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Efficient Policies for Environmental Protection: An Econometric Analysis of Incentives for Land Conversion and Retention

Andrew J. Plantinga and SoEun Ahn

This study investigates the costs of subsidies for land retention and conversion, in addition to a policy that combines these incentives. A Markov model of forest and agricultural land use is estimated for the U.S. South Central region and used to simulate retention and conversion policies. Results suggest a conversion policy is less costly for increasing forest area, and a retention policy is less costly for increasing agricultural land area. The costs of separate subsidies can be up to 300% higher than the costs of combined incentives. However, when administrative costs are taken into account, conversion policies are likely to be less costly.

Key words: carbon sequestration, conservation, land use, land-use policy, Markov processes

Introduction

Private land-use decisions often give rise to significant external costs such as nonpoint source pollution, and external benefits such as habitat for wildlife. One role of land-use policies is to narrow the divergence between privately and socially optimal land allocations by modifying the economic incentives faced by private landowners. In the United States, these policies are most often designed to increase the relative net returns to land in the socially desired use and, in general, take one of two forms: (a) policies encouraging landowners to convert their land to the desired use, and (b) policies encouraging landowners to retain land in the desired use.

Policies that encourage conversion include the Conservation Reserve Program (CRP), the Environmental Quality Incentives Program, and the Wetlands Reserve Program administered by the U.S. Department of Agriculture (USDA). The CRP, for example, offers subsidies to landowners to convert marginal cropland to grassland or trees for a period of 10 years in order to reduce soil erosion and provide other environmental benefits. A prospective policy receiving much attention is large-scale tree planting designed to sequester carbon and ameliorate the effects of climate change. Many researchers have analyzed programs providing subsidies for the conversion of agricultural land to forests (e.g., Moulton and Richards; Adams et al.; Parks and Hardie; Plantinga, Mauldin, and Miller).

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A variety of federal and state policies are designed to retain land in forests, wetlands, and agriculture. For example, the Tax Reform Act of 1986 limits tax deductions for wetlands drainage expenses. All states have some form of preferential tax treatment for forest and agricultural land (e.g., current use value assessment) which serves to increase the value of land in these uses relative to alternative uses such as development. Additional examples of retention policies are the Water Bank Program, Swampbuster, Section 404 of the Clean Water Act, the Forestry Incentives Program, and conservation easements.

The primary objective of this study is to investigate the costs of achieving given land-use policy goals with incentives for land conversion and retention. A number of analyses have examined the costs of actual and hypothetical land-use policies (e.g., Reichelderfer and Boggess; Parks and Hardie; Parks, Kramer, and Heimlich; U.S. Government Accounting Office). In their evaluations, however, these studies focus either on incentives or on disincentives for land conversion. Few analyses have compared the costs of the two approaches (an exception is Newell and Stavins).

If the decision rules for land conversion and retention are identical, then the two approaches should entail the same costs. Conversely, if there are asymmetries in factors such as conversion costs and uncertainty regarding future net returns, then, in general, the decision rules will differ. In this case, there may be important differences in the costs of achieving environmental objectives with incentives for land conversion and retention. It follows from first principles that the cost of a policy combining conversion and retention incentives will be less than or equal to the cost of either policy applied separately. Thus, a related empirical question is: How much can costs be reduced by using a two-part policy instead of a policy involving only one type of incentive?

In this study, we conduct an empirical investigation of these issues. The basis for the analysis is an econometric model of land use in the U.S. South Central region. The model quantifies the relationships between land in forest and agriculture as well as the determinants of land use, including net returns to forestry and agriculture and land quality characteristics. The estimated model is used to simulate the effects of hypothetical policies on forest and agricultural land area relative to land use in a baseline scenario. The simulations provide cost estimates of achieving given changes in land use by adopting alternative policy designs. These results inform future efforts to develop efficient policies. In particular, given the regional scope of the study, the results are most relevant to large-scale programs designed to effect changes in broad land-use categories.

A second contribution of this study is the presentation of a new method for estimating land-use models with aggregate data. The standard approach is to specify shares of land in alternative uses as functions of exogenous variables and unobserved parameters, and to estimate the share equations using county-level data (e.g., Wu and Segerson; Hardie and Parks). These models cannot be employed to separately evaluate conversion and retention policies because they yield predictions only of net changes in land use and not the shifts in land from one use category to another. Following MacRae, we use aggregate data to estimate a Markov model of land-use change that recovers unobserved transitions between forest and agricultural land uses, and accounts for unobserved net losses to urban and other uses.¹ The estimated model can then be utilized to simulate policies designed to influence transitions between land-use categories.

¹ Our approach is similar in some respects to Stavins and Jaffe, who model shifts between forest and agricultural land-use categories. It should be mentioned that transitions between use categories may be directly observed in plot- and parcel-level data on land use (Nelson and Hellerstein; Claassen and Tegene).

A Markov Model of Land-Use Change

In this section, a Markov model of changes in forest and agricultural land area is presented. From the solution to the individual landowner's problem of dynamic land allocation, the optimal shares of land to allocate to forest and agriculture are derived, conditional on the land's current use and land-use decision variables. The optimal allocation shares are then aggregated to the county level and expressed in terms of first-order Markov transition probabilities characterizing shifts between forest and agricultural land uses. Equations for net losses of forest and agricultural land to urban and other uses are specified, drawing on results from Capozza and Helsley's model of urban and rural land markets. Transition probabilities and net loss equations are combined to yield a system of estimating equations relating forest and agricultural land area in adjacent time periods.

First-Order Markov Transition Probabilities

In each period, a risk-neutral landowner is assumed to allocate a one-acre parcel of uniform quality land to forestry or agriculture in order to maximize discounted expected net revenues less conversion costs. This problem has been analyzed by Stavins and Jaffe, and by Plantinga. We summarize their results and refer readers to these studies for additional details.

If the parcel is forested (use 1) at the start of time t , it is optimal for the landowner to convert to agriculture (use 2) if $NPV_{2t} - C_{2t} + R_{2t} \geq NPV_{1t}$; otherwise, leave the parcel in forest. If the parcel is in agriculture at the start of time t , it is optimal to convert to forest if $NPV_{1t} - C_{1t} - R_{1t} \geq NPV_{2t}$; otherwise, leave the parcel in agriculture. NPV_{kt} is the present discounted value of the infinite stream of annual net revenues from use k ($k = 1, 2$), and C_{kt} is the cost of converting land to use k . When a forested parcel is converted, the merchantable trees are sold, yielding revenues R_{2t} . When an agricultural parcel is converted, the forested parcel does not begin generating revenue until the trees grow to merchantable size. R_{1t} equals the present value of net timber revenues that are not collected by the landowner during forest establishment.

Net revenues from forestry and agriculture vary considerably with the productivity, or quality, of the land. Thus, to move from the individual landowner's decision problem, which considers a single parcel of uniform quality, to an aggregate county-level model of land use, land quality differences within and across counties must be recognized. For landowner n in county i ($n = 1, \dots, N_{it}$), the net revenue function for a parcel of quality j ($j = 1, \dots, J$) land is denoted by $W_{j1t} = W_1(NPV_{j1t}, NPV_{j2t}, C_{j2t}, R_{j2t})$ if the parcel is forested in time t , and by $W_{j2t} = W_2(NPV_{j2t}, NPV_{j1t}, C_{j1t}, R_{j1t})$ if the parcel is in agriculture in time t (for now, the landowner notation is suppressed).

Suppose the landowner holds A_{jkt} acres of quality j land in use k at the start of time t . Assuming net revenues depend linearly on acres, the landowner maximizes net revenues by allocating all A_{jkt} acres either to forestry or to agriculture. The optimal allocations are given by the functions $A_l^*(W_{jkt}, A_{jkt})$ ($l = 1, 2$), which indicate the area of quality j land optimally allocated to use l in time t given the land is in use k at the start of time t .

If the landowner holds a total of $A_{kt} = \sum_j A_{jkt}$ acres of land in use k at the start of time t , then the optimal share of the land to allocate to use l (the optimal transition share) is specified as:

$$(1) \quad S_l^*(\mathbf{X}_{kt}) = \frac{1}{A_{kt}} \sum_{j=1}^J A_j(W_{jkt}, A_{jkt}),$$

where \mathbf{X}_{kt} is a vector of decision variables which includes the J functions W_{jkt} and composite measures of land quality for use k . Equation (1) gives the optimal transition shares for the n th landowner in county i . To conform to the available data, the shares must be aggregated to the county level. If w_{knt} is the share of use k land held by the n th landowner in county i at the start of time t , we may write the county-level transition share as:

$$(2) \quad S_l^*(\mathbf{X}_{ikt}) = \sum_{n=1}^{N_{it}} w_{knt} S_l^*(\mathbf{X}_{knt}),$$

where \mathbf{X}_{knt} is the vector of decision variables for landowner n . Data on individual landowners are not readily available, and thus the transition shares in (2) are expressed as a function of county-level decision variables, \mathbf{X}_{ikt} , which include county-level averages of the elements of the functions W_{jkt} and variables measuring the distribution of land quality within the county. By substitution, the right-hand side of (2) is shown to be an average of the W_{jkt} functions over landowners and land quality classes.

The land-use data consist of a panel of observations of forest and agricultural land area; therefore, the county-level transition shares in (2) are not observed. Accordingly, we specify the optimal transition shares as a parametric function of \mathbf{X}_{ikt} and estimate the transition model parameters from the data. The optimal transition shares are allowed to differ from the actual transition shares due to exogenous shocks occurring after land-use decisions have been made (e.g., unfavorable weather). Specifically, the stochastic model of actual transition shares,

$$(3) \quad S_{iklt} = S_l^*(\mathbf{X}_{ikt}) + \varepsilon_{iklt} = P_{iklt} + \varepsilon_{iklt},$$

is expressed in terms of \mathbf{X}_{ikt} through the logistic cumulative distribution function (CDF), where $P_{ik1t} = e^{\beta_k \mathbf{X}_{ikt}} / (1 + e^{\beta_k \mathbf{X}_{ikt}})$ and $P_{ik2t} = 1 / (1 + e^{\beta_k \mathbf{X}_{ikt}})$. The vector of unknown parameters is β_k ($k = 1, 2$), and ε_{iklt} is an error term with zero mean and finite variance. The expected value of S_{iklt} is the first-order Markov transition probability, P_{iklt} , or the probability that land in county i in use k moves to use l between t and $t + 1$, conditional on the land remaining in either forestry or agriculture. As such, the probabilities P_{ik1t} and P_{ik2t} must sum to one, a condition which is satisfied by the parameterization employed above.

Net Loss Equations

The Markov transition probabilities characterize the movement of land between forestry and agriculture. Land in forest and agricultural uses may also be converted to urban and other uses, and vice versa. In this study, urban and other land is defined as a residual category including all land other than forest and agricultural land. While it is rare for urban land to be converted to forest and agricultural uses, other land, including wetlands, corridors for electrical lines, and land in other miscellaneous uses, may shift into forest and agricultural uses (Vesterby and Heimlich).

NL_{ikt} is defined as the net loss of land in use k between t and $t + 1$. The net loss of forest land, for example, equals the acres of land converted from urban and other uses to forests

minus the acres converted from forests to urban and other uses. Net losses can be defined formally in terms of transition probabilities for urban and other uses and the aggregate areas of land in forest, agriculture, and urban and other uses: $NL_{ikt} \equiv P_{i3kt}A_{i3t} - P_{ik3t}A_{ikt}$ ($k = 1, 2$). In principle, one could specify parametric functions for the transition probabilities, as in (3), and estimate this expression directly; however, this approach is infeasible in our case because the net losses are unobserved in aggregate data.

Instead, we model net losses as a deterministic function of observed exogenous variables and unobserved parameters and a random shock causing actual land-use decisions to depart from ex post optimal decisions. Specifically, $NL_{ikt} = \alpha_k'Z_{it} + \mu_{ikt}$, where α_k is a vector of parameters, Z_{it} is a vector of exogenous variables for county i in time t , and μ_{ikt} is an error term with zero mean and finite variance.

To guide the selection of exogenous variables, Capozza and Helsley's model of a competitive market for developed and rural land is used. In the model, people live in the area around a city center and commute into the central business district for employment. Over time, land in the surrounding rural region is developed to accommodate the city's growing population. Capozza and Helsley solve for the land market equilibrium and the equilibrium rents from developed land. The two key factors determining development rents are the distance to the city center and changes in the city's population. In the application presented below, distance and population change measures are included as determinants of net losses of forest and agricultural land. We focus on the determinants of developed land. Unfortunately, data are not available to explicitly model the factors influencing changes in the area of land in other uses.

System of Estimating Equations

As noted above, the land-use data consist of a panel of aggregate observations, A_{ikt} , on the acres of land in county i ($i = 1, \dots, I$) in land use k ($k = 1, 2$) at time t ($t = 1, \dots, T$). For each county, the observed data are related to the latent transition shares by the accounting identity:

$$(4) \quad A_{ikt+1} \equiv NL_{ikt} + \sum_{l=1}^2 S_{ilk}A_{ilt}.$$

By substitution of the Markov transition probabilities (3) and the net loss equations, an estimable parametric function relating the area of forest and agricultural land in adjoining time periods is formed:

$$(5) \quad \begin{aligned} A_{i1t+1} &= \alpha_1'Z_{it} + \left[\frac{e^{\beta_1'X_{i1t}}}{1 + e^{\beta_1'X_{i1t}}} \right] A_{i1t} + \left[\frac{e^{\beta_2'X_{i2t}}}{1 + e^{\beta_2'X_{i2t}}} \right] A_{i2t} + \gamma_{i1t}; \\ A_{i2t+1} &= \alpha_2'Z_{it} + \left[\frac{1}{1 + e^{\beta_1'X_{i1t}}} \right] A_{i1t} + \left[\frac{1}{1 + e^{\beta_2'X_{i2t}}} \right] A_{i2t} + \gamma_{i2t}. \end{aligned}$$

The composite error term,

$$\gamma_{ikt} = \sum_{l=1}^2 A_{ilt} \epsilon_{ilk} + \mu_{ikt},$$

represents the noise from the transition share and net loss equations. Accordingly, γ_{ikt} has zero mean, is heteroskedastic due to the weights on the ε_{ikt} , and is serially uncorrelated (MacRae). Exogenous shocks to the transition shares and net loss equations for forest land may be correlated with those for agricultural land, implying the γ_{ikt} are contemporaneously correlated. In sum, the covariance structure of the model may be stated generally as $E[\gamma_{ikt}\gamma_{ikt}] = \sigma_{ikt}^2$ ($k = 1, 2$); $E[\gamma_{ikt}\gamma_{ilt}] = \sigma_{iklt}$ ($k \neq l$; $k = 1, 2$; $l = 1, 2$).

The parameters in (5) are estimated with the nonlinear seemingly unrelated regressions equations (NLSURE) estimator. Because the aggregate land-use data do not conform to a grouped data sampling model, the generalized least squares procedure discussed by MacRae (p. 190) cannot be used to correct for heteroskedasticity. In particular, because the land-use observations are taken from different sources, the group size [N in MacRae's equation (3.5)] is not defined in our application. Instead, White's estimator of the covariance matrix is used to compute consistent standard errors. Explicit adjustment for contemporaneous correlation of the error terms is made by estimating the forest and agricultural land equations as a system of seemingly unrelated regression equations. Under the stated model assumptions, the NLSURE estimates of the parameters are consistent.

Application of the Empirical Model

Description of the Study Region

The application here is to the South Central U.S. region, which consists of Alabama, Arkansas, Kentucky, Louisiana, Mississippi, and Tennessee, and eastern portions of Oklahoma and Texas. The South Central region was chosen for several reasons. The region has a mix of land uses. In 1997, approximately 28% of the region's land base was in agricultural uses, 51% was in privately owned forest, and 21% was in urban and other uses (Ahn, Plantinga, and Alig). The land base has also undergone considerable change in recent decades. For instance, in some parts of the region, there have been increasing land development pressures, particularly around fast-growing cities such as Nashville, Tennessee.

The South Central region is also of considerable policy interest. Due to good growing conditions for trees, the presence of valuable timber species such as southern pines, and available markets for wood products, the region is considered a logical place to encourage forest expansion for carbon sequestration (Sedjo and Solomon). Further, there are high concentrations of endangered plants and animals in the Appalachian Mountains of eastern Kentucky and Tennessee, and in coastal Alabama, Louisiana, and Mississippi (Bartlett, Mageean, and O'Connor).

Data Description

The model in (5) is estimated with panel data consisting of 558 counties and eight time-series observations at roughly five-year intervals over the period 1964 to 1997. Table 1 presents summary statistics of the variables used in the empirical analysis. (For additional details on the measurement of variables, refer to the appendix.) The observations of forest area (A_{ilt}) are from periodic inventories conducted by the U.S. Forest Service. Forest area is defined as the total area of privately owned timberland.

Table 1. Mean Values of Variables Used in the Empirical Analysis, by Census Year (1964–1997)

Variable	Census Year							
	1964	1969	1974	1978	1982	1987	1992	1997 ^a
County Land Area (000 acres):								
▸ Forest (A_1)	188	183	179	177	177	178	182	186
▸ Agriculture (A_2)	107	118	113	115	111	106	104	103
▸ Urban and Other	56	49	58	58	60	63	59	56
Net Returns (1982 \$/acre):								
▸ Forestry (NPV_1)	284	369	446	473	397	365	459	—
▸ Agriculture (NPV_2)	1,425	1,311	1,928	1,964	1,170	961	904	—
▸ Revenues during Forest Establishment (R_1)	226	293	355	376	316	290	365	—
▸ Revenues from Conversion to Agriculture (R_2)	65	85	102	108	91	84	106	—
Land Quality:								
▸ Mean ($MEAN_LQ$)	0.53	0.53	0.53	0.53	0.53	0.53	0.53	—
▸ Variance (VAR_LQ)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	—
Net Loss Variables:								
▸ Distance to MSA in Miles ($DIST$)	51	51	51	51	51	51	51	—
▸ Change in MSA Population in millions (ΔPOP)	0.024	0.023	0.029	0.024	0.018	0.015	0.027	—

^aNet returns, land quality, and net loss variables are not reported for 1997 because only lagged values of these variables are used in the empirical analysis [see text equation (5)].

Agricultural land area (A_{i2t}) is defined as the total area of cropland and pasture. County-level observations are taken from the *Census of Agriculture* (USDA) for the eight census years between 1964 and 1997. Because the available measurements of forest and agricultural land area are taken at different points in time, the forest area data series is interpolated to produce a consistent set of observations.

Following the theoretical development in the previous section, measures are constructed of the elements of \mathbf{X}_{ikt} , the exogenous variables in the transition probability expressions. The net revenue functions (W_{jkt}) are measured as county-level averages over landowners and land quality classes. These functions include the net present value of returns to forestry (NPV_{i1t}), measured as the discounted value of an infinite stream of annual real timber revenues per acre, and returns to agriculture (NPV_{i2t}), measured as the discounted value of an infinite stream of annual real net revenues per acre from cropland and pasture.

The net revenue functions also depend on conversion costs. The costs of converting agricultural land to forest (C_{i1t}) are the costs for tree planting, which are incorporated into NPV_{i1t} . Data on the costs of converting forests to agriculture (C_{i2t}) are unavailable. However, if the real costs of converting forests are constant across counties and time, then their effect is measured in the constant term included in the forest-to-forest transition probability. Separate constant terms are included in the other transition probabilities.

The net revenue functions also include the net timber revenues during forest establishment (R_{i1t}) and upon conversion to agriculture (R_{i2t}). The net revenue during forest

establishment is computed as the present value of annual per acre timber revenues over the course of one rotation. The net timber revenue upon conversion to agriculture is measured as the current value of merchantable timber on one acre of forest. Diagnostics indicate R_{i1t} and R_{i2t} are perfectly correlated with the net present value measure for forests (NPV_{i1t}).

To alleviate the multicollinearity problem, R_{i1t} and R_{i2t} are combined with NPV_{i1t} and NPV_{i2t} , as appropriate. Specifically, the returns to forestry equal $NPV_{i1t} - R_{i1t}$ when the starting use is agriculture, and the returns to agriculture equal $NPV_{i2t} + R_{i2t}$ when the starting use is forest. Forest returns equal NPV_{i1t} when the starting use is forest, and agricultural returns equal NPV_{i2t} when the starting use is agriculture.

From (2), the transition probabilities also depend on the distribution of land quality for each county. $MEAN_LQ_i$ and VAR_LQ_i are the mean and variance, respectively, of the Land Capability Class (LCC) (i.e., land quality) rating for county i . (LCC ratings are derived from USDA Natural Resources Conservation Service soil surveys, and are more fully defined in the appendix.) For ease in interpreting the results, the LCC data are rescaled so that a value of 1 corresponds to the highest quality land, and 0 corresponds to the lowest quality land. Accordingly, a county with a higher value of $MEAN_LQ_i$ has higher quality land, on average.

The exogenous variables influencing the net loss of forest and agricultural land (the elements of Z_{it}) are the distance to and the population change in the closest city. $DIST_i$ is calculated as the travel distance from the center of each county to the center of the closest Metropolitan Statistical Area (MSA). ΔPOP_{it} is the change in the population of the closest MSA. To explain net losses between t and $t + 1$, that is, between agricultural census years, ΔPOP_{it} is measured as the population change between $t - 1$ and t .

Federal, state, and local regulations, including the policies discussed in the introduction section, can affect aggregate land-use allocations. To the extent these effects are transmitted through prices, they are accounted for in the net present value measures. No attempt is made to explicitly model the influence of other government policies. Large-scale land-use programs have had a relatively small effect on aggregate land use within the region. For instance, under the CRP—which is by far the largest federal land-use program in terms of total acres—conversions of cropland to forest to date amount to only about a 1% increase in forest area. In addition, it would be impossible within this framework to account for the myriad of local regulations with implications for land use (e.g., zoning restrictions). Instead, the influences of government policies are modeled as fixed effects. Indicator variables are entered linearly in the forest and agricultural land equations for each Forest Service survey unit, which correspond to sub-state groupings of counties with similar physical geography and land use.

Estimation Results

Estimation results for the forest and agricultural land equations are reported in table 2 for the U.S. South Central region. In most cases, the coefficient estimates have the expected signs and are significantly different from zero at the 5% level. Because the standard R^2 measure is not necessarily confined to the unit interval in nonlinear models, goodness of fit is gauged with the Chow R^2 , as follows:

Table 2. Estimation of Forest and Agricultural Land Equations for the U.S. South Central Region

Variable	Forest Land Equation		Agricultural Land Equation	
	Coefficient	Asymptotic <i>t</i> -Statistic	Coefficient	Asymptotic <i>t</i> -Statistic
NET LOSS:				
Constant	-1.33	-1.18	6.31*	4.68
MSA Distance (<i>DIST</i>)	0.37	0.41	2.91*	2.74
Change in MSA Population (ΔPOP)	-20.34*	-3.49	-4.42	-0.65
TRANSITION PROBABILITIES:				
• Forest-to-Forest (P_{11}):				
Constant	2.11*	4.56		
Forest Returns (NPV_1)	0.013*	12.61		
Agricultural Returns ($NPV_2 + R_2$)	-0.0005*	-7.68		
Mean Land Quality (<i>MEAN_LQ</i>)	-3.49*	-6.44		
Variance Land Quality (<i>VAR_LQ</i>)	5.39*	2.14		
• Agriculture-to-Forest (P_{21}):				
Constant	-4.05*	-5.63		
Forest Returns ($NPV_1 - R_1$)	0.008*	2.93		
Agricultural Returns (NPV_2)	-0.0006*	-5.28		
Mean Land Quality (<i>MEAN_LQ</i>)	0.44	0.52		
Variance Land Quality (<i>VAR_LQ</i>)	3.41	0.98		
Chow R^2	0.99		0.97	
Sample Size = 3,906				

Notes: An asterisk (*) denotes significance at the 5% level. Thirty-seven fixed effects for Forest Inventory and Analysis survey units were estimated in each equation. Other fixed effects parameters are not reported, but are available from the first author upon request. The transition probabilities in the agricultural land equation are defined in terms of the transition probabilities in the forest land equation (i.e., $P_{12} = 1 - P_{11}$, and $P_{22} = 1 - P_{21}$).

$$Chow R^2 = 1 - \frac{\sum_{i,t} (A_{ikt} - \hat{A}_{ikt})^2}{\sum_{i,t} (A_{ikt} - \bar{A}_{ikt})^2},$$

where \hat{A}_{ikt} and \bar{A}_{ikt} are predicted and average values of the dependent variables, respectively. The Chow R^2 values in table 2 indicate the estimated model produces a substantially better prediction of the dependent variables than the dependent variable means.

Net returns to forestry (NPV_1 or $NPV_1 - R_1$) and agriculture (NPV_2 or $NPV_2 + R_2$) have the expected effects on the transition probabilities (table 2). A higher net return to forestry, all else equal, increases the probability that the land remains in forestry (P_{11}) and the probability that agricultural land is converted to forest (P_{21}). Since $P_{12} = 1 - P_{11}$, and $P_{22} = 1 - P_{21}$, higher forestry returns decrease the likelihood of forest conversion to agriculture (P_{12}) and the likelihood of land remaining in agriculture (P_{22}). All else equal, higher net returns to agriculture decrease the probability of land remaining in forest and the probability of agricultural land being converted to forest. Conversely, higher agricultural returns increase the likelihood that land remains in agriculture and the likelihood that forest is converted to agriculture.

As expected, average land quality ($MEAN_LQ$) negatively affects the probability that land remains forested (P_{11}) (table 2). An alternative interpretation is forests are more likely to be converted to more intensive agricultural uses in counties with higher quality land, on average. For similar reasons, average land quality is expected to negatively affect the probability of agricultural land shifting to forest (P_{21}); however, the estimated coefficient is not significantly different from zero. VAR_LQ has a positive and significant effect on the probability that land remains in forest. Holding mean land quality constant, an increase in the variance of land quality implies greater amounts of the lowest and highest quality lands. The lowest quality lands are more likely to be kept in forest and the high quality lands are less likely to be converted from agriculture to forest. VAR_LQ is found to have an insignificant effect on the probability of agricultural land shifting to forest.

Because the net loss equations are not estimated directly, the coefficients on $DIST$ and ΔPOP must be interpreted as the marginal effects of these variables on the areas of forest and agricultural land rather than as marginal effects on net losses. In the agricultural land equation, the estimated coefficient on the distance variable ($DIST$) is positive (table 2), indicating that as the distance to the closest MSA increases, the area of agricultural land increases. This result is consistent with losses of agricultural land to urban and other uses declining with distance to the closest MSA. The coefficient on $DIST$ in the forest land equation is not significantly different from zero. MSA population change (ΔPOP) has a negative effect on the area of forest land. For example, greater increases in MSA population may increase the conversion of forest to urban and other uses. The effect of MSA population changes on agricultural land area is not statistically different from zero.

The expected values of the transition probabilities are estimated by substituting the coefficients in table 2 and the variables in \mathbf{X}_{ikt} and \mathbf{Z}_{it} into the expressions for P_{iklt} ($k, l = 1, 2$). The expected transition probabilities are averaged across counties to produce a single estimate for each time period. Standard errors for the estimates are computed using the delta method (Hall and Cummins). The estimated probabilities (not reported) are all significantly different from zero and one at the 5% level. The results reveal a strong tendency for land to remain in its current use. Estimates of the probability that forest land remains forested (P_{11}) range from 0.956 to 0.994, and estimates of the probability that land remains in agriculture (P_{22}) range from 0.967 to 0.981. Note, however, the probabilities are for land-use changes over five-year periods. The probability that forested land in 1964 would still be forested in 1997 is estimated to be 0.87. The corresponding estimate for agricultural land is 0.84.

Simulation of Land Conversion and Retention Policies

In this section, the county-level responses to incentives for forest and agricultural land conversion and retention in the South Central region are examined. The approach is to use the estimated econometric model to simulate subsidies for conversion and retention. The subsidies augment the net returns to forestry (NPV_1 or $NPV_1 - R_1$) or agriculture (NPV_2 or $NPV_2 + R_2$) and increase the respective area of land in these uses relative to a baseline. Thus, each level of the subsidy is associated with an estimated change in land

use, and this defines a marginal cost or supply schedule for forest or agricultural land. By comparing the estimated supply schedules for alternative policies, the least costly approach to achieving a given change in land use can be identified. The supply schedules measure the net loss in marginal profits associated with the change in land use. Sensitivity analysis to quantify potential differences in the costs of administering retention and conversion programs is presented in the next section.

The simulation analysis covers a period of 50 years, beginning in 1997.² With the exception of metropolitan area population change (ΔPOP), all of the exogenous variables (i.e., the elements of \mathbf{X}_{it} and \mathbf{Z}_{it}) are assumed to remain at 1997 values in the baseline. To test the sensitivity of the baseline to assumptions regarding future values of ΔPOP , three alternatives were considered: (a) future MSA population changes equal those observed between 1992 and 1997, (b) the population of each MSA increases at the annual rate (1.63%) projected by the Bureau of the Census for total MSA population in the U.S. South, and (c) Bureau of the Census population change projections for each state are apportioned to MSAs within the state according to each MSA's share of the population increase between 1980 and 1990.

For the three alternatives, the estimated econometric model (5) is used to project the area of forest and agricultural land in five-year increments to 2047. The residual area of land in urban and other uses is computed as the difference between the total land area in the county and the projected area of forest and agricultural land. The results are similar for the three alternatives. The policy simulations are conducted relative to the baseline for the first alternative, which produces changes by 2047 in the areas of forest, agricultural, and urban and other land of 2%, -12%, and 10%, respectively.

Six policies are evaluated. The goal of policies 1, 2, and 3 is to increase the area of forest land, and the goal of policies 4, 5, and 6 is to increase the agricultural land area. Policies 1 and 4 provide subsidies for retaining land in the targeted use, policies 2 and 5 provide subsidies for converting land to the targeted use, and policies 3 and 6 subsidize both land retention and conversion.

To simulate the subsidy for forest land retention, for example, the NPV_{it} term in P_{it} is replaced with $NPV_{it} + G$, where G is the subsidy in real dollars per acre needed to induce a landowner to keep land in the targeted use for the subsequent five-year period. For annualized values of G ranging from \$0 to \$120 per acre per year, and given the assumed values of ΔPOP and the other exogenous variables,³ the fitted model (5) is used to compute the area of forest and agricultural land in five-year increments to 2047. For each subsidy level, the change in the targeted use relative to the 1997 baseline is computed. Supply schedules are constructed by plotting the annualized values of G against the corresponding percentage change in forest or agricultural land area by 2047 (figure 1, panels A and B, respectively).

² Because our interest is in the *relative* positions of the marginal cost schedules for different policies, the length of the simulation period is not an important consideration. The same conclusions are drawn, for example, from the results of a 25-year simulation.

³ Prices are treated as exogenous in the simulations. In particular, timber and agricultural commodity prices are assumed to be unaffected by changes in the area of forest and agricultural land. Adams et al. found endogenous price effects are negligible when 50 million acres of agricultural land in the U.S. are converted to forest. The highest conversion amount considered in this study is approximately 46 million acres.

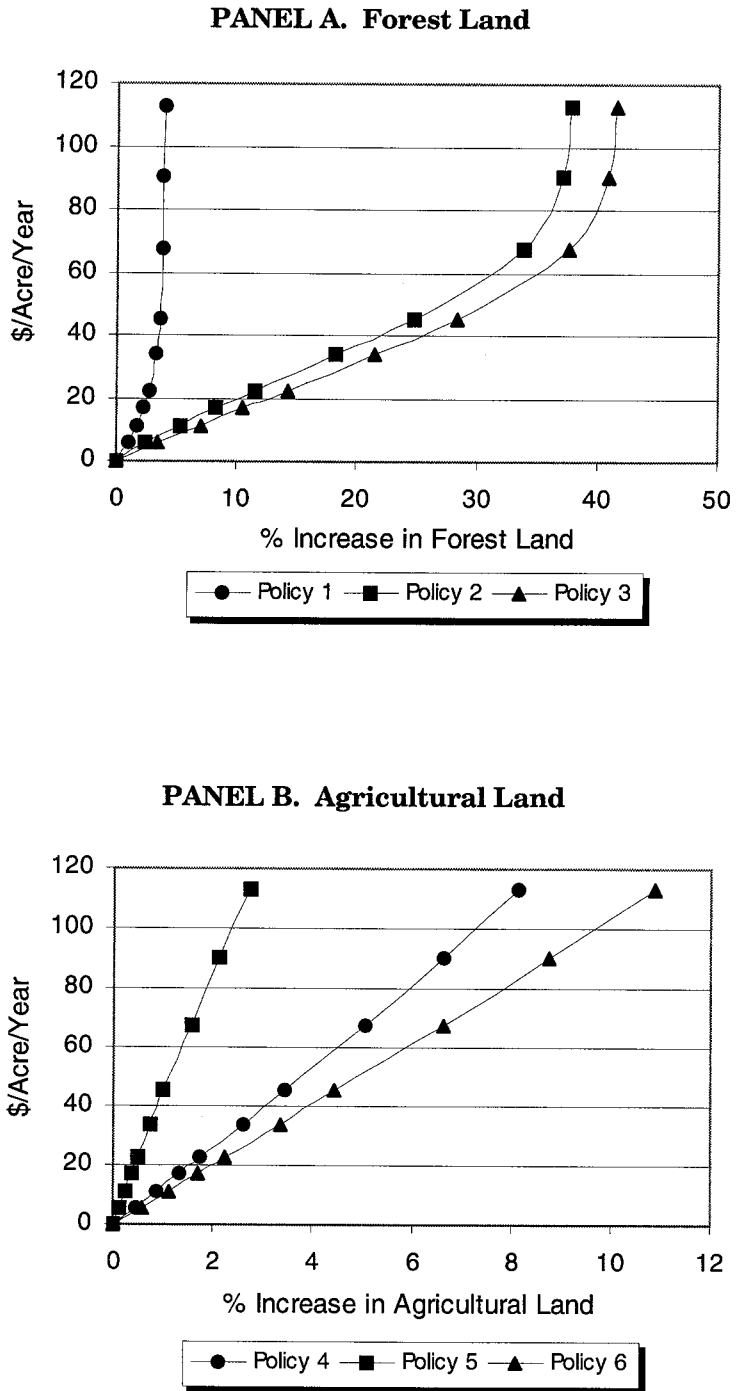


Figure 1. Supply schedules for forest and agricultural land (50-year simulation: 1997 to 2047)

Discussion

The simulation results reveal retention subsidies (policy 1) cost more than conversion subsidies (policy 2) to achieve any increases in forest area (figure 1A). At a 4% increase in forest area, the conversion supply schedule remains elastic whereas the retention schedule becomes practically vertical. At this point, the retention policy discourages almost all of the conversion which occurred in the baseline, and the cost of achieving further increases in forest area rises rapidly. The supply schedule for conversion to forest becomes inelastic at a 35% increase in forest area because almost all of the baseline agricultural land is converted to forest.

The marginal cost curves for agriculture exhibit a contrasting pattern (figure 1B). The schedule for conversion from forest to agricultural land (policy 5) is steeper than the schedule for the retention of agricultural land (policy 4). This result is reasonable because the cost of converting forest to agricultural land is expected to be very high. The supply schedules for the agricultural land policies remain linear because, over the range considered, the subsidies are not high enough to discourage all baseline conversion of agricultural land or encourage the conversion of all of the baseline forest land. In general, the cost of increasing the area of agricultural land is much higher than the cost of increasing forest area. This finding is consistent with the recent trend in the region of landowners converting agricultural land to forest.

As expected, the combined policies 3 and 6 are less costly than the individual retention and conversion policies because they effectively select the lowest cost units of land. The savings from using the combined policy can be substantial. Under policy 1, the total cost of increasing forest area by 4% (4.3 million acres), computed as the area under the marginal cost curve, is estimated to be \$99 million per year in 1982 dollars. The same goal could be achieved with the combined policy 3 for \$27 million per year. The costs of policy 3 and the conversion policy 2 are much more similar. Increasing forest area by 38% (42 million acres) with policy 2 costs \$1,871 million per year, whereas the cost under the combined policy is \$1,563 million per year. The cost of increasing agricultural land area by 8% with the retention policy 4 is 28% higher than with the combined policy 6. It is 365% more expensive to increase agricultural land area by 3% with the conversion policy 5 compared to the combined policy.

In conducting the simulations, it was assumed the agency administering the policy can determine the actions of individual landowners in the baseline. Of course, in practice, the agency cannot observe baseline actions once the policy is implemented. As a result, when the government offers a subsidy for land retention or conversion, landowners who would have retained or converted land in the baseline without a subsidy can claim the subsidy.⁴ This does not have implications for social costs, provided the policies are costless to administer and the income effects of the subsidies are negligible. However, if the agency has a fixed budget, large payments for actions which otherwise would have been taken can limit a policy's effectiveness.

To gauge the magnitude of these effects, we compute the minimum and maximum payments needed to achieve given policy goals with retention and conversion policies. To calculate the minimum payments, we assume the agency pays the subsidy only to

⁴The reason the government may have to pay landowners for actions these landowners otherwise would have taken is that the government employs a system of rewards rather than penalties. If the government can tax undesired conversion and retention, this problem is avoided. The simulated marginal cost curves for tax policies are identical to those for subsidies.

Table 3. Sensitivity Analyses on Total Payments to Landowners, and Administrative Costs

Description	Forest Policies		Agricultural Policies	
	Retention (Policy #1)	Conversion (Policy #2)	Retention (Policy #4)	Conversion (Policy #5)
Increase in Land Area (mil. acres)	4	4	1	1
Subsidy (\$/acre/year)	50	8	30	97
Minimum Total Payments (\$ mil./year)	200	32	30	97
Maximum Total Payments (\$ mil./year)	5,505	44	1,486	142

Equilibrating Difference in Administrative Costs (D^*):				
▸ Minimum Payments (\$/acre/year)		42		-67
▸ Maximum Payments (\$/acre/year)		> 990		> 925

landowners whose behavior changes relative to the baseline. For the maximum payments, all landowners who take the desired action receive the subsidy.

For this sensitivity analysis, the goal of the forest policies is to increase the area of forest by 4 million acres (table 3). We assume the agency knows the aggregate supply schedules (figure 1), but not the supply schedules of individual landowners. Accordingly, all landowners are subsidized at the same rate, given by the subsidy required to draw in the last unit of land. For the forest retention policy 1, the minimum and maximum payments are \$200 and \$5,505 million per year. For the forest conversion policy 2, the figures are \$32 and \$44 million. The total payments for forest retention increase much more dramatically because the baseline area of land retained in forest greatly exceeds the baseline area of land converted to forest.

For the agricultural policies, the goal is to increase the area of agricultural land by 1 million acres (table 3). The minimum total payments are lower for the retention policy 4 than for the conversion policy 5 (\$30 million compared to \$97 million). However, as with the forest policies, the maximum payment for the retention policy is many times greater than that for the conversion policy (\$1,486 million compared to \$142 million).

The costs incurred by the government agency to administer the retention and conversion policies are also a component of social costs. Obviously, the magnitude of administrative costs will depend on the scale of the program, the criteria used to grant subsidies to landowners, and the methods used to monitor compliance. One administrative approach, similar to that used in the first years of the CRP (Smith), is to establish a subsidy rate and accept bids for land enrollment if parcels meet established criteria. Enrolled parcels must then be monitored to ensure landowners keep their land in the specified use. Under this approach, the total variable costs of administration should be roughly proportional to the acres of enrolled land, implying the difference in the cost of administering retention and conversion policies will depend on the difference in the acres enrolled under the policies.

Assuming administration costs are proportional to enrolled acres, we can find the difference in unit administrative costs which equalizes the total costs to the government (total payments plus total administrative costs) of retention and conversion policies. Formally, we solve for $D^* = AC^C - AC^R$ conditional on $(G^R + AC^R)SA^R - (G^C + AC^C)SA^C = 0$, where AC^C and AC^R are the costs (per acre per year) of administering the conversion and

retention policies, respectively; G^C and G^R are the respective conversion and retention subsidies (per acre per year); and SA^C and SA^R are the total subsidized acres under the conversion and retention policies, respectively.

D^* is computed for the scenarios presented in table 3. For the minimum payments case, the cost of administering the forest retention policy would have to be \$42 per acre per year lower than the cost of administering the corresponding conversion policy in order for the total costs of the policies to be the same. For the agricultural policies, the cost of administering the retention policy would have to be \$67 higher than the cost of the conversion policy. In the maximum payments case, the cost difference must be implausibly large (over \$900 per acre per year) before the total costs of the retention policies are equal to those for the conversion policies.⁵

Conclusions

In the United States, land-use policies are employed in pursuit of a variety of environmental objectives, including pollution control and the preservation and creation of wildlife habitat and open space. In this study, we estimate the costs of increasing forest and agricultural land area in the U.S. South Central region with subsidies for land retention and conversion. As expected, the least costly approach is to adopt a combined retention and conversion policy. The cost savings from a combined policy depend on the enrollment goal of the policy, but in the examples provided here, the costs of individual policies are between 20% and 365% higher than the costs of the combined policy.

Federal wetlands policy involves this dual approach, offering conversion incentives under the Wetlands Reserve Program and retention incentives under Swampbuster and other programs. In the case of the CRP and its predecessors, the Soil Bank Program and the Agricultural Conservation Program, however, only a conversion incentive is used. Adoption of a combined policy could potentially reduce the costs of these programs by a significant amount.

Whether a retention, conversion, or combined policy is the least expensive depends also on the costs of administering these policies. As a first approximation, it is reasonable to assume variable administrative costs are proportional to the number of acres enrolled and, further, that unit costs of administering retention and conversion policies are equal. If the government can identify (or closely approximate) the actions of landowners in the absence of subsidies—or, alternatively, impose taxes, which obviates the need for this information—then the policy choice depends on the relative positions of the marginal cost curves. As above, the combined policy will always be the least costly. If only a single incentive is used, for the U.S. South Central region our findings show a conversion policy is least costly for increasing forest and a retention policy is least costly for increasing agricultural land.

If the government is constrained to use subsidies (because, for example, subsidies tend to be more politically acceptable than taxes), and the actions of landowners in the absence of subsidies cannot be identified, then conversion subsidies are likely to be the least expensive policy. The reason is that the total area of land retained in the desired use will tend to be much greater than the total area converted to the desired use. Accordingly, the number of acres enrolled under a retention policy should be much greater than under

⁵ When $SA^C < SA^R$, only a lower bound for D^* , given by $G^R(SA^R/SA^C) - G^C$, can be found.

a conversion policy, and administrative costs will be correspondingly higher. Estimates of D^* presented above indicate the difference in unit administrative costs must be implausibly large (over \$900 per acre per year) before a retention policy is less costly than a conversion policy.

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Appendix: Data Sources and Variable Measurement

- A_{1t} is measured as the total area (in acres) of privately owned timberland in county i in time t . Timberland is defined as forest land: (a) producing, or capable of producing, more than 20 cubic feet per acre per year of industrial wood crops under natural conditions; (b) not withdrawn from timber utilization; and (c) not associated with urban or rural development. The small amount of forest land in the region not meeting the timberland definition is excluded because timber yields are low on these lands, suggesting their use is determined by noneconomic factors. Publicly owned forest land is excluded for similar reasons. Data are from periodic forest inventories conducted by the U.S. Forest Service.
- A_{2t} is measured as the total area (in acres) of cropland and pasture in county i in time t . Data are from *Census of Agriculture* (USDA) reports.
- NPV_{1t} is measured as the present discounted value (5% discount rate) of an infinite stream of annual real (1982 = 100) timber revenues per acre. Forest stands are assumed to be "fully regulated," implying a uniform distribution of age classes from zero to the optimal rotation age (a^*). Each year, the oldest trees, corresponding to $1/a^*$ of the stand area, are assumed to be harvested. Timber revenues are calculated separately for major forest types in the region (planted pine, naturally regenerated pine, oak-pine, oak-hickory, and oak-gum-cypress). Yield data are from Birdsey, and optimal rotation ages correspond to Faustmann rotations for a 5% discount rate. State-level stumpage price data were purchased from Timber-Mart South and taken from Howard. Landowners are assumed to consider prices in the preceding year in forming expectations of future prices. Static expectations are consistent with the land allocation decision rules discussed in the theoretical section of the text (see Plantinga). Tree planting costs from Osborn, Llacuna, and Linsenbigler are subtracted from timber revenues for planted pine stands. Costless natural regeneration is assumed for the other forest types. Costs for timber management (e.g., thinnings) are ignored since intensively managed stands are a small portion (less than 5%) of the private timberland base in the region (USDA/Forest Service). Finally, net returns for individual counties are constructed as a weighted average of type-specific net returns, where the weights are based on the forest-type composition of timberland in the county.

- NPV_{i2t} is measured as the present discounted value of an infinite stream of annual real net revenues per acre from cropland and pasture. Net revenues for each county are calculated as a weighted average of revenues (price times yield) less variable production costs, where the weights correspond to crop and pasture shares in the county. For program crops grown in the region (wheat, rice, corn, soybeans, cotton, and sorghum), the price is computed as the maximum of the market price and the target price supported by deficiency payments. When the market price is below the target price, the latter is an approximate indicator of the economic incentives faced by the landowner. Average annual market prices are compiled from each state's Agricultural Statistics Service and target prices are taken from USDA *Agricultural Statistics* reports. Yield data for each county and crop are obtained from the *Census of Agriculture* (USDA) and from various USDA/Economic Research Service (ERS) publications. Variable production costs equal the total variable cash expenditures per acre, as reported in regional crop budget reports developed by the ERS. Landowners are assumed to base their expectations of future net returns on the net returns in the previous year.
- R_{i1t} is measured as the present value of 32.5 years of annual per acre timber revenues, where 32.5 is the average optimal rotation length for the five forest types in the region. Thus, we assume the forest must grow for the period of one rotation before timber harvesting begins.
- R_{i2t} is computed as the current value of merchantable timber on one acre of forest, assumed to be the timber in the five oldest age classes.
- $MEAN_LQ_i$ equals the mean Land Capability Class (LCC) rating for county i . LCC ratings are derived from USDA Natural Resources Conservation Service soil surveys and based on 12 soil characteristics, including slope, drainage, and permeability. Each land parcel is assigned a rating (on our scale) from 0 to 1, where 1 is the highest rating and indicates the greatest potential to use the land for intensive agricultural production.
- VAR_LQ_i is the variance in the rescaled LCC rating.
- $DIST_i$ is calculated, using PCMiller software (ALK Technologies), as the travel distance over major roads from the center of each county to the center of the closest Metropolitan Statistical Area (MSA). The U.S. Office of Management and Budget defines an MSA as: (a) a city of at least 50,000 population, or (b) an urbanized area of at least 50,000 with a total metropolitan population of at least 100,000. Changes in MSA definitions during the sample period had negligible effects on the distance measure.
- ΔPOP_{it} is the change (in millions of people) in the population of the closest MSA. Data are from the *Census of the Population* (U.S. Department of Commerce, Bureau of the Census).