---		-2699.22	10.01%
No Change in Crop excluded govt. Return	-2653.46	-1.70%	---		-2653.46	-1.70%
No Change in Population Density	-2641.01	-0.47%	---		-2641.01	-0.47%
Forest Lands						
Factual Simulation	840.41	0.00%	-443.94	0.00%	396.47	0.00%
No Change in any return	1141.92	35.88%	214.43	-148.30%	1356.35	242.10%
No Change in Crop Return	837.37	-0.36%	-464.32	4.59%	373.05	-5.91%
No Change in Pasture Return	805.64	-4.14%	-451.31	1.66%	354.33	-10.63%
No Change in Range Return	841.11	0.08%	-443.94	0.00%	397.17	0.18%
No Change in Forest Return	836.37	-0.48%	-451.97	1.81%	384.40	-3.05%
No Change in CRP Return	840.90	0.06%	-442.75	-0.27%	398.15	0.42%
No Change in Developed Return	1182.33	40.68%	248.25	-155.92%	1430.58	260.83%
No change in Govt. payment	819.01	-2.55%	-548.04	23.45%	270.97	-31.65%
No Change in Crop excluded govt. Return	837.28	-0.37%	-464.55	4.64%	372.73	-5.99%
No Change in Population Density	801.69	-4.61%	-458.52	3.28%	343.17	-13.44%

Table 13. (Continued) Simulated Changes of Land Use Categories in the Southern U.S. under Alternative Scenarios

Simulation Scenario	**Subregion with rangelands**		**Subregion without rangelands**		**U.S. South**	
	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant	Change in Acreage (,000 of acres)	Percentages of Acreage change attributable to Variable Held Constant
CRP Lands						
Factual Simulation	6457.63	0.00%	2841.4	0.00%	9299.03	0.00%
No Change in any return	6344.41	-1.75%	2773.83	-2.38%	9118.24	-1.94%
No Change in Crop Return	6427.09	-0.47%	2813.25	-0.99%	9240.34	-0.63%
No Change in Pasture Return	6447.47	-0.16%	2836.08	-0.19%	9283.55	-0.17%
No Change in Range Return	6457.89	0.00%	2841.4	0.00%	9299.29	0.00%
No Change in Forest Return	6457.65	0.00%	2841.49	0.00%	9299.14	0.00%
No Change in CRP Return	6375.14	-1.28%	2799.56	-1.47%	9174.70	-1.34%
No Change in Developed Return	6466.94	0.14%	2848.68	0.26%	9315.62	0.18%
No change in Govt. payment	6461.20	0.06%	2824.77	-0.59%	9285.97	-0.14%
No Change in Crop excluded govt. Return	6440.08	-0.27%	2816.42	-0.88%	9256.50	-0.46%
No Change in Population Density	6527.52	1.08%	2852.81	0.40%	9380.33	0.87%
Developed Lands						
Factual Simulation	5779.88	0.00%	5947.66	0.00%	11727.54	0.00%
No Change in any return	4030.87	-30.26%	4305.31	-27.61%	8336.18	-28.92%
No Change in Crop Return	5772.83	-0.12%	5930.54	-0.29%	11703.37	-0.21%
No Change in Pasture Return	5736.33	-0.75%	5931.34	-0.27%	11667.67	-0.51%
No Change in Range Return	5783.06	0.05%	5947.66	0.00%	11730.72	0.03%
No Change in Forest Return	5780.45	0.01%	5950.97	0.06%	11731.42	0.03%
No Change in CRP Return	5780.54	0.01%	5948.29	0.01%	11728.83	0.01%
No Change in Developed Return	4064.50	-29.68%	4325.58	-27.27%	8390.08	-28.46%
No change in Govt. payment	5775.00	-0.08%	5928.22	-0.33%	11703.22	-0.21%
No Change in Crop excluded govt. Return	5776.57	-0.06%	5932.06	-0.26%	11708.63	-0.16%
No Change in Population Density	5816.53	0.63%	5945.67	-0.03%	11762.20	0.30%

greater (smaller) than the factual simulation. The bigger the absolute value of the difference, the more important the attribute contributes to land use transition aggregate behavior.

The historical simulation results are first displayed by subregion, and then summed to the whole of the U.S. South. Take croplands as an example, for the change of cropland between 1987-1997, the factual simulation reports an 8.2 (6.5) million decrease in the subregion with (without) rangelands. In total, the U.S. South looses about 14.7 million acres of croplands during 1987-1997 based on the factual simulation result, which is much closer to the actual loss of 13.0 million acres from the NRI reports. According to counterfactual simulation results, the simulated effects of no changes in the return variable in the study period cause a 2.03 percent (0.17 million acres) smaller decrease on croplands in the subregion with rangelands, and a 3.60 percent (0.23 million acres) smaller decrease compared to the factual simulation result.

Comparing the factual and counterfactual simulation results, in general, keeping all the economic returns for different land use alternatives at their 1978-1982 level, we could have 0.40, 0.52 and 0.17 million acres more lands in crop, pasture and range uses respectively, accompanied by a 0.96, 0.18 and 3.40 million acres decrease lands in forest, CRP, and developed purposes respectively. Compared to the role of the assumed constant economic return for each land use alternative, the significant appreciation of developed lands is the main cause of losses of rural lands. Without the $405.49 (46.33%) increase from 1978-1982 to 1988-1992 period, there could be 1.59 percentage, 291.27 percentage, 7.25 percentage, 40.68 percentage more lands on crop, pasture, range and forest respectively in the subregion with rangelands, and 2.19 percentage, 24.24 percentage and 260.83 percentage more lands in crop, pasture and forest uses respectively in the subregion without rangelands. As a trade-off, 3.34 million acres rural lands will be kept from transiting to developed use.

As a subsidy, government payments aim to motivate landowners to keep cropping by providing financial supports. It accounts for approximately 50 percent of the total real crop return from the period 1978-1982 and 1992-1997, and 77 percent in 1983-1987. During the study period, government payments decreased more than a half. The significant decrease mitigated the competitive ability of croplands compared to other land use alternatives. In total, the 51.10 percent decrease of government payments could cause an additional 5.29 percent (0.78 million acres) more lands to switch from crop usage, an additional 3.95 percent (0.38 million acres) more lands on pasture, and an additional 10.01 percent (0.05 million acres) more lands on rangelands in the South. Forests, lands in CRP, and developed lands are not affected as much as agricultural lands under the change of government payments.

Additionally, the impacts of population density have been revealed in Table 13 under each land use category by subregion. The growth rate of population density is approximately twice higher in the subregion with rangelands than without. The contribution of population density to pasture and forests are more significant than that to croplands and forests. Comparing the factual and counterfactual simulation results, the 34.66 percentage increase of population density in the region with rangeland could decrease cropland, rangeland, and forest uses by 0.02 million acres (0.26%), 0.01 million acres (0.47%), and 0.04 million acres (4.61%), respectively, and increase pasture by 0.06 million acres (74.60%). For the whole region, no change in population from 1978-1982 to 1988-1992 periods could provide 0.09 million acres more croplands (0.63%), 0.01 million acres more rangelands (0.47%), 0.12 million acres (15.98%) less pasture, and 0.05 million acres less forests (13.44 %).

7. Conclusions and Discussions

A panel RPL model is constructed in this study to explore the determinants of land use transitions among six major land use categories in the southern U.S. using NRI plot-level land use and land quality data and county-level per acre economic returns to various land use alternatives. The results demonstrate that land use transitions are highly related to land rents, land quality and population density. The probabilities and elasticities analyses provide further information on the effect of different factors on land use change decisions. Both the elasticities of land use transition probabilities with respect to the mean of the net economic returns and the mean of population density are inelastic, and population growth contributed more than economic returns to the decrease in rural land uses, and sped up urbanization. With the historical simulation, we address the different importance of economic returns on land use alternatives as well as population density on aggregate behaviors of land use changes. We find that urbanization associated with land value appreciation is the most important factor for the decrease of rural lands. Increases of economic return of each land use category is another contributing factor causing less decrease of that certain land use.

Though the RPL model could provide an unbiased estimator for each probability and is quite appealing as noted earlier, the application of RPL model has been restricted by simulation methods. There might be a potential simulation bias in estimating the unknown distribution of the random components with a log-normal distribution and the lognormal predictions need to be adjusted because the predicted mean is lower from the distribution than the observed data.

Chapter 3. An Econometric Study of Forest Type Changes and Related Canbon Consequences in the Southern U.S.

1. Introduction

Forests in the South account for 27 percent of all forest lands in the United States (Smith et al. 2009). A fairly constant 96 percent of these forest lands in the South is timberland over the past half century (Alig and Butler 2004). It is the most important timber production region that holds about two-fifths of the country's timberland, producing about 58 percent of U.S. industrial roundwood and three-fourths of total U.S. pulpwood in 2002 (Zhang and Polyakov 2010). Although the fraction of planted stands is only 22 percent of the total timber land (about 45 million acres) in the South in 2007, it contributes to 57 percent of accrual of the net annual growth of softwood species based on recent remeasurement data and provides 43 percent of the softwood removals in 2007 (Smith et al. 2009).

Between 1952 and 1997, planted pine area increased by more than 10.1 million hectares in the South, mainly caused by artificial regenerations of harvested natural pine, mixed-oak-pine, and hardwood stands or plantations on old agricultural lands. Naturally generated pine lost a total of 59 percent of its area, which is the largest change of forest type, followed by increases of planted pine and upland hardwood, and decrease of lowland hardwood (Alig and Butler 2004). These trends might continue and perhaps be expected because regenerated plantations, the vast majority of which are composed of softwood species, could produce larger volumes of higher-value sawtimber in less time relative to hardwoods, and provide relatively larger returns for forest owners (Siry 2002). However, hardwood forests have higher annual wood production and higher carbon stocks than softwood forests (Brown et al. 1999, Brown and Schroeder 1999). On average, the carbon storage ability of planted pine is only from 46 percent to 70 percent of that of upland hardwood forests, depending on site quality (FIA 2003). The different growth rates and carbon sequestration capabilities of forest types could cause unclear consequences for the future availability of timber, wildlife habitat, forest carbon, and other forest ecosystem goods and services.

The Intergovernmental Panel on Climate Change (IPCC) has reported that total land use, land use change and forestry activities has resulted in net carbon (C) sequestration increases by approximately 26 percent between 1990 and 2007. In 2007, about 17.4 percent of total U.S. CO_2 emissions were offset by changes of land use and forestry, with a net C sequestration of 1,062.6Tg CO_2 (289.8 Tg C). This increase was primarily due to an increase in the rate of net C accumulation in forest C stocks (EPA 2009). Previous studies on terrestrial carbon analysis suggest that afforestation, including tree plantations may be an effective way to increase terrestrial carbon stores in the United States (Sedjo 1989, Moulton and Richards 1990, Adams and Haynes 1996, Birdsey et al. 1999). while econometric examinations are quite limited to deal with the quantitative effects of this kind of environmental change on carbon consequences, except for Alig and Bulter (2004) and Sohngen and Brown (2006).

The purpose of this study is to project the future distribution of southern forest types, and to examine related carbon consequences. This study takes the advantages of discrete choice models described in Chapter 2 by using available point level forest type data from the Forest Inventory and Analysis (FIA), and considers land use dynamics between forestry and non-forestry sectors as a simultaneous process on land use dynamics within forest sectors.

The next section introduces the method for projecting the future forest type changes and the data used in the study. Section 3 and 4 present our model estimation results, and land use and forest type projections. Section 5 shows the comparison results of carbon sequestrations with forest type changes and without. The final section summarizes and draws conclusions and policy implications based on our findings.

2. Methods and Data

Forest type changes cannot be isolated from land use dynamics since total land area for the region is fixed. Because conversion among forest and non-forest land uses and conversion within forest sectors happens at the same time, it is more reasonable to estimate these two kinds of change simultaneously. Sohngen and Brown (2006) used a share model to examine the shares of lands in three forest types and agricultural use based on aggregated county-level land use data from NRI and forest type data from FIA. With the parameter estimates, and the assumed rental rates for future time periods, the proportion of land allocated to these four land uses are predicted for each county. Models simultaneously exploring land use changes and forest type changes other than a share model could not accomplish in a one-stage model due to data availability and convertibility (Alig and Butler 2004, Zhang and Polyakov 2010). Therefore, to project future patterns of forest types, we follow Zhang and Polyakov (2010) ‘s conceptual scheme of pine plantation simulation to project land use dynamics in the coming half century in the first stage, and then project forest type changes conditional on land use projection results in the first stage.

2.1. Projection of Future Land Use Change Patterns

Similarly to the study in Chapter 2, we perform the econometric study of U.S. South land use and land use change, and project future land use patterns with the random parameter logit (RPL) model, but with a different data construction. The available latest ten-year interval U.S.

South land use data that trace land use transitions are derived from National Resources Inventory (NRI) from 1987 to 1997. Plots in non-federal rural purposes are chosen with four initial uses (crop, pasture, range and forest) and five final uses (crop, pasture, range, forests, and developed lands). Lands classified as Conservation Reserve Program (CRP) in NRI are reclassified into crop or forest uses according to further CRP information. Other lands including water, federal lands and lands in developed purposes in 1987 are excluded from the analysis. Our dependent variable in the RPL model is land use category in 1997. Explanatory variables in the model include socio-economic and bio-physical factors which could limit and influence the chance of a particular land parcel being converted to another use, with previous ten-year average real values for time-variant variables and fixed values for time-invariant variables. To be consistent with the forest type change projection in the second stage, we exclude non-forest counties which are mostly in western Texas in NRI according to Forest Inventory and Analysis (FIA) records.

In total, our land use change study covers 1,027 forest counties in the South, including 188,823 plots, representing 67 percent of the total non-federal rural lands. The key variables used in the model are economic returns for land use alternatives, dummy variable "Prime farmland" from NRI, population interaction index (PII) from the Census block group population data, and continuous variable of slope for each point from NRI. We also include three dummy variables, Piedmont, Mississippi Delta, Mountains and Plateau to capture land use transition patterns with respect to physical geographical features. Counties in coastal plain are set as the base. In terms of classic land theory, we assume that the higher the economic return of a kind of land use, the higher probability of lands remaining or converting to that certain use. Lands classified as "prime farmland" are more likely to stay in or convert to agricultural use due to high productivity of agricultural products (Polyakov and Zhang 2008, Zhang and Polyakov 2010). Slope of a site is assumed to negatively influence lands in agricultural use and developed use. The steeper the slope is, the less probability of land remaining in or converting to those uses.

Parameter estimates in the RPL model are used to project major land use areas in the coming half century. Keeping all time-invariant variables with the same values, we adjust county land rents for different land use types based on their historical growth rates from 1987 to 1997. The average annual growth rates of land rents for cropland, pasture, rangeland and forests are 2.22 percent, 4.68 percent, 0.48 percent, 3.49 percent, and 0.85 percent, respectively. PII adjustment is based on the annual growth rate of population projected by US Census Bureau.

2.2. Projection of Future Forest Type Patterns

Forest types change is a prominent environmental change along with land use and land cover changes in the South. The dramatic increases of planted pine plantation transited from other forest types or afforested from marginal agricultural lands are not only of interest for forest managers or investors, but also for policy makers and environmentalists. Previous econometric studies emphasized modeling the dynamics of forest plantation by examining or projecting forest plantation using aggregate forest type data, however, as Zhang and Polyakov (2010) said, “they seldom consider the possibility of diminishing of land resources available for plantation (Kline et al. 2001, Wear and Greis 2002, Zhou et al. 2003, Li and Zhang 2007).”

In the second stage, the RPL model is used to explore dynamics of forest type changes among five major forest types: planted pine, natural pine, mixed pine, upland hardwood, and bottomland hardwood using the FIA remeasurement data. The FIA data are collected on an approximate 10-year cycle for sample plots located roughly in a 5 by 5 grid pattern. To match data collection time between NRI and FIA, we use inventory data between 1980 and 1990 as the initial point, and data between 1990 and 2000 as the final point. Remeasurementable plots in these two periods record the actual forest types in the two different time periods.

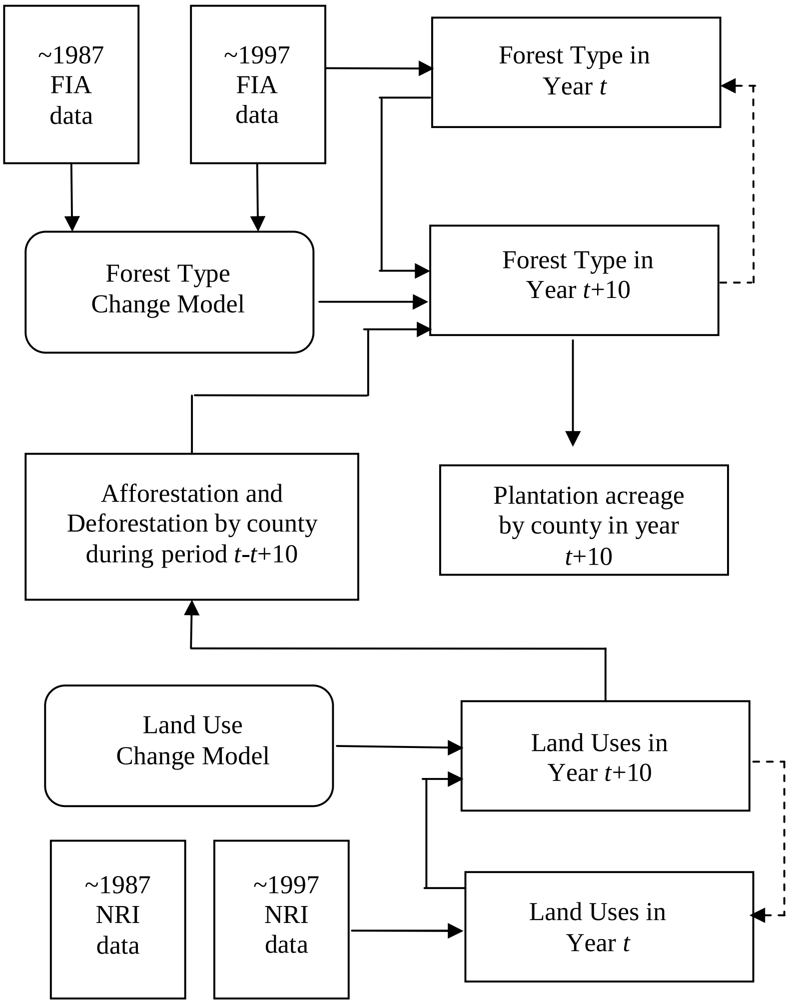

Figure 3. The structure of plantation development simulation.
Source: Zhang D, Polyakov M, 2010.

Explanatory variables for the analysis include socio-economic and bio-physical factors as well. Due to lack of harvest volume data, and market transactions usually happen on a stand tree. We use growing-stock volume of live trees instead of harvest volume to calculate the economic return for each forest cover type. We first separate sawtimber and pulpwood based on the diameter of breast for each tree and aggregate the yields based on their growing-stock volume provided by FIA. Prices for sawtimber and pulpwood are derived from Timber Mart South (TMS). Thus the product of growing- stock volume and unit price for each forest cover type is the gross economic return, and is used as a proxy of returns to different forest type. Two more variables other than dummies of geographical features, slope and PII are added into the model. Soil hydricity represents high content of moisture in the soil. The higher the soil hydricity is, the less suitable for a pine plantation. The remeasurement period for each plot is included. A longer remeasurement period will lead to a higher probability of observed forest type change (Zhang and Polyakov 2010).

The projection of forest type change is based on parameter estimates in the first stage, and the projection of forestlands in the second. We assume that the growth rates of economic returns for different cover types in future decades follow the same change trend in 1987-1997. Using the rates of forest loss and gain calculated from the land use change projection for each FIA unit in each state, we adjust area of each forest plot to make sure that the dynamics of forest loss and gain can be fully presented.

3. Estimation Results

With the assumption of log-normal distribution of the economic returns in each stage, we estimate the model with Conditional Logit (CL) and Random Parameters Logit (RPL) specifications, and test the model preference between CL and RPL in each stage. Then we report the estimation results for the preferred model. Tables 14 and 15 present our model estimates for the RPL model and CL model for the two steps, respectively. For both of the two stages, most parameters are highly significant at the 1% or 5% level with expected signs. Both the mean of economic returns for different land uses in the land use change model and the difference of economic earnings for different forest types in the forest types change model positively influence the probability of lands or forests remaining or converting to that kind activity. The standard deviation of economic returns in the first model is significant at the 1% level, indicating that economic returns vary among plots with a log-normal distribution.

Table 14. Plot-level RPL model estimation results for land use changes

Variables	**Final Land Uses (choices)**				
	Crop	Pasture	Range	Forest	Developed
Initial Crop	0	-2.1856***	-5.2509***	-2.1793***	-3.4005***
	---	(0.0349)	(0.1773)	(0.0355)	(0.0557)
Initial Pasture	-2.3079***	0	-3.5133***	-1.3274***	-3.1546***
	(0.0385)	---	(0.0975)	(0.0339)	(0.0572)
Initial Range	-3.2120***	-2.3547***	0	-2.2242***	-3.8102***
	(0.1117)	(0.0739)	---	(0.0772)	(0.1135)
Initial Forest	-5.6016***	-4.6611***	-7.4261***	0	-4.6249***
	(0.0500)	(0.0374)	(0.1071)	---	(0.0418)
PII	-0.0023***	-0.0038***	-0.0016***	-0.0025***	---
	(0.0002)	(0.0001)	(0.0002)	(0.0001)	---
Change of PII	-0.0054***	-0.0015***	-0.0027***	-0.0071***	---
	(0.0005)	(0.0005)	(0.0008)	(0.0003)	---
Prime land	1.3816***	1.0300	0.3144*	0.4807***	---
	(0.0530)	(0.0527)	(0.1633)	(0.0516)	---
Slope	0.1159***	0.1603***	-0.6014***	0.0398***	---
	(0.0070)	(0.0065)	(0.0352)	(0.0068)	---
Pie	-0.4312***	0.3289***	0.6659***	0.1489***	---
	(0.0489)	(0.0465)	(0.1132)	(0.0407)	---
Mountain	-0.0232	0.2053***	-0.1900	-0.0796	---
	(0.0584)	(0.0560)	(0.2278)	(0.0523)	---
Delta	1.5689***	0.7517***	-1.2986*	0.5966***	---
	(0.1256)	(0.1312)	(0.7234)	(0.1308)	---
Economic Return for All Land Use Alternatives	Mean of economic return	-9.6244*** (0.2532)	Std. Dev. Of Return	1.2475*** (0.1394)	
Number of observation	188,823				
Log-likelihood	-64915.68				
Preudo R^2	0.7864				

*** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level

Table 15. RPL model estimation results for forest type changes

Variables	Final Forest Types (choices)				
	Pine Plantation	Natural Pine	Mixed Pine	Upland Hardwood	Bottomland Hardwood
Initial Pine Plantation	0	-3.5650***	-2.6353***	-3.3690***	-3.2017***
	---	(0.2129)	(0.2258)	(0.5066)	(0.2327)
Initial Natural Pine	-1.5277***	0	-0.7903***	-1.6046***	-1.5480***
	(0.2040)	---	(0.2192)	(0.4571)	(0.1875)
Initial Mixed Pine	-1.5854***	-1.8691***	0	-1.2591***	-4.5938***
	(0.2491)	(0.2198)	---	(0.4684)	(0.4655)
Initial Upland Hardwood	-2.3058***	-4.1947***	-1.6123***	0	-0.9976**
	(0.2255)	(0.1974)	(0.2470)	---	(0.4503)
Initial Bottomland Hardwood	-4.5938***	-6.8684***	-3.9383***	-3.7817***	0
	(0.4655)	(0.4937)	(0.4674)	(0.4533)	---
Population Influence Index	-0.1859***	-0.0229**	-0.0325***	-0.0426***	---
	(0.0141)	(0.0106)	(0.0089)	(0.0142)	---
Change of Population Influence Index	0.0524*	0.0770***	0.0225	0.0369	---
	(0.0312)	(0.0238)	(0.0205)	(0.0297)	---
Slope	-0.0369***	-0.0186***	-0.0149***	-0.0512***	---
	(0.0034)	(0.0025)	(0.0019)	(0.0054)	---
Soil Hydricity	-0.2640	0.6008***	0.9255***	2.3828***	---
	(0.1721)	(0.1369)	(0.1168)	(0.0992)	---
Piedmont	-0.5691***	-0.2848***	-0.2755***	-0.1678**	---
	(0.0526)	(0.0492)	(0.0419)	(0.0726)	---
Mountains and Plateau	-1.6115***	-0.6300***	-0.6544***	-0.4658***	---
	(0.1047)	(0.0945)	(0.0680)	(0.1625)	---
Mississippi Delta	-0.3523**	0.4486**	0.0075	0.9537***	---
	(0.1580)	(0.1331)	(0.1259)	(0.1658)	---
Log(re-measurement period)	0.7862***	0.3778***	0.0972	-0.5450**	---
	(0.1130)	(0.0940)	(0.1213)	(0.2245)	---
Earning Profits	**Mean of Gross Return**	0.0002			
		(0.0001)			
Number of observation	40459				
Log-likelihood	-30576.95				
Preudo R^2	0.57				

*** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level

The significant land use transition terms and forest type conversion terms indicate that there are dynamics among different land uses and forest types. Forest lands are more likely to convert from pasture lands, and to convert to developed use. Except for the existed pine plantation, currently planted pines mainly transitioned from natural pine, followed by mixed pine and upland hardwood. Hardwoods prefer to transit within hardwoods. They are less likely to convert to softwood forests after harvested.

All other things being equal, lands converted to urban (forest) use are most (least) likely to happen under a greater PII and a greater change of PII. High population pressure leads to a higher probability of forest type change converted to hardwoods. And the probability of pine plantation converted from other type decreases as PII increases. High slope and productive soil increase the probability of lands under or converted to forest use compared to land use alternatives in developed purpose. While the same condition causes a lower transition probability of forest lands for pine plantation. Forests under different geographical regions have different transition preference. Basically, forests in coastal plain have higher probabilities for planted pine, followed by Mississippi Delta, Piedmont, and Mountains and Plateau.

4. Land Use and Forest Type Projections

Based on the estimation results and the method described in section 2, we start our land use simulation from 1997 to 2047 in decades. We could not use land use data between 1997 and 2007 due to data unavailability of NRI. While the land use simulation results for 2007 with assumed change rates of economic return and population influence index indicates a 2.10 percent (3.71 million acres) decrease of forest lands from 1997 to 2007, which is 0.3 percentage overestimate of the decrease compared to FIA statistics (1.8 percentage decrease in FIA). For the ten-year interval simulation from 2007 to 2047, forests increase by 0.13 percent during 2007-2017, then presents an increasing decrease trend with rate of 0.42 percent, 0.77 percent, and 1.11 percent in every decade, where the total decrease of the study period is 4.24 percent.

Table 16 presents the region aggregate land area projected for each forest type after adjusted by projection of forest land areas in the first stage from 1997 to 2047. During this period, pine plantations increase by 57.77 percent, but natural pine, mixed pine-hardwood, bottomland hardwood, and upland hardwood decrease 30.30 percent, 22.74 percent, 17.63 percent and 5.20 percent, respectively. Figures 4-8 display the simulated percentage change of each forest type by county from 2007 to 2047. At the state level, pine plantations will increase a large amount in Alabama, Mississippi, and Louisiana, mainly caused by dramatic conversion from natural pine. A high increase of natural pine is projected in the mountain area and western Arkansas. The common use for this region is farmland; a small amount increase in pine plantation will bring a high percentage change. Bottomland hardwoods highly increase in coastal area. The influences of geographical situation on the distribution of forest type can be seen from these figures.

Table 16. Projections of the areas of private timberland in the South by forest type between 1997 and 2047, million hectares

	1997	**2007**	**2017**	**2027**	**2037**	**2047**	**Change (1997-2047)**
Pine plantation	10.2	13.7	15.1	15.9	16.2	16.1	57.77%
Natural pine	10.8	10.2	9.1	8.5	8.0	7.6	-30.30%
Mixed-pine hardwood	10.1	9.1	9.1	8.8	8.3	7.8	-22.74%
Bottomland hardwood	10.4	9.2	8.9	8.7	8.5	8.6	-17.63%
Upland hardwood	24.0	22.1	22.1	22.2	22.5	22.7	-5.20%
Total forest	65.6	64.2	64.3	64.0	63.5	62.8	-4.21%

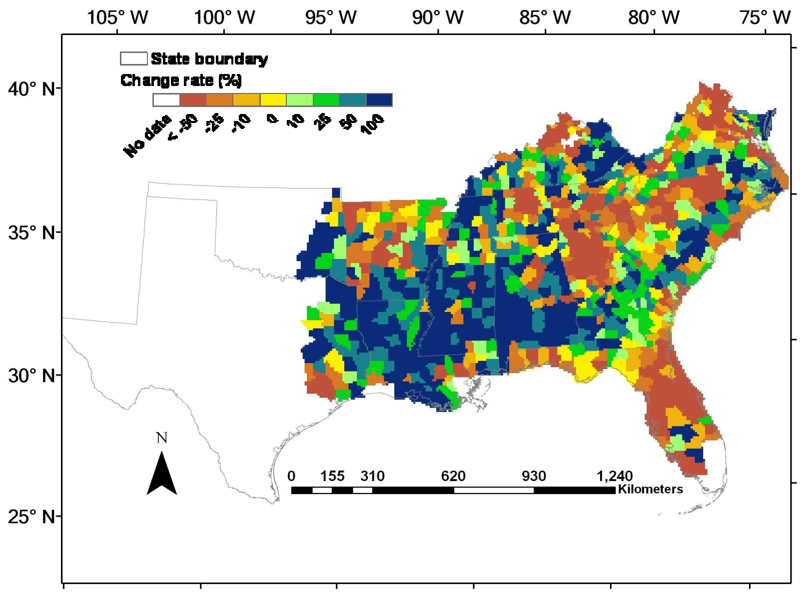

Figure 4. Simulated percentage change of private pine plantations between 2007 and 2047

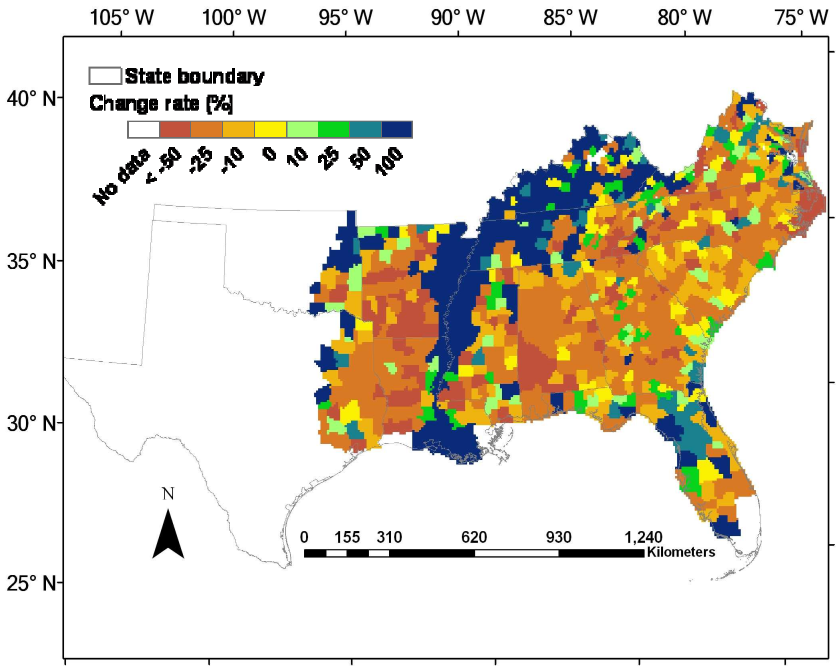

Figure 5. Simulated percentage change of natural pine between 2007 and 2047.

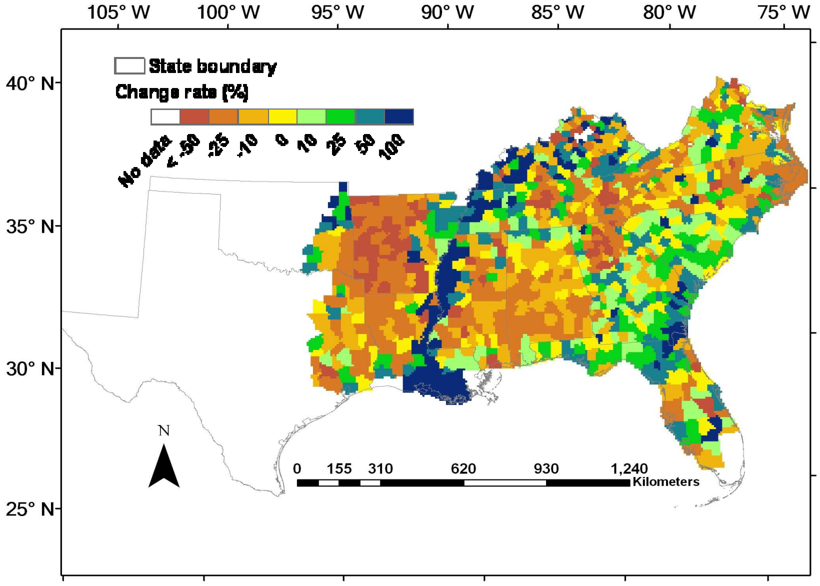

Figure 6. Simulated percentage change of mixed pine hardwood between 2007 and 2047

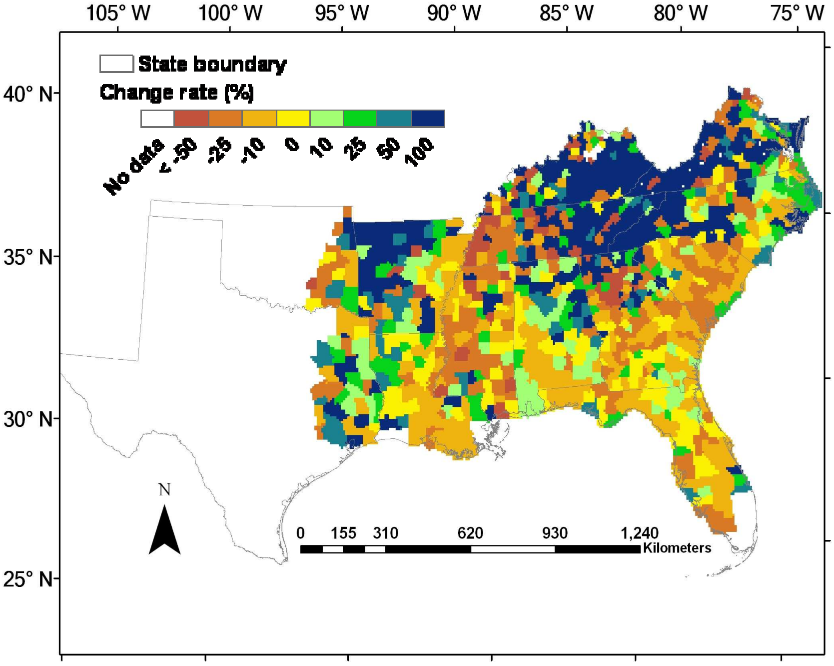

Figure 7. Simulated percentage change of upland hardwood between 2007 and 2047

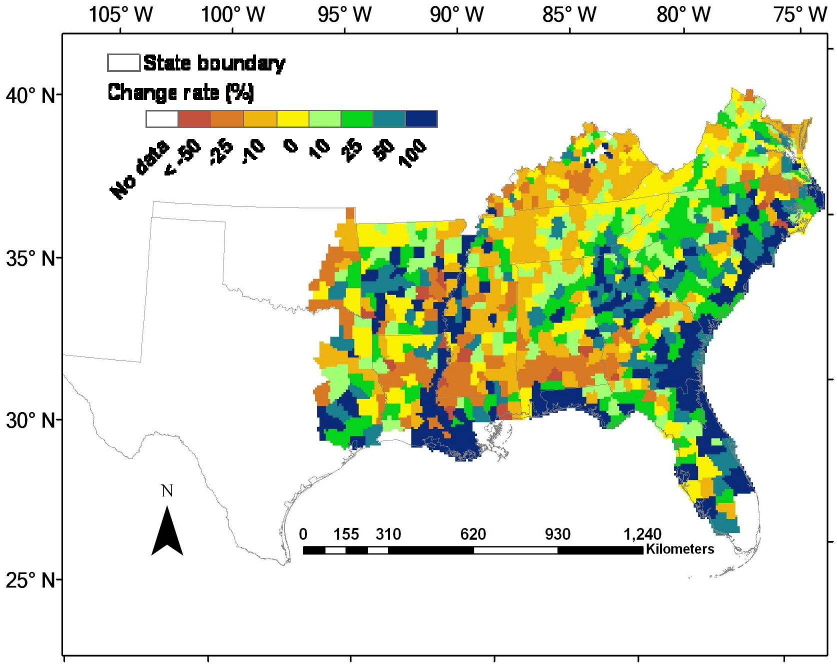

Figure 8. Simulated percentage change of bottomland hardwood between 2007 and 2047

5. Carbon Consequences from Forest Inventory Projection

This section quantifies the approximate contribution of the forestry sector to the region's carbon balance. Our goal to compare the influence of forest type changes on carbon emission allows us to not to account for long-term effects of prior land-use changes on soil carbon, which means that soil carbon sequestrated by different land use categories other than forests in 1997 or by land-use changes from or to forest in the following decades is not considered. We first estimate the growing-stock volume of each forest cover type under the initial and the projected forest type distributions in each period, and then calculate the forest ecosystem and harvested carbon using the standard estimates for forest types from Smith et al. (2006). By comparing the differences of carbon sequestration under the scenario of the initial and the projected forest type distribution, we examine how forest type changes contribute to carbon emissions in forest sector.

As in Sohngen and Brown (2006), we assume that rotation age for all forest types are 40 years. The harvesting is assumed to occur at fixed rates through the projection period, which is 100 percent for pine plantation and 25 percent for natural pine stands above 40 years old, and 11 percent of the hardwood stands above 40 years in each decade. The initial age class distribution for each forest type is from USDA FIA (2003). We adjust the age of standing tree in each plot to the age in 1997, and adjust the unit growing-stock volume to 1997 volume based on the growth rate between the remeasurement years under each age interval. With the state mean growing stock volume of each forest type by age, we modify the standard estimate table including the mean volume and mean carbon density in carbon pools in Southeast and South Central as defined in Smith et al. (2006). Then we calculate the carbon stocks for different forest types on forest land with the modified defaults and the projected forest area of each forest type under different ages. The aggregate carbon stock for a specific forest type in each decade is the sum of carbon stocks of that certain type under all ages. For example, total carbon stock for pine plantation in 2007 is the sum of the stocks of pine plantation from age 1 until the oldest.

Following Smith et al. (2006), carbon stocks in forest products include four dispositions. Carbon in use, carbon in landfills, carbon emitted with energy recapture, and carbon emitted without energy recapture. We convert growing-stock volume to carbon mass in these four categories based on the factors of calculating carbon in growing-stock volume under different region and different forest type group provided by Table 4 in Smith et al. (2006), and then convert carbon mass in growing-stock volume to carbon in industrial roundwood according to factors provided by Table 5 in Smith et al. (2006). With the calculated carbon stocks in industrial roundwood (including softwood saw log carbon, softwood pulpwood carbon, hardwood saw log carbon, hardwood pulpwood carbon), and the average disposition patterns of carbon as fractions in industrial roundwood in Table 6 in Smith et al. (2006), the carbon in forest products in use at a specific year can be computed (see example 4 in Smith et al. (2006)). The cumulative carbon in each disposition in the calculated year is the sum of the carbon stocks in forests of all ages at the year.

Table 17 presents the cumulative carbon stock for the five cited forest types under the scenarios that the transitions among forest types exist or not. Panels A, B, and C present the projected forest areas for each forest type, the cumulative carbon stocks in forests only, and total carbon stocks in forests, forest products, and landfills, respectively. We adjust forestland areas for the one without transition based on land use projections in the first stage to make the total forestlands in each decade equal to the areas with transition. From Table 17, the carbon stock in forests only for scenario that no forests types transition exists but only within self-regeneration and self-harvest increases by 8.39 percent, from 11.3 Gg (1Gg $=10^{15}$g) to 12.2 Gg, while the carbon stock is projected to decline by 0.6 Gg (4.90 percent) over the 50-year period when forest type conversions are allowed. The associated 1.5 Gg ton reduction of carbon stock in forests is mainly caused by the loss of carbon stocks from natural pine and other hardwood species, and the conversion of these stocks to pine plantation. While this reduction can be made up by increases in total carbon stocks of forests and forest products. The conversion among forest types brings in a 0.5 Gg increases of total carbon stock including standing forests, forest products, and landfills.

We also project carbon emissions from energy recapture to estimate carbon fluxes in the forest within forest products. These emissions will reduce carbon stocks by releasing carbon to the atmosphere. On the other side, these emissions would offset emissions from using other sources of fuel to produce the same energy, and are used to measure how much fuel is needed to

Table 17. Forest area inventories and carbon stocks (Billion tonnes carbon by the year given; 1 tonne=1 Mg=10^6 g; 1 Gg=10^9 Mg)

	Forest cover type without transition							**Forest cover type with transition**						
	1997	2007	2017	2027	2037	2047	Change (1997-2047)	1997	2007	2017	2027	2037	2047	Change (1997-2047)
Panel A: Forestland area (Million hectares)														
Pine plantation	10.2	10.0	10.0	10.0	9.9	9.8	-4.22%	10.2	13.7	15.1	15.9	16.2	16.1	57.77%
Natural pine	10.8	10.6	10.6	10.6	10.5	10.4	-4.22%	10.8	10.2	9.1	8.5	8.0	7.6	-30.30%
Mixed-pine hardwood	10.1	9.9	9.9	9.9	9.8	9.7	-4.22%	10.1	9.1	9.1	8.8	8.3	7.8	-22.74%
Bottomland hardwood	10.4	10.2	10.2	10.2	10.1	10.0	-4.22%	10.4	9.2	8.9	8.7	8.5	8.6	-17.63%
Upland hardwood	24.0	23.5	23.5	23.4	23.2	23.0	-4.22%	24.0	22.1	22.1	22.2	22.5	22.7	-5.20%
Total forest	65.6	64.2	64.3	64.0	63.5	62.8	-4.22%	65.6	64.2	64.3	64.0	63.5	62.8	-4.21%
Panel B: Carbon stocks in forest only (Gg carbon)														
Pine plantation	1.6	1.8	1.8	1.6	1.6	1.8	14.68%	1.58	2.38	2.37	2.36	2.38	2.74	73.23%
Natural pine	1.9	1.9	1.9	1.9	1.9	1.9	1.39%	1.86	1.76	1.57	1.44	1.34	1.26	-32.05%
Mixed-pine hardwood	1.7	1.8	1.8	1.9	1.9	1.9	11.64%	1.70	1.58	1.59	1.51	1.39	1.27	-25.07%
Bottomland hardwood	2.1	2.2	2.2	2.2	2.2	2.2	5.83%	2.12	1.85	1.80	1.76	1.74	1.76	-16.91%
Upland hardwood	4.0	4.1	4.2	4.3	4.3	4.4	9.12%	4.00	3.73	3.99	3.66	3.68	3.67	-8.29%
Total forest	11.3	11.8	12.0	11.8	11.9	12.2	8.39%	11.3	11.3	11.3	10.7	10.5	10.7	-4.90%
Panel C: Carbon stock in forests, forest products and landfills (Gg carbon)														
Pine plantation	1.6	2.0	2.2	3.1	3.2	3.1	93.09%	1.6	3.5	4.5	4.9	4.7	6.1	283.12%
Natural pine	1.9	2.8	2.6	2.5	2.6	2.4	31.62%	1.9	2.6	2.2	1.9	1.9	1.7	-9.27%
Mixed-pine hardwood	1.7	2.0	2.0	2.1	2.2	2.2	28.12%	1.7	1.8	1.8	1.7	1.6	1.5	-12.51%
Bottomland hardwood	2.1	2.4	2.4	2.4	2.4	2.4	13.05%	2.1	2.3	2.1	2.0	2.0	2.1	-2.51%
Upland hardwood	4.0	4.8	4.8	4.9	5.0	5.0	25.71%	4.0	4.4	4.5	4.2	4.3	4.3	7.65%
Total forest	11.3	14.0	14.1	15.0	15.3	15.1	34.14%	11.3	14.7	15.0	14.8	14.5	15.6	38.65%
Energy emission	--	1.4	1.8	3.5	3.9	2.3	64.29%	--	1.87	2.79	2.94	3.13	3.04	62.57%
Total carbon stock	11.3	12.7	12.3	11.5	11.5	12.8		11.3	12.8	12.2	11.9	11.4	12.6	

generate the same power. The last row in panel C presents cumulative carbon emission from using forest by-products in the energy stream in each decade. In general, energy emissions from forest type transition are higher than that from non-transition except two periods, 2017-2027, and 2027-2037. Total carbon stock from all cited factors indicates that there is not too much difference between these two kinds of forest type distributions for the environmental perspective.

6. Conclusions and Discussions

Land use, land use changes and forest type changes have environmental impacts. Policy analysts try to find appropriate policy to maximize social benefits and to balance landowners' economic goals. In this study, we project future forest type distribution under land use and land use change dynamics through a two-stage discrete choice model, and explore the influence of this change from the side of carbon sequestrations for the forest sector.

Our results indicate that the increasing trend of pine plantation adoption and decrease of other forest types will continue in the coming half century. Private pine plantations will increase by about 58 percent, from 10.2 million hectares in 1997 to 16.1 million hectares in 2047, and natural pine, mixed hardwoods, bottomland hardwoods, and upland hardwoods will decrease by 30 percent, 23 percent, 18 percent, and 5 percent, respectively, in the study period. Economic returns and population growth are highly correlated to the conversion. Assuming economic returns growing at their historical growth rates and population density changing as United States Census Bureau projected, the transition among forest types results in 1.23 Gg Carbon (C) decrease of carbon stocks in standing forests, and 0.5 Gg C increase of carbon stocks on both forests and forest products in 2047 than that without forest cover type change. Difference of total amounts of carbon storage including sequestrations in standing forests, forest products, landfills, and energy emission is 0.2 Gg Carbon (C). Thus, there is no obvious evidence to say that the expansion of pine plantations and shrinkage of other forest types could produce severe environmental problems caused by carbon emissions under these two proposed forest management strategies.

Our result indicates the potential effects of converting hardwoods or natural pine to intensive pine plantations. However, there might be some factors mitigating this forest type change. First, we assume that the growth rates of economic returns for each forest type follow their historical records. This assumption may not hold for a 40-year projection. In fact, economic profit is the primary factor when private landowners make their land or forest management decisions, and there have already been some public policies such as cost-sharing programs, government subsidies, carbon credits and so on to encourage private landowners to make their land management strategies consistent with climate change mitigation goals. Any particular program could redistribute landowners' returns, and influence their future performance.

Second, there is more than one type of atmospheric greenhouse gases. Only considering carbon effects produced by forest type changes resulted in a somewhat weak conclusion that the expansion of pine plantations and shrinkage of other forest cover types would not produce severe environmental problems caused by carbon emissions. When under an intensive forest management strategy, the impacts of nitrous oxide (N_2O) from fertilization should be considered.

Third, we set a fixed rotation age and fixed harvested proportion when for harvest decisions. Previous studies indicate that carbon sequestration will increase as the rotation length increases (Chen 2010). Changing rotation length might bring a new dimension to this study.

Finally, the call for renewable energy makes the idea of converting woody biomass to bio-energy more appealing. The increase of pine plantation could mitigate forest fragmentation, augment timber supplies and meet the demand of bio-energy production. This would potentially enhance the conversion of hardwoods to softwoods. We have not adjusted the analysis if bio-energy incentives are involved.

Further studies could focus on sensitivity and policy analysis, referring to the change of growth rates of economic returns, the change of rotation length, government subsidies for hardwood preservation, and public policies on motivating bio-energy production.

Chapter 4. Impacts of Current Use Property Tax Policy on Land Use Change Decisions in North Georgia

1. Introduction

Property tax is the primary revenue source for local government and for most public school systems in the United States. It is an ad valorem tax levied on an individual’s real properties. A property tax levied on lands and items that are permanently built or attached to the land, is essentially a real property tax, based on the property’s fair market value. Due to economic pressures from economic development and population growth, fair market value of rural lands often exceeds the capitalized income-producing capability of rural land uses, making individual landowners endure a higher tax burden, and influencing their land management and use decisions (Hickman 1982). It has been found that property taxes have important impacts on the management of private forest and farm lands (Hibbard et al. 2000). Property tax deductions have been ranked as the top preference for government-sponsored programs for nonindustrial private forest landowners in the Midwest and as the second top in the Southeast (Hibbard et al. 2000, Megalos and Cubbage 2000). It is considered to be indirectly or directly related to some other public policies, and an effective way to redistribute income and wealth of landowners and the society.

Georgia is the ninth most populous state (United States Census Bureau, 2000) and is currently one of the fastest growing states in the U.S. From 2007 to 2008, 14 of Georgia's counties ranked among the nation's 100 fastest-growing counties, second only to Texas. In the past few decades, Georgia has experienced significant land use changes in rural and developed uses. Figure 1 shows trends of land uses in rural and developed purposes from 1945 to 2002−a 9.60 percent decrease in rural lands and a 564.92 percent increase in developed lands. From 1992 to 1997, Georgia was second among states losing cropland, forests, and other types of rural open space to urban development in the United States (Bell et al. 2006). Changes in land use have produced significant economic and environmental effects such as traffic congestion, increases in property tax rates, lower air and water quality, and loss of biodiversity.

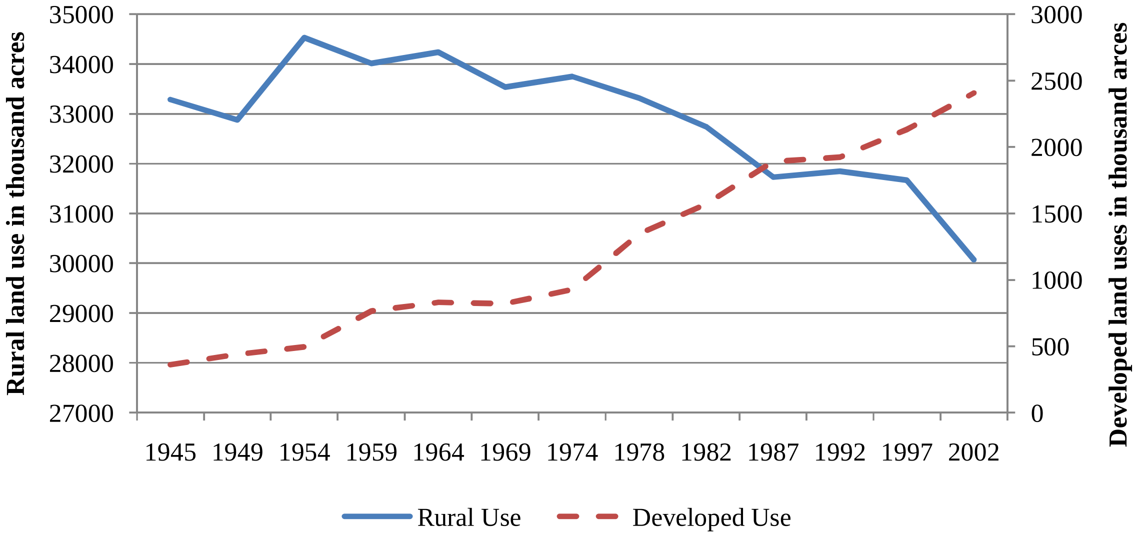

Figure 9. Rural and development land uses in Georgia between 1945 and 2002.

To find out how property tax policy influences private landowners' land use and land use transition decisions, we pursue a series of discrete choice (DC) analyses based on the first-order Markov transition probabilities in five major land use categories using the panel data of USDA Natural Resources Inventory (NRI) sample plots. In conjunction with classic land use theory, Markov transition probabilities are specified as functions of land-use net returns, property tax levied on different land use types, and land quality measures. Additionally, we evaluate the relative importance of CUV property tax policy on land use and land use change decisions through simulation scenarios based on DC model estimates.

The remainder of this chapter is divided into six sections. Section 2 reviews literature on land use and land use studies from the standpoint of public policy. Section 3 describes our theoretical and empirical model. Section 4 documents data sources. Section 5 presents estimation results of parameters, probabilities and elasticities and the impacts of CUV property tax policy. Section 6 provides concluding comments.

2. Literature Review of Studies on Land Use Public policies

The goals of public policy on land use and land use changes are concerned with the public's interest in sustainably managing private land resources through a complex mix of information, education, regulation, technical assistance, and fiscal and tax incentive programs. Land use public policies aim to narrow the divergence between privately and socially optimal land allocations by modifying the economic incentives faced by private landowners. Programs such as Conservation Reserve Program (CRP), the Environmental Quality Incentive Program (EQIP), Wetland Reserve Program (WRP), tax incentives, cost sharing, easements, and certification programs are established in order to slow down conversion of rural lands to more intensive uses, encourage reforestation and sustainable forest management, and mitigate negative environmental externalities (Lubowski 2002, York et al. 2005). They could affect land use decisions in a variety of ways.

Government-funded federal programs and infrastructure developments provide policy support for land use reservation and land use transition. The Conservation Reserve Program (CRP) was created to reduce soil erosion through the retirement of marginal agricultural lands and conversion to permanent cover (Osborn et al. 1995, Plantinga et al. 2001, Schatzki 2003, Carmen-Flores and Irwin 2004). The Wetland Reserve Program (WRP) was designed to protect existing wetlands or restore converted wetlands, and most protection policies are designed to slow conversion from agricultural use (Parker and Kramer. 1995). Flood control projects were established to enhance the economic viability of agricultural production in selected areas (Stavins and Jaffe 1990). The Environmental Quality Incentive Program (EQIP) could promote agricultural production and environmental quality by providing payments to eligible lands subjected to National Resource Conservation Service (NRCS) technical standard of up to 75 percent or 90 percent of the incurred costs and income foregone due to the use of certain conservation practices and activities.

Government price supports could affect the extensive margins by altering the relative return between commodities that are supported and those that are not, but it has been criticized for encouraging more intensive farming practices with the externality of increasing chemical use and pollution (Just and Antle 1990, Wu and Segerson 1995, Plantinga 1996). Tax codes may fit certain land uses depending on their treatment of associated investments, and tax policies could be held accountable for a significant fraction of investments in center pivot systems (Just and Antle 1990, Wu and Segerson 1995, Plantinga 1996). Crop insurance is used to promote crop cultivation in relatively risky places by reducing the risk in crop production (Wu 1999, Goodwin et al. 2004). Zoning policies of specific land use areas could influence land price by setting restricted or unrestricted use (Vaillancourt and Monty 1985, Hite et al. 2003).

The primary state mechanism which is used to encourage rural landowners to retain lands in traditional uses is property tax relief in the form of preferential assessments with use value assessment methodology (Anderson 2003). In the United States, 19 states use pure preferential assessment programs; 26 states use preferential assessment with deferred taxation, and 5 states practice preferential assessment with restrictive agreements and deferred tax (Morris 1998).

By conducting a survey of the Current Use Valuation Assessment (CUVA) program implementation in Georgia, Pan (2005) finds that the program is effectively implemented, but it is not considered to be a significant factor impacting covenanters' land use decisions. Applying a logistic analysis of attrition on historical property tax records, Snider (2002) examines the effects of North Carolina's use-value property tax on landowners' decisions to either subdivide or sell their property, or whether to withdraw from the use-value program while retaining ownership of the property. Polyakov and Zhang (2008) find that without current use valuation in Louisiana, property taxes on forestry and agricultural lands would have doubled and tripled respectively, leading to an additional 2.1% loss of agricultural lands, an additional 1.3% gain in forestry, and an additional 0.2% gain of developed lands over the years 1992 to 1997. Meng and Zhang (2011) explore a study on how the general property tax policy influence private landowner's land use management decisions in Georgia and they find property taxes have significantly negative impacts on private landowners' land use change decisions, but these impacts are relatively small. At the national-level, Morris (1998) examines the effects of preferential taxation on the retention of lands in farming using data from 3,000 counties in 47 states, and concludes that about 10% more farmlands are retained in counties with use-value taxation than those without.

3. Methodology

In terms of microeconomic theory, landowners choose specific land use for each parcel among a set of alternative uses in order to maximize the present discounted value of the stream of expected future net benefits. To describe the decision making pattern of such behavior, we make some assumptions before describing the theoretical model.

Firstly, we assume that each parcel of land is of homogeneous quality, and in a unique use. Secondly, landowners are risk-neutral, so they will keep or convert all lands to a single use when facing land use decisions. Thirdly, land-use returns are linear in the quantity of land, and the size of parcel will not affect the relative profitability of different land-use options. Finally, though it is not realistic, due to the unknown spatial information on each sample plot, spatial externalities are assumed to not exist among parcels, and the land-use decision for one parcel does not depend on the choices made for other parcels.

Given the above assumptions and following Lubowski (2002) and Polyakov and Zhang (2008), for a parcel of land n in use i at time t, a profit-maximizing landowner will choose use j at time $t+1$ that yields the highest expected present discounted value of an infinite stream of net returns minus conversion costs. Let R_{it} or R_{jt} be the instantaneous net benefits from any acre of land in use i or j at time t, respectively, and $C_{jit}(a_{jit})$ be the total cost of converting a acres of land from use i to use j at time t, then land use conversion from i to j happens if:

$$R_{jt} - C_{jit}\left(a_{jit}\right) > R_{it} \tag{16}$$

When faced with more than one potential use j, the landowner will choose the alternative with the highest positive value of $R_{jt} - C_{jit}\left(a_{jit}\right) - R_{it}$.

We define a utility function of converting parcel n from land use i to j as:

$$U_{n(t+1)j|i} = R_{ntj} - R_{nti} - C_{ntj|i} = V_{n(t+1)j|\,i} + \varepsilon_{nti} \tag{17}$$

Equation (16) captures both observable and unobservable factors that might affect the landowners' returns and conversion costs to different land uses. $V_{n(t+1)j|\,i}$ is a representative utility that contains factors of observable attributes of initial and final land uses x_{nti} and x_{ntj}, and observable attributes of parcels $\boldsymbol{S}_{nt}$ that are related to either returns or conversion costs. The random expression ε_{nti} is used to capture unobservable or non-quantitative factors that could affect land use conversion decisions, assumed to be independently and identically distributed

(IID), and follow the type I extreme value distribution. Land use change happens when $U_{n(t+1)j|i}>0$, and land initial use in i will convert to j instead of k when

$$U_{n(t+1)j|\,i} > U_{n(t+1)k|\,i} \tag{18}$$

where

$$U_{n(t+1)j|\,i} = V_{n(t+1)j|\,i} + \varepsilon_{nti}$$

$$U_{n(t+1)k|\,i} = V_{n(t+1)k|\,i} + \varepsilon_{ntk} \qquad (j \neq k)$$

The probability of converting land use j to land use i is:

$$P_{n(t+1)j|i} = prob\big(U_{n(t+1)j|\,i} > U_{n(t+1)k|\,i}\big)$$

$$= prob(V_{n(t+1)j|\,i} + \varepsilon_{ntj} > V_{n(t+1)k|\,i} + \varepsilon_{ntk}) \tag{19}$$

Based on McFadden's (1973) conditional logit (CL) model, and following Polyakov and Zhang (2008), the empirical model is specified as

$$P_{n(t+1)j|i} = \frac{\exp\,(\alpha_{ij}+\tau_{tj}+\boldsymbol{\beta}'\boldsymbol{X}_{ntj}-\boldsymbol{\beta}'\boldsymbol{X}_{nti}+\boldsymbol{\gamma}_j'\boldsymbol{S}_{nt}-\boldsymbol{\gamma}_i'\boldsymbol{S}_{nt})}{\sum_{k=1}^{J}\exp\,(\alpha_{ik}+\tau_{tk}+\boldsymbol{\beta}'\boldsymbol{X}_{ntk}-\boldsymbol{\beta}'\boldsymbol{X}_{nti}+\boldsymbol{\gamma}_k'\boldsymbol{S}_{nt}-\boldsymbol{\gamma}_i'\boldsymbol{S}_{nt})} \tag{20}$$

where α_{ij} are the conversion-specific constants equal to 0 $\forall\, i = j$, τ_{tj} are fixed year effects equal to 0 for τ_{Ti} and τ_{tJ}, $\boldsymbol{\beta}$ is a vector of coefficients of the attributes characterizing alternative land uses, and γ_j is a vector of coefficients of the plot-specific attributes for land use j ($\gamma_J = 0$ to remove an indeterminacy in the model). Components of representative utility specific to initial land use ($\boldsymbol{\beta}'\boldsymbol{X}_{nti}$ and $\boldsymbol{\gamma}_i'\boldsymbol{S}_{nt}$) cancel out due to appearance in both numerator and denominator. So the final form of the empirical model is

$$P_{n(t+1)j|i} = \frac{\exp\,(\alpha_{ij}+\tau_{tj}+\boldsymbol{\beta}'\boldsymbol{X}_{ntj}+\boldsymbol{\gamma}_j'\boldsymbol{S}_{nt})}{\sum_{k=1}^{J}\exp\,(\alpha_{ik}+\tau_{tk}+\boldsymbol{\beta}'\boldsymbol{X}_{ntk}+\boldsymbol{\gamma}_k'\boldsymbol{S}_{nt})} \tag{21}$$

When the parameters of attributes of alternative land uses are assumed to be random and vary among sample points, the CL model of equation (4-6) can be specified to the random parameters logit (RPL),

$$P_{n(t+1)j|i}(\boldsymbol{\beta}_n) = \frac{\exp(\alpha_{ij}+\tau_{tj}+\boldsymbol{\beta}'\boldsymbol{X}_{ntj}+\boldsymbol{\gamma}_j'\boldsymbol{S}_{nt})}{\sum_{k=1}^{J}\exp(\alpha_{ik}+\tau_{tk}+\boldsymbol{\beta}'\boldsymbol{X}_{ntk}+\boldsymbol{\gamma}_k'\boldsymbol{S}_{nt})} \tag{22}$$

The inclusion of the random parameter in the empirical model allows us to measure implicitly some unobservable point-level effects, and helps us lessen deviations from using county-level socioeconomic factors rather than the approximate point-level values due to data information limitation (Lewis et al. 2011).

4. Data

According to the classic land use theory developed by David Ricardo and Johann von Thünen, land use patterns are determined by relative land rents to alternative land use, land quality and location. Thus, land use decisions should be based on quantified assessments of potential and development possibilities of the land resources, taking into account the biophysical, environmental, public policy, and socio-economic factors.

Land use data for Georgia were derived from National Resources Inventory (NRI). It is a longitudinal panel survey providing information on land use, land characteristics, and conservation practices for about 800,000 sample sites of nonfederal US lands every five years from 1982 to 1997. After 2001, data has been collected every year with a slightly less than 25 percent of these same sample sites (NRI 2001), which made our study period limit to 1982-1997.

The NRI dataset for Georgia contains 35,972 points with a total area of 37.4 million acres. Land use in NRI is classified into twelve broads, which include three types of federal lands and nine types of non-federal ones. [11] In this study, six categories of non-federal lands are chosen to represent five land use types: croplands, pasture, forests, lands in Conservation Reserve

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[11] Federal lands are small water areas, census water and federal land. The nine kinds of nonfederal lands are: cultivated cropland, noncultivated cropland, pastureland, rangeland, forestland, other rural land, urban and built-up land, rural transportation land, and conservation reserve program (CRP) land.

Program (CRP) and developed lands. Data were taken at the beginning and the end of each of the five-year periods from 1987 to 1997, representing 21,384 sample sites, covering 31.1 million acres. The reason we exclude points representing other rural lands and rural transportation is because they account for only a small percentage of the total lands and land use transitions of these types are not mainly driven by market forces (Polyakov and Zhang 2008). Lands in CRP are considered to be an independent type due to their relatively larger land use transitions from other major land use compared to changes among other land-use categories. Table 18 shows the flow of lands between the different major land-use categories considered in this study at five year increments from 1982 to 1997. Lands in CRP from 1982 to 1987 do not exist, because lands

Table 18. Changes in major non-federal land uses between 1982 and 1997 from National Resources Inventory (NRI) in Georgia (Thousand acres)

Initial Land Use	**Period**	**Final Land Use**					
		Crop	**Pasture**	**Forest**	**CRP**	**Urban**	**Total**
Crop	1982-87	5670.70	247.70	323.20	267.30	48.20	6557.10
	1987-92	4994.40	298.00	273.60	260.90	62.50	5889.40
	1992-97	4433.30	260.70	311.30	44.80	88.80	5138.90
Pasture	1982-87	106.70	2563.30	197.50	24.00	33.00	2924.50
	1987-92	105.40	2604.00	124.60	26.70	53.10	2913.80
	1992-97	181.10	2431.70	278.50	0.00	112.50	3003.80
CRP	1987-92	-	-	-	301.20	-	301.20
	1992-97	1.10	5.30	56.60	536.70	0.40	600.10
Forest	1982-87	112.90	101.40	21471.00	9.90	183.20	21878.40
	1987-92	63.50	110.90	21420.00	11.50	358.30	21964.20
	1992-97	128.30	146.00	20865.00	11.90	623.20	21774.40
Urban	1982-87	0.20	1.50	3.00	0.00	2361.70	2366.40
	1987-92	0.10	0.90	2.70	0.00	2624.60	2628.30
	1992-97	0.90	1.00	5.40	0.00	3098.10	3105.40
Total	1982-87	5890.50	2913.90	21994.70	301.20	2626.10	33726.40
	1987-92	5163.40	3013.80	21820.90	600.30	3098.50	33696.90
	1992-97	4744.70	2844.70	21516.80	593.40	3923.00	33622.60

in this program can only be obtained from 1986, when CRP programs were first established and contacts were signed by landowners.

A land quality dummy is created in the same way as described in chapter 2 for controlling land heterogeneity and to capture potential conversion costs that cannot account for by the explanatory variable. LCC dummy equals 0 for LCC I to IV, 1 otherwise. County-level net returns for major land use alternatives are collected based on Lubowski (2002). It is used as a proxy for plot-level economic return due to limited information of confidentially designed NRI sample sites. Additionally, population density is used as an explanatory variable to see how the demographics influence land use change decisions.

Property tax data for different land uses are obtained from the Georgia Department of Revenue. Land records are classified into ordinary agriculture use, preferential use, conservation use, and lands in industrial, commercial, residential and other kinds of non-rural uses for tax purposes. All properties are assessed by their fair market values and 40 percent of the values are taken for tax purposes except for lands in preferential and conversion use. The amount of deducted taxes in these two programs are provided by the "tax consolidate summary". As described by the state's official documents, property taxes collected for preferential use are based on 30 percent of the fair market value, while the tax collected for conservation use is based on current use value rather than fair market value. Under this program, landowners can have their ad valorem taxes lowered by 90 percent or more, which represents significant tax relief.

Property taxes can be calculated by using the taxable values of each land category, the nominal mileage rates and acreages information, excluded qualified exemptions for each land use type. Rural tax provided by the Georgia Department of Revenue is the sum of crop, pasture and forest taxes. There is not any explicit way to split the rural tax into crop, pasture and forest due to limited data information from both the state and county property tax assessor's office. Thus we separate the taxes into three particular types based on the assessed land values of each type. Firstly, we collected farmland value data for croplands and pasture from Department of Agriculture, United States. Forest land values cannot be directly obtained from any available source. We took 27 percent of the farmland value as forest land value according to Binkley et al. (1998). Secondly, we calculated the proportion of land values for each land use type by using per acre value of each land type and the corresponding acreages. Thirdly, we use this proportion to separate the totally collected property tax from Georgia Department of revenue into three specific kinds, and then calculate property tax per acre for each category based on the property taxes value and the detailed acreage information.

Property taxes for crops, pastures and forests in a preferential use program are 75 percent of the tax of lands in ordinary crops, pastures and forests in terms of the relationship between ordinary agriculture lands and lands under preferential use. Property taxes for conservation use are more complicated. The percentage is calculated based on the exempted tax values and total collected land values. On average, the percentage is 40 percent, which means that property taxes of rural lands under conservation program are levied on 16 percent of the average fair market value. The preferential use program is heavily utilized in the South of Georgia, while, the conservation program is more populous in the North. Both of the programs have a maximum acreage limit of 2,000 acres for each owner, which means that the owner cannot enroll more than a total of two thousand acres of land into the program. The applicant has to be a natural or naturalized citizen. The preferential assessment program requires 80 percent of the owner's income to come from farming, and lands qualified as conservation use program must be used primarily in the production of timber. According to Newman (2000) and Pan (2005), though the two programs are prevailed along the state, they are effective ways on mitigating landowners' property tax burden, not on influencing land use decisions. In this study, we only focus on the CUVA program since it provides greater tax relief than preferential use (comparing 75 percent to 16 percent of the taxes in ordinary agriculture use). Because the CUVA program is dominated in the North, the study area is reduced to 73 counties, which includes 9,577 sample sites, covering 11.22 million acres of whole rural lands (Figure 10).

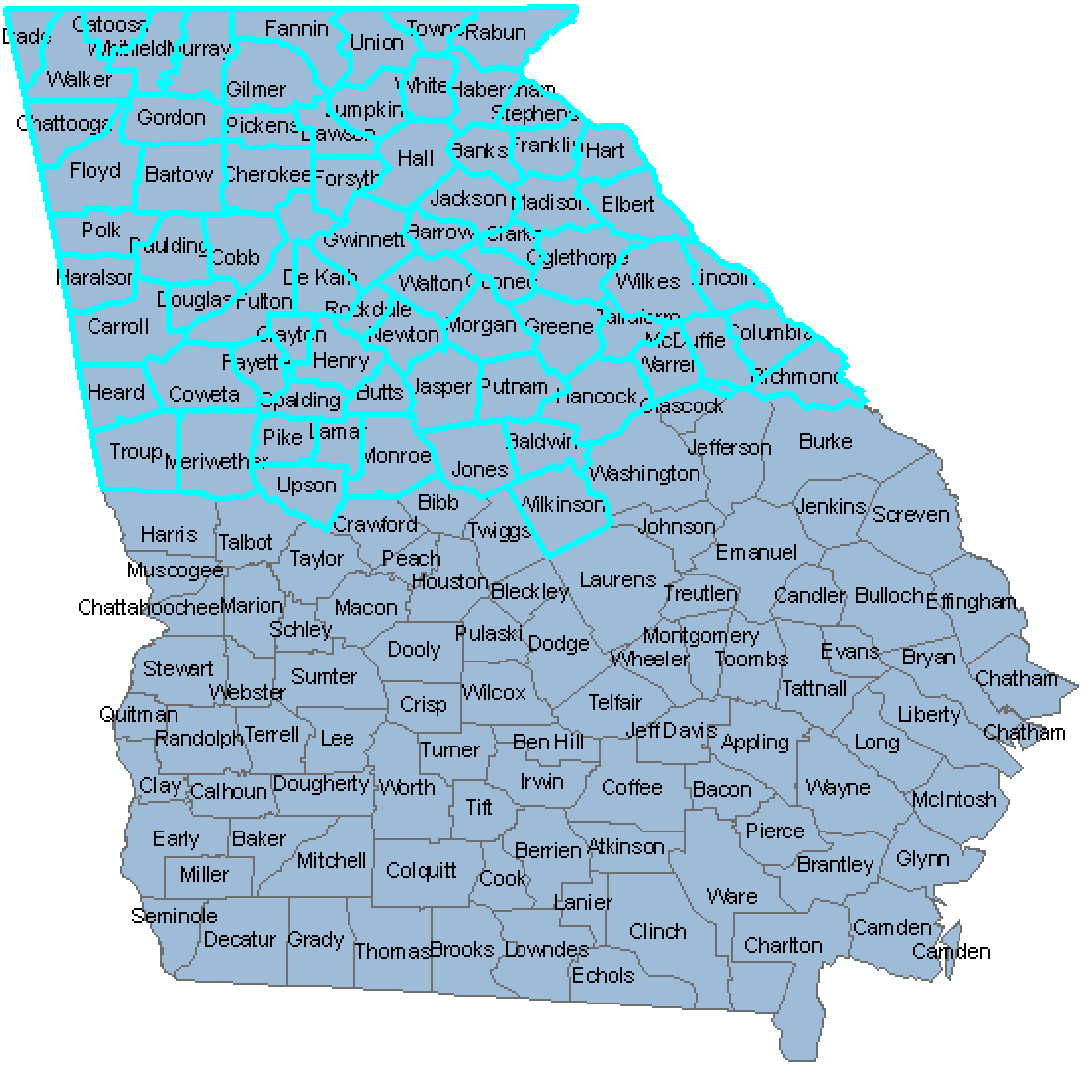

Figure 10. Study area of North Georgia

Due to unknown spatial information of each sample plot, we could not tell which plot was taxed as ordinary agricultural lands, and which is under conservation use program. Therefore, we randomly choose plots whose total acreage is equal to the acres under the conservation use program with a 1 percent deviation. Take Carrol County as an example, in 1997, private forest land in the county is 386.9 thousand acres, and 19.5 thousand acres are under CUVA program. Thus we randomly choose sample plots from all forest plots whose total acreage is 21.45 and 17.55 thousand acres ($19.5+/-19.5\times0.01$) to represent plots under the CUVA program, and leave the extra plots under ordinary forest use. We create random sample sites based on county-level CUVA program information, and randomly combine the chosen plots from the 73 counties to represent all plots under CUVA program. To make this simple, we only examine ten combined random samples. Then we report the estimation results based on the sample whose parameter of property tax approaches to the mean of the parameters of property tax from the ten samples most.

Historical records of property tax date back to 1990. The tax value for a specific year is calculated as the mean of the previous five years data. Property taxes for 1987 are extrapolated using data for 1992 and 1997. The county property tax per acre is used as proxy for plot-level property tax as well. All values in this study are deflated using the 1987 consumer price index (CPI) as the base (*i.e.*, $\text{CPI}_{1987}=100$).

Table 19 presents the summary statistics for the explanatory variables. NRI land use data from 1987 to 1997 are pooled together. Missing values for each variable are replaced by county-average data. After merging county-level data with NRI plot level data, 18,380 plots are generated for use in this study.

Table 19. Description statistics of explanatory variables

Plot-level variables	**Number of plots**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Plot in Land Capability Class 1-4	18380	0.37	0.48	0	1
NRI Sampling Weight	18380	1.21	0.73	0.1	10.2
County-level Variables (in US$ 1987)	**Number of counties**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Return from crop (with gorvenment payment) lands, $/acre	132	6.36	24.98	-86.32	70.02
Return from pasture lands, $/acre	146	-9.21	4.00	-18.12	-4.51
Return from forest lands, $/acre	146	10.94	3.30	4.50	21.85
Return from developed lands, $/acre	146	1720.43	1109.61	612.86	4695.27
Property tax for Croplands, $/acre	146	3.75	10.83	-36.46	34.64
Property tax for Pasture, $/acre	146	2.96	5.67	-29.17	25.48
Property tax for Forest, $/acre	146	1.01	7.56	-14.02	13.86
Property tax for developed lands, $/acre	146	29.05	72.07	-425.79	227.18
Property tax for Croplands (CUV), $/acre	132	1.55	6.61	-14.59	18.86
Property tax for Pasture (CUV), $/acre	146	1.21	8.39	-11.67	13.29
Property tax for Forest (CUV), $/acre	146	0.50	4.35	-5.72	6.79
Population density	146	152.78	245.00	14.58	1620.76

5. Estimation Results

Our dependent variable is the choice of land use in period t at each NRI point. Explanatory variables are lagged in one period with values for period t-1. We model the transition between five major land use categories (crop, pasture, forestry, CRP, and developed) simultaneously, and consider land use transition terms α_{ij} with three initial land uses i (crop, pasture and forestry) and five final uses j in two periods, 1987-1992 and 1992-1997. CRP lands are excluded from initial land use, because the number of parcels converted from CRP to other land is relatively small, and land transition from CRP could happen only during 1992-1997 period, when the first signups began to expire. Developed land use is considered to be irreversible. DC models are estimated using Nlogit 4.0. Scaled NRI expansion factors are created as weights to avoid shrinking the standard error, thus the sum of scaled NRI expansion factors equals the total number of actual observations used in the model (Greene 2002).

5.1. Parameter Estimates

The conditional logit model (CL) is estimated by the maximum likelihood method, and the random parameter logit (RPL) model is estimated using maximum simulated log-likelihood. The coefficients of returns and property taxes are specified as random parameters in the RPL model to account for the variation among parcels since county-level returns and property taxes are used as proxies for parcel-level values. They are specified as log-normal distributions as recommended by Hensher et al. (2005) and 1000 Halton draws instead of random draws are performed to provide better estimates.

Table 20 reports the complete set of parameter estimates for the CL and RPL models. The estimation results indicate a good model fit and the estimated parameters are generally highly significant with expected signs. Likelihood ratio tests in both models reject the hypothesis that all of the coefficients are simultaneously equal to zero at the 0.01 level, and rejection of null hypothesis from likelihood ratio tests between the CL and RPL models proved that the RPL model is preferred over the CL model.[12] The coefficients and standard errors for fixed parameters in the CL and RPL models are similar, and the statistically significant standard error of property tax derived from the RPL model indicates that the influence of property tax are varied among parcels.

The conversion-specific constants α_{ij} are statistically significant at the 0.01 level with the expected negative signs. Since lands remaining in their initial rural uses α_{ii} account for high probabilities of the corresponding transitions, restricting α_{ii} to zeros leads to negative estimates of land transition terms. Estimates of α_{ij} determine land use transition probabilities in the first-order Markov transition matrix. A high value of α_{ij} indicates a high transition probability from

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[12] The value of likelihood ratio statistic is $(-5346.64) - (-5338.30) = 8.34$ with 95% critical value of $\chi^2_2 = 5.99$.

Table 20. Regression results of conditional logit and ransom parameter logit models

		CL	**RPL**
Transition Specific Constants (α_{ij})			
Crop→ Pasture		-1.3840** (0.1162)	-1.3841**(0.1170)
Crop→ Forest		-2.2587**(0.1494)	-2.2589**(0.1597)
Crop→ CRP		-2.1427**(0.2878)	-2.1477**(0.2823)
Crop→ Developed		-4.2845**(0.2259)	-4.2987**(0.2288)
Pasture→ Crop		-4.0106**(0.1650)	-4.0101**(0.1613)
Pasture→ Forest		-2.6105**(0.0937)	-2.6108**(0.0903)
Pasture→CRP		-35.0754 (120748)	-35.0754 (530362)
Pasture→ Developed		-4.4800**(0.1492)	-4.4790**(0.1530)
Forest→ Crop		-6.2321**(0.2325)	-6.2336**(0.2342)
Forest→ Pasture		-4.5505**(0.1127)	-4.5519**(0.1081)
Forest→ CRP		-7.0491**(0.5564)	-7.0531**(0.8438)
Forest→ Developed		-4.2672**(0.1102)	-4.2637**(0.1183)
Fixed Time Effects (τ_{ij})			
Crop	1987-1992	0.9400* (0.1561)	1.0308**(0.1709)
Pasture	1987-1992	0.8669**(0.1221)	0.9559**(0.1283)
Forest	1987-1992	0.7303**(0.0948)	0.8143**(0.1170)
CRP	1987-1992	0.4307 (0.3400)	0.5227 (0.4046)
Attributes of Land Uses (β)			
Return	Mean of Coefficient	0.0007**(0.0000)	0.0005
	Mean of ln(coefficient)		-7.7385**(0.1519)
	Std.Dev. of ln(coefficient)		0.0323 (1.6243)
Property Taxes	Mean of Coefficient	0.0025**(0.0005)	0.0024
	Mean of ln(coefficient)		-7.5530**(0.7935)
	Std.Dev. of ln(coefficient)		1.9802** (0.5662)
Attributes of Plots (γ_j)			
Crop	Population density	-0.0001 (0.0003)	-0.0001 (0.0003)
	Land quality	-0.7939**(0.2432)	-0.7933**(0.2614)
Pasture	Population density	-0.0003 (0.0002)	-0.0004* (0.0002)
	Land quality	-0.2783* (0.1369)	-0.2737* (0.1423)
Forest	Population density	-0.0004**(0.0001)	-0.0005**(0.0001)
	Land quality	0.2190* (0.0874)	0.2271**(0.0907)
CRP	Population density	-0.0083* (0.0036)	-0.0083* (0.0042)
	Land quality	-0.7380 (0.6998)	-0.7345 (0.9790)
McFadden R^2		0.7625	0.8195
Log Likelihood		-5346.64	-5338.30

** is significant at the 1% level, * is significant at the 5% level use i to j. Among the twelve transition terms, conversion from forestry to CRP has the lowest value, implying such a conversion is less likely to happen. Comparing three conversion-to-CRP terms, conversion from croplands has the highest estimates, which means CRP lands most likely came from croplands. This is consistent with land quality statistics in the NRI records. From NRI, the weighted mean of land capability class of CRP lands is 2.50, close to croplands with 2.244 (LCC for pasture is 3.229, and 4.276 for forestry). Estimates of conversions from croplands or pasture lands to other types except CRP are generally greater than that from forests, which provides evidence that land use transitions from lands in high qualities to low qualities take place easier than transition from low quality lands to high quality lands.

Fixed time effects τ_{ij} are used to capture the impacts of time on the probability of choosing a land use type rather than developed use in a period. Using the transition period from 1992-1997 as the base year, parameters of transition from 1987-1992 for different land use alternatives are highly significant at the 0.05 level with positive signs. With the assumption of irreversible developed land uses, influences of time on lands in different alternatives can be positively traced, which means that the rate of transition to developed land use increases with time.

Generally speaking, high quality lands may be flatter and have fewer trees, and thus have fewer barriers to development. We believe that converting lands in low land quality to another use costs more than the ones in high land quality. Interactions of land quality dummy (LCC) and land use alternatives are created to capture conversion costs of land use transitions. The sign of LCC estimates indicates the direction of the effect on the relative probability of choosing the associated use versus choosing developed lands, compared to lands of higher quality. The significant negative estimates of land quality dummy interacted with croplands and forests in the

CL model indicate decreasing probabilities of lands being converted to these certain uses when land quality is low, and the probabilities of choosing pasture and CRP are not influenced by land quality. Though the magnitudes of the two models are almost the same, the influence of land quality on pasture is no longer equal to zero in the RPL model.

Population expansion usually precipitates land use transition. It increases developed land use in order to provide more public facilities or residential development. Interaction between population density and land use alternatives is expected to yield low land transition probabilities for rural use. The RPL model estimates show that population density does not play as important a role as other factors. Compared to conversion to developed use, an increase in population density will negatively affect land uses in forestry and pasture by highly significant negative signs, and will not affect land uses in crops or CRP. Compared to other existing land use studies (Plantinga 1996, Plantinga et al. 2002, Nagubadi and Zhang 2005), the insignificant impacts of population density can be explained by the plot-level observations used in this work. It is acceptable to use population density to measure population influence in a county-level study, while for a plot or parcel level study, population size and proximity to populated place for each plot cannot be fully reflected by the density of population of that county. A better variable called the population influence index has been used to capture population characteristics for a specific parcel, and has been proved to have highly significant influences on land use change studies (Breneman 1997, Polyakov and Zhang 2008, Polyakov and Zhang 2008). It will be used to reanalyze the model when the data is available later.

Economic factors reflected by net returns and property taxes are significant and positively impact land use transition probabilities in the CL model, which means that higher economic returns and lower property taxes could motivate landowners to keep or convert lands to that particular use. This is consistent with the classic land rent theory. The positive sign of property taxes derived from the negative definition of initial tax values due to requirements of model estimation of the RPL model.[13] The means of the coefficients of returns and property taxes in RPL model are calculated using the estimated means and standard errors of log-normal distributed returns and property taxes in terms of the formula $\beta_i = \exp\,(b_i + \frac{s_i^2}{2})$. Both of the means of the coefficients of the two variables are greater in the CL model than those estimated from the RPL model.

The estimated means of natural logarithm of the coefficients as well as the standard errors for random parameters are both highly significant at the .01 level. Highly significant estimated standard error of property taxes and returns indicates that variation exists in the two coefficients. Usually, return and property tax can be combined as one explanatory variable, while, the concrete function of economic return and tax burden cannot be examined to provide further policy implication in this case. To examine if these two variables can be combined, we create a new variable by combining returns with property taxes, and estimate the restricted RPL model with the same model specification but a new land rent. The value of the likelihood ratio statistic is 132.46 with 99% critical value of $\chi_1^2 = 6.635$, which indicates that separating returns and property taxes is more appropriate to specify the RPL model.

5.2. Probabilities and Elasticities

It is well-known that a parameter estimate of a choice model could not provide any straightforward behavioral interpretation aside from the sign of the parameter, which indicates

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[13] A parameter estimate for an attribute with an expected negative mean estimate in a RPL model could face the problem of nonconvergence or to converge with unacceptably large mean estimates when the attribute in a utility expression specified with a random parameter that is lognormally distributed. It can be fixed by reversing the sign of the attribute prior to model estimation. A positive lognormal parameter for the negative of the attribute is the same as a negative lognormal parameter to the attributes itself (Hensher et.al.2005).

whether the variable of interest has either positive or negative effects on the probabilities of choosing choices. It is even more difficult to interpret in this study because the same vector of coefficients is a component in all utility functions. One coefficient could influence twenty-five elasticities (Polyakov and Zhang 2008). To quantify the impact of property tax on land use change decisions, we evaluate land-use transition probabilities and elasticities for land transition specific constants α_{ij} and land retention constants α_{ii} at the means of the data using the estimated coefficients from the RPL model.

Table 21 presents the estimated land-use transition probabilities and elasticities of associated transition probabilities with respect to property tax per acre on lands initially in crops, pasture and forestry at the mean of the data. Standard errors are provided in the parentheses, estimated using the Delta Method. The predicted probabilities of land transitions from each initial use calculated by parameters estimated from the RPL model are consistent with the land transition specific constants in Table 20. Overall, the estimated probabilities are generally significantly different from zero at the 10% level or better. Lands remaining in their initial uses during the study periods have the highest estimated probabilities with 1% significant level. Lands initially in crop and pasture uses are more likely to convert to forestry; however, transitions from forestry to any other major rural uses are in quite low probability, even zero, which again indicates that land transition are more likely for higher quality parcels than for lower quality parcels. Lands for CRP use can only be converted from croplands. Only the probability of transition from crop to CRP is not equal to zero. This is consistent with the fact that land must first be in cropland before qualifying for the CRP. Still none of them are statistically significant.

The diagonal elements of the elasticity sub-table in Table 21 represent own elasticities, indicating percentage change in probability of converting to a certain land use with 1 percent

Table 21. Transtion probabilites and elasticities of probabilities with respect to property tax

Transition (Retention)	**Predicted Probabilities**	**Elasticities of Transition Probabilities with respect to property tax per acre on**				
		Crop	**Pasture**	**Forest**	**CRP**	**Developed**
Crop→ Crop	0.690*** (0.27)	**-0.0032**	0.0018	0.0005	0.0002	0.0016
Crop→ Pasture	0.157*** (0.071)	0.0079	**-0.0092**	0.0005	0.0002	0.0016
Crop→ Forest	0.059*** (0.017)	0.0079	0.0018	**-0.0075**	0.0002	0.0016
Crop→ CRP	0.035*** (0.014)	0.0079	0.0018	0.0005	**-0.0077**	0.0017
Crop→ Developed	0.059*** (0.017)	0.0078	0.0018	0.0005	0.0002	**-0.0462**
Pasture→ Crop	0.015 (0.10)	**-0.0084**	0.0075	0.0005	0.0019	0.0015
Pasture→ Pasture	0.855*** (0.028)	0.001	**-0.0010**	0.0005	0.0001	0.0015
Pasture→ Forest	0.061*** (0.013)	0.001	0.0075	**-0.0071**	0.0001	0.0015
Pasture→ CRP	0.000 (0.014)	0.0000	0.000	0.0010	**-0.0090**	0.0012
Pasture→ Developed	0.070*** (0.022)	0.0001	0.0075	0.0005	0.0007	**-0.0353**
Forest→ Crop	0.002 (0.006)	**-0.0087**	0.0001	0.0074	0.0000	0.0017
Forest→ Pasture	0.008 (0.008)	0.0004	**-0.0087**	0.0074	0.0000	0.0017
Forest→ Forest	0.917*** (0.081)	0.0001	0.0001	**-0.0004**	0.0000	0.0017
Forest→ CRP	0.0003 (0.006)	0.0001	0.0001	0.0075	**-0.0078**	0.0016
Forest→ Developed	0.073** (0.027)	0.0002	0.0001	0.0073	0.0000	**-0.0377**

Note: The bold figures of diagonal elements are own elasticities, and the off-diagonal elements are cross-elasticities.
*** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level

change of property tax on this land use, and the off-diagonal elements are cross elasticities showing percentage change in probability of converting to a certain land use when property tax on different land use increases by 1 percent. For example, a 1 percent increase in property tax on forestry will decrease the probability of land use conversion to forestry by 0.0075 percent, 0.0071 percent and 0.0004 percent from lands initially used for crops, pasture and forestry, as respectively show by the sub-table diagonal elements under Forest.

The cross−elasticities have positive signs while own elasticities are negative, which indicates that tax increase in one use will increase the probability of land transition to other uses. For example, when property tax of forestry increases by 1 percent, probability of transition from crop to pasture will increase by 0.0005 percent, as shown by the entry corresponding to Crop→Pasture under Forest. The small values of elasticity imply inelastic land use transitions such that a change in property tax for one kind of land use has a minor impact on landowners' decisions to convert to other land use types.

5.3. Implication of Current Use Valuation Assessment Program

As is described in section 4, both of the two property tax programs in Georgia aim to mitigate landowners' tax burdens and motivate them to keep lands in rural uses. Under the enrollment requirements, the dominant CUVA program in North Georgia from 1992 to 1997 has allowed nearly 22 percent eligible rural lands into this program. According to the property tax collection procedures described in section 4, in this section we did a simulation to find out how the CUVA influences aggregate land use behaviors. In our final chosen dataset, for plots under CUVA program, we use the property taxes of ordinary crops, pasture and forest to replace the taxes of these three types of lands under CUVA, forcing all rural lands to be in regular uses. Then we do a simulation based on this scenario using the regression result of the RPL model. We find that without the CUVA program, there will be an extra 8,000 acres croplands, an extra

10,000 acres pasture lands, and an extra 10,000 acres forests decrease in the North, which is about 0.25% of the total rural lands in North Georgia.

Enrollment of the CUVA program in the South is quite few, and the degree of tax mitigation compared to preferential use program in this region is relatively small, we believe that the influence of CUVA program on land use transition in South Georgia is not as significant as that in North Georgia.

6. Conclusions

This study presents an econometric analysis of the effects of property taxes on land use transitions among five major land uses in Georgia during the period 1987-1997. By using the NRI plot-level land use and land quality information, and aggregate county-level economic returns and property tax data, a panel random parameters logit model is pursued to relax the IIA assumption of multiple choices models, and account for temporal correlation between observations of the same sample points, as well as heterogeneity of marginal utility of property taxes among landowners.

The results of the model estimation confirms the classic land rent theory that land use patterns are determined by the rents of alternative uses and land quality. High economic return from a particular land use could increase the probability of land remaining or converting to this use, and decrease the probability of transiting to other uses. Land quality is an important factor to influence land use decisions, and transitions within high quality parcels is more likely than transitions within low quality parcels. Property taxes have significant influences on land use transitions and random among land parcels. The greater the property tax associated with a particular land use, the lower probability of lands remaining in its original use. Land use transition with respect to property taxes is found to be inelastic, which is consistent with Polyakov and Zhang (2008).

Based on the estimated parameters and the essence of CUVA program, simulation with no existing CUVA program results in an extra 8,000 acres, 10,000 acres and 10,000 acres more decrease on croplands, pasture, forests, respectively in the Northern Georgia. Influence of CUVA program in the southern Georgia is not as significant as that of the northern part because of the fewer enrollments of the program in the south. Thus, we believe that the total influence of this program is not very effective in the state. Newman (2000) revealed a similar conclusion that the CUVA program is an effective way to lessen landowners' tax burden, but does not influence their final land use transition decisions.

Chapter 5. Conclusions

This dissertation presents a series of econometric analyses that explain the causes and consequences in land use, land use changes, and forest type changes in the southern U.S. These studies combine plot-level land use and land quality information from National Resources Inventory (NRI), NRCS with county-level socio-economic and demographic factors, and estimate the parameters of a set of first-order Markov transition probabilities using panel random parameters logit models. With different model specifications, these studies take the advantage of recent development in RPL models, and make a contribution in the following aspects.

First, in chapter 2, land use and land quality information from NRI are fully captured by using the entire sample plots rather than a randomly selected sample, which could mitigate bias, and provide more accurate estimation and simulation results. Using the county-level average economic return as a proxy for plot-level economic return ignores the heterogeneity of land quality for each plot, thus applying the RPL model to allow heterogeneity of marginal utility of economic factors among landowners and complex substitution patterns among land use alternatives is necessary. The panel RPL model helps trace the effects of both time-variant and time-invariant forces, which could not fulfill in the early time.

Second, Chapter 3 projects the future forest type distribution in the South based on a two-stage discrete choice model where land use change dynamics are concerned in the first stage. It provides policy makers about how to balance the social benefit from environments and the individual benefits from intensive forest management strategy. Overall, forest carbons are unaffected by change in forest types in the next 40 years in the southern US.

Third, Chapter 4 quantifies the impacts of property tax and the Current Use Valuation Assessment (CUVA) program on land use change decisions in North Georgia. Due to information limitation, previous studies on this subject concentrate on using descriptive methods rather than an econometric analysis, which is done here. Further in this study, we separate tax for rural lands to crops, pasture and forests in term of their land values. Based on communication with both Georgia Department of Revenue and county property tax assessors, taxes created by this method is much closer to the county facts, which provides a way to fill the gap of losing historical property tax records.

Based on our model estimation, elasticity analysis and simulation results, the main conclusions of this dissertation are:

Land use transitions are highly related to land rents, land quality and human disturbances such as population density. The elasticities of land use transition probabilities with respect to the mean of the net economic returns and the mean of population density are inelastic, and population growth contributed more to the decrease of rural lands, and sped up urbanization.

Urbanization associated with land value appreciation is the most important factor in decreasing the percentage of rural land uses comparing the impacts of economic returns on as well as population density on aggregate behaviors of land use changes. This might put rural lands in the South into too much pressure in the future, since the U.S. South is projected to be the fastest growing region in the United States.

During 1997-2047, forest land is projected to decrease by 4.21 percent, accompanied with a 57.77 percent increase of pine plantations, and 30.30 percentage, 22.74 percent, 17.63

percent and 5.20 percent decline in natural pine, mixed pine hardwood, bottomland hardwood, and upland hardwood respectively. This kind of forest cover type conversion could produce 1.3 Gg more carbon in total, including the decrease of 0.6 Gg carbon in forests only, and an increase of 4.3 Gg carbon in forests and forest products.

Thus, whether forest type transitions exist or not, the total carbon storage in southern forests is similar. There is only 0.2 Gg more carbon stocks for self-type regenerated forest management strategy in 2047. The optimal profit goal of private landowners by converting long-rotation hardwoods and natural pine to intensive pine plantation does not hurt social welfare from the point of carbon storage, while there might be some potential problem caused by other greenhouse gases, such as N_2O and CH_4.

Property taxes have important impacts on the management of private forest and farm lands. Higher property taxes on a land decrease the probabilities of lands transited to this certain use. The transition probability with respect to per acre property tax is inelastic. Its impact is more complicated and cannot be treated as only a cost when making land management and conversion decisions. A Current Use Valuation Assessment (CUVA) program is effective in mitigating private landowners' higher tax burdens, and may be used to help curb rapid loss of rural lands in Georgia and perhaps elsewhere. But its impact, in terms of acreage saved, could be rather small. Overall, only an extra 8,000 acres of croplands, 10,000 acres of pasture and 10,000 acres forests can be saved in North Georgia in 1997, which is only 0.25% of the total area of the rural lands.

In terms of the conclusions and potential problems we mentioned in the dissertation, future works will focus on refinement of the model and sensitivity analysis. Because our analyses are based on the RPL model and simulation results, while there is a potential simulation bias in the RPL model, we have to find a way to mitigate this bias.

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