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Impacts of Incorporating Land Exchanges Between Forestry and Agriculture in Sector Models

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ABSTRACT

The forest and agriculture sectors are linked by having a portion of their land bases suitable for use in either sector. A substantial part of the southern land base is suitable for either forestry or agriculture use, with most of forestation on U.S. agriculture land in the South. We examine how land exchanges between forestry and agriculture are influenced by specific federal conservation and farm support policies, including changes in the Conservation Reserve Program. Reallocation of land is a significant part of the sectors' responses to the policies, along with intensification of timber management on existing southern forests.

Key Words: agriculture, conservation, forest sector, land use, projections.

Agriculture and forestry are the two largest uses of land in the United States. Although both sectors have lost land to urbanization and infrastructure development over the past several decades, historical land use shifts are dominated by exchanges between these sectors. During 1982–92, approximately 90% of the 115 million acres of nonfederal land use changes involved shifts between agriculture and forestry [Vesterby, Heimlich, and Krupa; U.S. Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS)], with a large proportion of these movements in the South. Despite their magnitude, most past models and studies of the two sectors either have treated land transfers as exogenous or have ignored them. This study examines the role of land transfers in models of the two sectors and considers whether the treatment of land use transfers matters in the results of sectoral projections or policy analyses.

Our analysis employs a model of the U.S. forest and agriculture sectors in which the land bases of the two uses may be explicitly linked, and land moved to either sector depending on relative rents. We simulate activity in the sectors under two extreme cases: (*a*) with this land market interface in place and land movements explicit and endogenous, and (*b*) without sectoral links, ignoring intersectoral shifts.

We consider four policy scenarios, varying in their focus on forestry or agriculture: (*a*) reinstatement of agricultural target prices and loan rates, (*b*) an altered Conservation Reserve Program (CRP) scenario, (*c*) a large-scale tree planting program on agricultural land (as might be designed for global warming mitigation), and

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(d) reduced harvest from U.S. public timber lands. For comparisons, the characteristics of sectoral welfare, land transfers, shadow prices for land, product markets, and nonland factor use are examined for each scenario.

Nature of Land Transfer Modeling in Past Studies

Sector models used to analyze policies have not included full land base interaction between the forest and agriculture sectors. Previous sectoral studies have indicated that at broad scales, land allocation is driven largely by economic incentives, but these analyses have not modeled land price equilibrium between the forestry and agriculture sectors. In most agriculture sector analyses and sector models, such as the Food and Agricultural Policy Research Institute (FAPRI) model (Meyers et al.), forest land has been viewed simply as a pool of potential crop land that may be drawn into agricultural use. Effects of land transfers on markets in the source sector, such as the forestry sector in the FAPRI case, are ignored in such approaches. Other models used in national studies—such as the Center for Agricultural and Rural Development model [USDA/Soil Conservation Service (SCS)] on the agriculture side, and the Timber Assessment Market Model (Adams and Haynes) and the Timber Supply Model (Sedjo and Lyon) on the forestry side—have treated land transfers as fixed and exogenous.

The Agricultural Sector Model (ASM) (Chang et al.) uses excess land supply curves to allow land prices to adjust as transfers change, but the relations are fixed over time and invariant across policies. Adams et al. (1993) modified the ASM model to include planting and harvesting on former agricultural land, but did not consider the dynamics of tree growth, expectations of future prices, or linking the agricultural and forestry sectors in a dynamic framework. Generally, land flows have been assumed to be strictly uni-directional, with forestry viewed as a residual use. National-level forestry models also have failed to recognize the simultaneous nature of decisions of land allocation and land management, which is critical in the face of long timber rotations. As a consequence, these approaches do not represent land price equilibrium between sectors.

Linked Model of Forest and Agriculture Sectors

The Forest and Agricultural Sector Optimization Model (FASOM) is a dynamic, nonlinear programming model of the forestry and agricultural sectors in the United States. With the linked sectors, the model depicts the allocation of land, over time, to competing activities in agriculture and forestry. An overview of the model is presented below, with definitions of variables and parameters in table 1. Details of some model components are provided in Adams et al. (1996a, b). The objective function (1) comprises the present value of the quantity integrals of forestry and agriculture inverse demand curves less the costs of harvesting, reestablishment, intermediate timber management, and any land transfer:

$$
\begin{aligned}
(1)\quad \text{Max} \sum_{t=0}^{T} (1+r)^{-t} \Bigg\{ & \int PF_t(QF_t)\, dQF_t - CE_t EX_t - \sum_k CN_{t,k} N_{t,k} && \text{(forestry)} \\
& + EFA_t \left[\int PA_t(QA_t)\, dQA_t - \int PZ_t(Z_t)\, dZ_t - CA_t A_t \right] && \text{(agriculture)} \\
& - FC_t LTA_t - AC_t LFA_t \Bigg\} && \text{(land transfers)} \\
+ (1+r)^{-T} & \left[\frac{TF(TFQ)}{(1+r)^{10} - 1} + \frac{TA}{r} \right] && \text{(terminal values).}
\end{aligned}
$$

Table 1. Definitions of Variables and Parameters for the FASOM Model

Variables/ Parameters	Definition	Variables/ Parameters	Definition
Variables:		$EXCUT_t$	Exogenous timber harvest during period t.
A_t	Agricultural production in a typical year during period t.	FA_t	Factor use in annual operations in agriculture during period t.
TA	Amount of steady-state annual net revenue from agriculture produced every year after T (last explicit time period) in perpetuity.	FC_t	Cost of converting forested lands to agriculture in period t.
EX_t	Quantity of preexisting forest inventory harvested in period t.	IEX_0	Initial inventory of forested land.
LTA_t	Land transferred from forestry to agriculture in period t.	$LANDOUT_t$	Exogenous net land migration to other uses during period t.
LFA_t	Land transferred from agriculture to forestry in period t.	$PA_t(QA_t)$	Inverse annual demand for products from agriculture during period t.
$N_{t,k}$	Quantity of forest land planted in period t and harvested k periods later.	$PF_t(QF_t)$	Inverse forest product demand curve in period t.
QA_t	Agricultural consumption in a typical year during period t.	$PZ_t(Z_t)$	Inverse annual supply for factors to agriculture during period t.
QF_t	Quantity of forest products consumed in period t.	r	Discount rate (equal to 4%).
$TF(TFQ)$	Amount of steady-state periodic net revenue from timber produced every period after T (last explicit time period) in perpetuity, as a function of the terminal forestry stock (TFQ).	SAF	Amount of agricultural land suitable for transfer to forestry.
		SFA	Amount of forest land suitable for transfer to agriculture.
		t, t^*	Time period in decades (t^* refers to prior periods).
		T	Last explicit time period.
Z_t	Agricultural factor supply in a typical year during period t.	$TYN_{t-k,k}$	Yield from new forest when harvest period falls after last explicit period in model.
Parameters:			
AC_t	Cost of converting agricultural lands to forestry in period t.	TYX_{T+1}	Yield of existing forest when not cut during explicit model period.
$AGLAND_0$	Initial inventory of agricultural land.	XF	Expansion factor for steady-state forest after period T.
CA_t	Cost of annual operations in agriculture during period t.	YX_t	Yield from harvesting existing forest in period t.
CE_t	Net present cost of maintaining and harvesting existing forest in period t.	$YN_{t-k,k}$	Yield from new forest planted in period t and harvested k periods later.
$CN_{t,k}$	Net present cost of planting, maintaining, and harvesting new forest ($N_{t,k}$).	YA_t	Yield from annual operations in agriculture during period t.
EFA_t	Net present value of 10 annual $1 payments from period t.		

As a surplus-maximizing model (e.g., McCarl and Spreen), the model solution yields a set of quantities and prices that are consistent with a competitive market equilibrium (Takayama and Judge). The FASOM framework uses numerical optimization techniques to find the multi-market price and quantity vectors that maximize the value of the objective function, subject to the following set of constraints shown by equations (2)–(11):

(2) $$QF_t - YX_tEX_t - \sum_k^{k<t} YN_{t-k,k}N_{t-k,k} \leq EXCUT_t \quad \forall\ t$$ (forest commodity balances),

(3) $$-(XF)(TYX_{T+1})EX_t - \sum_k^{t+k>T} [(XF)(TYN_{t-k,k})N_{t-k,k}] + TFQ \leq EXCUT_{T+1}$$ (terminal forest quantity),

(4) $$\sum_{t=0}^{T+1} EX_t \leq IEX_0$$ (current available forest inventory),

(5) $$-EX_t + \sum_k N_{t,k} - \sum_k^{k\leq t} N_{t-k,k} + LTA_t - LFA_t \leq -LANDOUT_T \quad \forall\ t$$ (forest land balance),

(6) $$\sum_{t^*}^{t^*\leq t} [-LTA_{t^*} + LFA_{t^*}] + A_t \leq AGLAND_0 \quad \forall\ t$$ (agriculture land balance),

(7) $$-YA_tA_t + QA_t \leq 0 \quad \forall\ t$$ (agriculture commodity balances),

(8) $$FA_tA_t - Z_t \leq 0 \quad \forall\ t$$ (agriculture resource constraints),

(9) $$\sum_{t^*}^{t^*\leq t} [LTA_{t^*} - LFA_{t^*}] \leq SFA \quad \forall\ t$$ (transferable forest land),

(10) $$\sum_{t^*}^{t^*\leq t} [-LTA_{t^*} + LFA_{t^*}] \leq SAF \quad \forall\ t$$ (transferable agriculture land),

and

(11) $$QF_t, EX_t, N_{t,k}, LTA_t, LFA_t, A_t, QA_t, Z_t, TF \geq 0 \quad \forall\ t$$ (nonnegativity conditions).

For the land transfer component, there are two primary choice variables: LTA_t, which is land transferred from forestry to agriculture in period t; and LFA_t, which is land transferred from agriculture to forestry in period t. The forestry component is comprised of three endogenous variables: QF_t, quantity of forest products consumed in period t; EX_t, quantity of existing forest inventory harvested in period t; and $N_{t,k}$, quantity of forest land planted in period t and harvested k periods later. The agriculture component is represented by three endogenous variables: A_t, agricultural production in a typical year during period t; QA_t, agricultural consumption in a typical year during period t; and Z_t, agricultural factor supply in a typical year during period t.

FASOM is dynamic in that it solves jointly for the multi-market, multi-period equilibrium in the agricultural and forestry sectors. A solution reflects price and quantity equilibria established in each period where producers and consumers have perfect knowledge of market conditions in all periods. With an endogenous land-use margin, land is allocated to the highest valued available use as part of the intertemporal optimal set of choice variables.

Constraints represent the principal elements of the intertemporal market model: existing forestry and agricultural land endowments, resource limitations, commodity balances for market clearing, land transfer limits, and terminal inventories. The constraints for initial inventories of forest and agricultural land inventory reflect the nature of current land use and the age structure of the forest inventory. Forested land is differentiated by region, ownership class,[1] age cohort of trees, forest cover type, site productivity class,[2] timber management regime,[3] and suitability of forest land for agriculture use. An overview of the equations follows.

Equations (2) account for timber consumption and production, including timber growth and anticipated market conditions. Forest production activities include the harvesting and regeneration of existing and newly created forest stands over time and the intensity of management applied to forest stands. The basic form of the forest sector model is a "model II" even-aged harvest scheduling structure (Johnson and Scheurman) or a "transition" timber supply model (Binkley). Multiple-decade forest production processes are represented by periodic regional timber yields from the Aggregate Timber Land Analysis System (ATLAS) (Mills and Kincaid). Forestry harvest decisions have a dynamic dimension involving harvest age (i.e., harvest age is a variable) in contrast to fixed harvest ages typical in agriculture. Timber harvest yields are priced according to downward-sloping forest products demand relations, $PF_t(QF_t)$. Logs are differentiated by three product classes (sawlogs, pulpwood, and fuelwood) for both hardwoods and softwoods, yielding six classes in total. Substitution is permitted between sawlogs and pulpwood, pulpwood and fuelwood, and between residues generated in sawlog processing and pulpwood.

Empirical demand functions for sawtimber and pulpwood are derived from solutions of the Timber Assessment Market Model solidwood (Adams and Haynes) and North American Pulp and Paper pulpwood models (Ince) by summing regional derived demand relations. Because sawlog and pulpwood processing facilities possess some maximum capacities to produce output in any given period, log demands have upper bounds. Decisions to purchase additional capacity in each period to augment current and future log consumption are endogenous [not illustrated in equations (1)–(11); see Adams et al. 1996b]. Log trade with regions outside the U.S. is recognized by including regional price-sensitive, product-specific demand (export) or supply (import) functions based on historical or anticipated off-shore trading patterns.

Equation (3) is a terminal condition to recognize production from forests beyond the end of the explicit time horizon (T). We obtain a periodic quantity of production from the terminal forest inventory by assuming that forest management is, from the last period onward, a continuous or constant flow process with a forest inventory that is "fully regulated" on rotations equivalent to those observed in the last decades of the projection (see Comolli; Adams et al. 1996b). We use the last period demand curve, together with this volume and production costs, to obtain a periodic net revenue amount equal to TF. The terminal value of land remaining in agriculture is formed by assuming steady-state agricultural production that results in an annual net revenue amount TA, which is equal to net revenue in period T.

Equation (4) limits the sum of the cut and uncut areas in forests that existed at the start of the projection to be no more than the total initial inventory area. Equations (5) and (6)

[1] The two major private forest ownership classes are forest industry and nonindustrial private (Adams et al. 1996b). The two ownerships have significantly different initial endowments of forest resources, the industry class tends to practice more intensive forestry, and the nonindustrial class is composed of a diverse set of owners. Subscripts for owner, land suitability class, forest type, and site class are omitted in equations (1)–(11) to reduce the complexity of notation.

[2] Land flows from agriculture to forestry and those from forestry to agriculture may be of different qualities, and hence have different prices.

[3] The four timber management intensity classes are: passive—no management intervention between harvests of naturally regenerated aggregates; low—custodial management of naturally regenerated aggregates; medium—minimal management in planted aggregates; and high—genetically improved stock, fertilization, and/or other treatments in planted aggregates (Adams et al. 1996b). Specific practices and timber yields can vary by region, site quality, forest type, and agricultural suitability of land.

govern the inventory of forest and agricultural land each period, accounting for land transfers between sectors. Equation (5) limits the area of new forest stands planted or naturally regenerated since the start of the projection to no more than the sum of areas harvested from existing stands and previously established new stands, adjusted for land exchanges with agriculture and exogenous land transfers to urban and developed uses. When a timber stand is harvested, the decision is made whether to reestablish the stand with trees or to shift the land into agriculture. Simultaneously, land can be shifted into forestry from agriculture. When new timber stands are established, the decision is made once again whether to harvest it in a subsequent decade or to postpone cut indefinitely. The latter designation indicates that a stand's production enters the terminal inventory valuation component in equation (1), which values stands that are harvested beyond the explicit model time horizon. Equation (6) limits agricultural land use in a period t to the sum of the initial endowment plus cumulative net land transfers.

Equations (7) for agricultural consumption and production determine the quantity of agricultural output and the markets into which it enters (domestic or export). Equations (8) control factor use and supply in primary agricultural production, including potential substitution among livestock feedstuffs, drawing upon the ASM model described by Chang et al.[4] Crop and livestock production compete for land, labor, AUM grazing, and irrigation water at the regional level.[5] The original long-term equilibrium form of ASM was assumed to represent typical (annual) activities in each decade. Demand and supply components are updated between decades by means of projected growth rates in yield, input usage, domestic demand, exports, and imports. The model uses constant elasticity functions to represent domestic and export demands as well as factor and import supplies. In the first two decades, the production solution is required to be within a convex combination of historical crop mixes, following McCarl, but is free thereafter.

The agricultural component depicts typical annual activity during a decade. The forestry and land transfer components depict total activity during a decade. The objective function in equation (1) reflects this timing in that the agricultural objective function coefficient is multiplied by an expansion factor (EFA_t) that is the net present value of a dollar received in every year of the decade. Agricultural yields and factor usage vary by decade with historical trends in yield growth and input/yield interrelationships extrapolated (Chang et al.; McCarl et al.). We employ a nine-decade projection period, though our discussion of results and policies focuses on the 50 years from 1990 to 2040. Exogenous model elements are held constant after the fifth decade in the forest sector.[6]

Equations (9) and (10) limit the amount of land that is transferable between forestry and agriculture. Many forested tracts are not suitable for agriculture due to topography, climate, soil quality, or other factors. Costs for converting forest land (FC_t) reflect differences in site preparation costs because of stump removal amounts, land grading, and other land transformation factors, with three cost subclasses used to represent a range of intensity of land transformation efforts.

We can state a set of rules for land allocation based on the Kuhn-Tucker conditions for the land transfer constraints. Looking at equations (5), land can transfer from forestry to agriculture when the net present value of

[4] FASOM simulates the production of 50 primary crop and livestock commodities and 56 secondary, or processed, commodities. Many additional details go into the complete empirical specification for the 11-region model, and a longer paper with more model details (e.g., tableaus depicting typical decades in the FASOM framework) can be accessed at the internet site: agrinet.tamu.edu/mccarl.

[5] Land that can be converted between forestry and agriculture in FASOM consists of forest land, cropland, and pastureland. Rangeland provides AUM grazing, but is not eligible for transfer (Chang et al.). Conversions of forest and agricultural land to urban and developed uses are exogenous (Alig and Healy).

[6] FASOM is coded in GAMS (General Algebraic Modeling System; see Brooke, Kendrick, and Meeraus) as a separable programming formulation with solutions obtained by means of the CPLEX optimizer.

future uses in agriculture [λ_{LTA}, the shadow price of constraints (5)] is at least as large as the sum of: (*a*) opportunity cost of foregone production on forest land (*Forestry Rent*), (*b*) costs of converting forestry land [FC_t in equation (1)], and (*c*) any rents-to-conversion limits [equal to the shadow price for equations (9)]. This set of rules is specified by equation (12):

$$(12) \qquad \lambda_{LTA} \geq \textit{Forestry Rent} + FC_t + \sum_{e}^{e \leq T} \omega_{SFA,e}.$$

Rents-to-conversion limits in equations (12) equal the sum of the present values of the shadow prices (ω) for equations (9) in the current or any subsequent period (*e*).

If land is converted from agriculture to forestry, subject to land suitability limitations in equation (10), the shadow price of equation (5), λ_{LFA}, can be interpreted in a similar way:

$$(13) \qquad \lambda_{LFA} \geq \textit{Agricultural Rent} + AC_t + \sum_{e}^{e \leq T} \omega_{SAF,e}.$$

Equation (13) indicates that land can transfer from agriculture to forestry when the net present value of future uses in forestry is at least as large as the sum of: (*a*) opportunity cost of foregone agricultural production (*Agricultural Rent*), (*b*) costs of converting agricultural land [AC_t in equation (1)], and (*c*) any rents-to-conversion limits [equal to the shadow price for equation (10)]. The notation λ_{LFA} indicates how much the objective function would change if an additional acre were converted to forest use. This implicitly reflects upward-sloping supply curves for land due to opportunity costs of foregone production in alternative uses, costs of use conversion, and land movement limits.

Making land transfer decisions endogenous in a forestry/agricultural context requires a framework that melds decision processes that operate on different time scales in the two sectors. Time horizons for many agricultural decisions are one year, with others spanning four to five years. Time horizons for most forestry decisions span multiple decades, so that one has to blend frequent agricultural costs and returns with current and periodic costs and future forestry returns.

In addition to time horizon differences for uses, the dynamics of land use changes involve shifts due to technical change, demand growth, policies, and external events. Rates of growth in agricultural productivity generally have exceeded that for forestry; for example, a historical examination of corn yields shows about a 2% annual growth rate in yields. Demand for products in both sectors has grown with increases in domestic and world population; however, U.S. agriculture has been a net exporter while forestry has been a net importer. Policies that promote near-term conversion of agricultural land into trees may result in opposite conversions after a forest harvest cycle. The combined influence of such factors is likely to change over time, requiring the capability to model switching of land uses on the same parcel in the future. Given the model's detailed regional treatment of the land base, both LTA_t and LFA_t may be nonzero in any given period.

The Influence of Incorporating Land Transfers

Base Case and Policy Scenarios

To examine the effects of land transfer omission on policy evaluation, we employ FASOM with and without its land market interface to project a base case (BASE)[7] for comparison with four alternative policy scenarios: (*a*) FARM PROGRAMS—restoration for a decade of agricultural target, price, set-aside, and loan rate farm program provisions eliminated in the 1995 Farm Bill, with elimination thereafter; (*b*) PERMANENT CRP—maintaining a permanent CRP program on 22 mil-

[7] Agriculture sector assumptions for the base case are discussed by Chang et al. and by McCarl et al. Assumptions for the forestry sector (e.g., public timber harvest) are from the "1993 RPA Timber Assessment Update" (Haynes, Adams, and Mills). The base case specifies elimination of the Conservation Reserve Program by the year 2000, with only long-term tree cover maintained (viz., about 3 million acres of plantations) thereafter.

Table 2. Projected Welfare Changes Relative to Respective BASE, with (LINKED) and without (INDEPENDENT) the Land Market Interface (percent change relative to BASE)

	Forestry		Agriculture	
Scenario/Welfare Component	INDEPENDENT	LINKED	INDEPENDENT	LINKED
FARM PROGRAMS				
Producers' Surplus	0.0	−0.2	3.0	0.0
Consumers' Surplus	0.0	0.0	0.0	−0.0
PERMANENT CRP				
Producers' Surplus	0.0	2.8	3.8	−0.1
Consumers' Surplus	0.0	−0.3	−0.1	−0.1
AFFORESTATION PROGRAM				
Producers' Surplus	−9.2	−0.2	−0.4	0.0
Consumers' Surplus	1.1	0.0	−0.1	0.0
ZERO CUT				
Producers' Surplus	11.2	10.1	0.0	−1.0
Consumers' Surplus	−1.6	−1.4	0.0	0.0

lion acres;[8] (*c*) AFFORESTATION—a shift of 12.3 million acres of agricultural land into forest cover as discussed in EPA policy deliberations (e.g., Alig et al.; Parks and Hardie);[9] and (*d*) ZERO CUT—elimination of timber harvests on National Forest timberlands. Policies affecting land exchanges between forestry and agriculture historically have had the largest impacts in the South. For example, more than 90% of the afforestation of cropland under the CRP has been in the South. The AFFORESTATION scenario involves a similar concentration of future tree planting on southern agricultural land for climate change mitigation. Further, although the public timber harvest reductions under the ZERO CUT scenario are concentrated in the western United States, the resultant interregional impacts through markets on private timber producers (e.g., increased harvest in response to higher log prices) are expected to be most substantial in the South, which contains the majority of U.S. private timberland.

Results

We compare results from scenarios simulated with FASOM's intersectoral land exchange linkages intact to those treating the sectors as independent (i.e., "with and without" approach), to examine the effects on policy analysis results. Land transfers in all cases are zero when the sectors are projected in isolation, except in the independent afforestation case, where 12.3 million acres are removed from agriculture and added to forestry. We look at differences with and without land transfers in the FASOM projected characteristics of sectoral welfare (table 2), land transfers (figure 1), shadow prices for land (figure 2), product markets (table 3), and factor use.

In the linked model, we see net future shifts into forestry (figure 1). These are caused largely by recent declines in agricultural returns with farm program revisions, CRP expiration, and increased demand for and returns to private timberland due in part to reduced public supplies of timber. Net shifts into forestry are concentrated in the East—primarily in the South. Net shifts into forestry are concentrated in 1990–2010, in part because the

[8] The estimate of the amount of CRP land to retain in permanent reserve is drawn from analyses by the Congressional Budget Office and discussions with other experts.

[9] Afforestation likely will form the backbone of any program to expand sequestering carbon in forests and forest products as a potentially useful mechanism in global efforts to offset expanding greenhouse gas emissions (Alig et al.; Parks and Hardie).

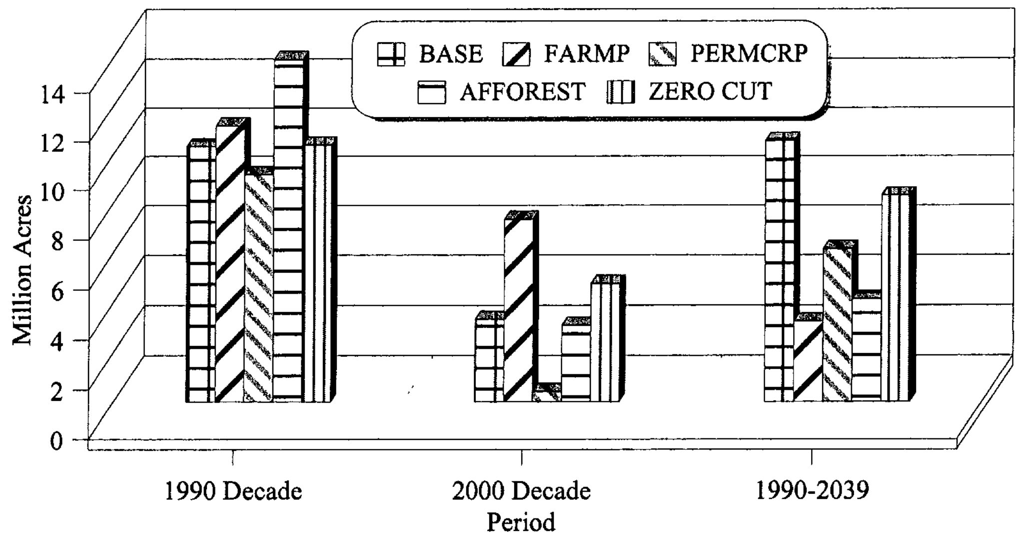

Figure 1. Projected U.S. net land transfers from agriculture to forestry in linked case, 1990 and 2000 decades and 1990–2039

availability of merchantable private timber is relatively limited up to 2010, leading to higher forestry prices and rents for forest use. Starting in 2010, the direction of net change in land use reverses, leading to net shifts to agriculture in response to rising agricultural demands and the growing accumulation of the stock of merchantable private timber. Such land transfer results are consistent with recent historical land reallocation between the two sectors and lie in the range of projections from other studies that used markedly different methods (Alig and Wear; Haynes, Adams, and Mills; USDA/SCS).

The first and foremost observation about the influence of allowing land transfers in the model is that land transfers tend to mitigate the welfare effects of policy shifts. Consider table 2 which projects welfare differences. This shows that welfare differences are larger when land transfers are not allowed, both in the cases of policies that directly reallocate land (AFFORESTATION Program and PERMANENT CRP) or indirectly affect land allocation (ZERO CUT and FARM PROGRAMS). For example, the forced afforestation of 12.3 million acres of agricultural land in the 1990 decade leads to higher land prices for agriculture (figure 2) as land becomes more scarce in that sector. Subsequently, this prompts countervailing land transfers from forestry to agriculture in the linked sector case, and by 2039, the afforestation policy leads to a smaller net shift to forest use (figure 1). However, in the independent sector case, welfare effects of the policy are larger—especially impacts on forestry surpluses—when the countervailing land transfers back to agriculture are not possible. In particular, the mitigative possibilities of moving land to solve relative scarcity problems both lower the size of the welfare difference in the target sector and raise it in the other sector. Land transfers have similar influences on output levels (table 3) and output price indices, where larger changes in production and prices result when linked land markets between the sectors are ignored.

Second, consideration of the intersectoral land exchanges may greatly reduce the effectiveness of some potential policies. Consider, for example, the climate change mitigation effect in the AFFORESTATION scenario. When the land market interface is ignored, the amount of forested land obviously increases when land is stimulated to transfer into forestry. However, when intersectoral land exchanges are included, then the model projects

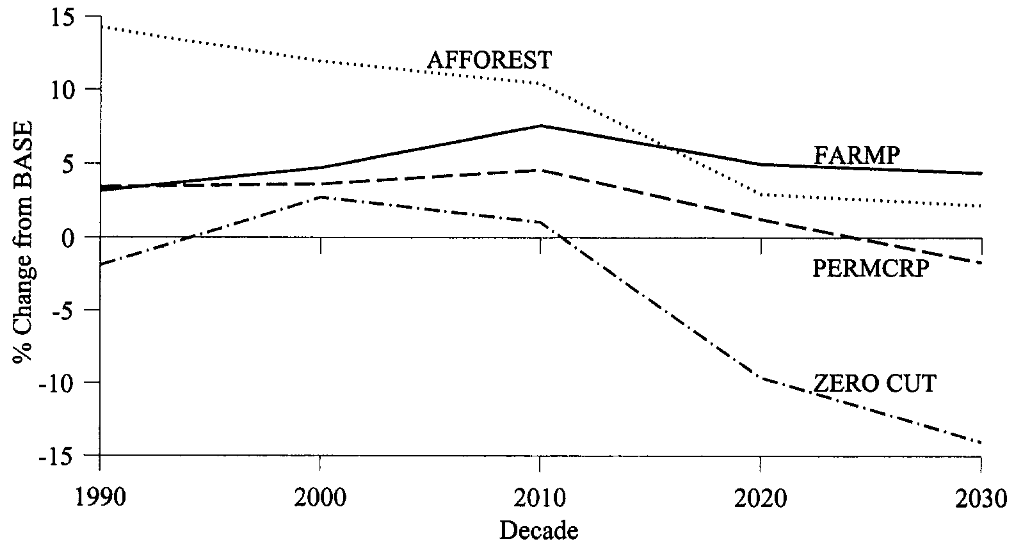

Figure 2. Percentage changes in shadow prices relative to BASE for scenarios, for convertible agricultural land in South Central region

countervailing transfers of land (figure 1), both in the current period and after one forest rotation. Many acres afforested under the policy are converted back to agriculture after the model's minimum requirement of one rotation in forestry—counter to static assumptions in some other analyses (e.g., Parks and Hardie). This substantially blunts the effect of the afforestation policy.

Third, consideration of intersectoral land

Table 3. Projected Output Changes Relative to BASE, with (LINKED) and without (INDEPENDENT) the Land Market Interface, in the 1990 and 2030 Decades (percent change relative to the respective BASE)

Scenario/Production Measure	1990 Decade INDEPENDENT	1990 Decade LINKED	2030 Decade INDEPENDENT	2030 Decade LINKED
FARM PROGRAMS				
Timber	0.0	−0.0	0.0	−1.0
Grains	2.8	0.0	0.0	3.0
Livestock	3.4	−0.2	0.0	4.7
PERMANENT CRP				
Timber	0.0	−0.2	0.0	−4.3
Grains	1.3	1.3	−5.4	−3.4
Livestock	0.2	0.0	−9.5	−6.4
AFFORESTATION PROGRAM				
Timber	1.9	−0.0	0.0	0.5
Grains	0.2	0.0	−2.6	3.3
Livestock	−1.7	−0.5	−5.1	5.0
ZERO CUT				
Timber	−4.0	−4.8	−2.5	−2.6
Grains	0.0	−0.0	0.0	−0.2
Livestock	0.0	−0.0	0.0	0.1

exchanges enhances the understanding of the possible effect of policies. Effects of land transfers from moving relatively less land from agriculture when scarcity increases (in the PERMANENT CRP scenario) or more to forestry when scarcity increases in that sector (in the ZERO CUT scenario) show the relevance to policy analysis of inclusion of intersectoral land exchanges. The linked model demonstrates that policies can have quite different impacts over time on competition for land between sectors, as indicated by the shadow prices for convertible agricultural land under the FARM PROGRAMS scenario versus those in the ZERO CUT scenario (figure 2). In addition to the intertemporal differences, the ZERO CUT scenario also reflects the interregional impacts of intersectoral land exchanges. An increase of about one million acres in southern timberland in the 1990s decade is projected in response to a ZERO CUT policy centered in the western United States.

Fourth, inclusion of intersectoral land exchanges clarifies the nature of possible reactions within the sectors. For example, the AFFORESTATION policy alters use of forest plantations rather than natural forest establishment methods and the use of irrigation in agriculture. The interconnected land allocation and land management investment is also illustrated by the FARM PROGRAMS scenario that results in the smallest net transfer of land to forestry during 1990–2039 of any scenario (figure 1). This prompts the forest sector to intensify management on the remaining forest land, primarily through establishment of an additional 3.4 million acres of plantations with higher timber volumes per acre, with more than 90% in the South. In contrast, the independent FARM PROGRAMS case shows no change in forest plantation area.

Discussion and Conclusions

Most past studies of forestry and agriculture have simplified in various ways the nature of land exchanges between the sectors, without representing land market equilibria in both sectors. The FASOM framework developed here links the two sectors, with land exchange determined spatially and intertemporally.

Our modeling of land exchange suggests that reallocation of land is a significant part of the sectors' responses to policies and external events. For example, analysis of the afforestation policy shows that countervailing land transfers are an important response, which partially offsets the implications of the policy. Another key component in adjustment strategies is intensification of timber management on existing forests. Although previous analyses have reported that land allocation is driven largely by economic incentives, those studies have not modeled land price equilibrium between the forestry and agriculture sectors and also have not introduced the additional complexity of adjustments in timber management investment over multiple decades. If land transfers between sectors are not considered, larger changes in output markets result from the reduced flexibility in land base adjustments. The relatively long production process for forestry means that existing stocks of standing timber are quite important in regard to time required generally to adjust fully to market or policy changes, relative to agriculture.

Our comparative policy simulations indicate that models which ignore land exchanges limit sectoral adjustments to policy. This can alter projections of policy impacts, both in the short and long term. In some cases, we observed both directional and order-of-magnitude differences in estimates of production and factor consumption impacts between the linked and independent cases, including significantly affecting shadow price estimates. Forest sector price response is largest when land exchange is disallowed, while agricultural output prices are less sensitive except in the afforestation policy case of a large "forced" land movement to forestry. Such impacts also vary regionally, with the South having the most potential for reallocating land from agriculture to forestry use. The model's empirical basis allows estimation of the magnitudes of projected changes, and captures dynamics such as some switching of land uses later in the projection period. In these cases, land use switches back to the original use, dependent in part on relative changes over time in demands for agriculture and forestry products.

Land use changes historically have been important to both agriculture and forestry, especially in the South, and this trend is likely to continue in the future. Our analysis of the impact of an endogenous land-use margin between agriculture and forestry in sector models suggests that land exchange can markedly influence the inferences drawn from analysis of alternative scenarios. We have examined only four specific programs and used a model with a high degree of foresight, but this limited view does suggest that it may be risky to dismiss the importance of land exchange a priori in sectoral-level studies.

References

Adams, R., D. Adams, J. Callaway, C. Chang, and B. McCarl. "Sequestering Carbon on Agricultural Land: Social Costs and Impacts on Timber Markets." *Contemporary Policy Issues* XI(1993):76–87.

Adams, D., R. Alig, J. Callaway, B. McCarl, and S. Winnett. "The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure and Policy Simulations." Res. Pap. No. PNW-RP-495, USDA/Forest Service, Portland OR, 1996a.

Adams, D., R. Alig, B. McCarl, J. Callaway, and S. Winnett. "An Analysis of the Impacts of Public Timber Harvest Policies on Private Forest Management in the U.S." *Forest Sci.* 43,3(1996b):343–58.

Adams, D., and R. Haynes. "The 1993 Timber Assessment Market Model: Structure, Projections, and Policy Simulations." Gen. Tech. Rep. No. PNW-GTR-368, USDA/Forest Service, Portland OR, 1996.

Alig, R., D. Adams, B. McCarl, J. Callaway, and S. Winnett. "Assessing Effects of Mitigation Strategies for Global Climate Change with an Intertemporal Model of the U.S. Forest and Agriculture Sectors." *Environ. and Resour. Econ.* 9(1997):259–74.

Alig, R., and R. Healy. "Urban and Built-up Land Area Changes in the United States: An Empirical Investigation of Determinants." *Land Econ.* 63(1987):215–26.

Alig, R., and D. Wear. "Changes in Private Timberlands: Statistics and Projections for 1952 to 2040." *J. Forestry* 90(1992):31–37.

Binkley, C. "Economic Models of Timber Supply." In *The Global Forest Sector: An Analytical Perspective,* eds., M. Kallio, D. Dykstra, and C. Binkley, pp. 109–36. New York: John Wiley and Sons, 1987.

Brooke, A., D. Kendrick, and A. Meeraus. *GAMS: A User's Guide,* Release 2.25. San Francisco: The Scientific Press, 1992.

Chang, C., B. McCarl, J. Mjelde, and J. Richardson. "Sectoral Implications of Farm Program Modifications." *Amer. J. Agr. Econ.* 74(1992): 38–49.

Comolli, P. "Principles and Policy in Forestry Economics." *Bell J. Econ.* 12(1981):300–09.

Haynes, R., D. Adams, and J. Mills. "The 1993 RPA Timber Assessment Update." Gen. Tech. Rep. No. RM-259, USDA/Forest Service, Ft. Collins CO, 1995.

Ince, P. "Recycling and Long-Range Timber Outlook." Gen. Tech. Rep. No. RM-242, USDA/ Forest Service, Ft. Collins CO, 1994.

Johnson, N., and L. Scheurman. *Techniques for Prescribing Optimal Timber Harvests and Investment Under Different Objectives.* Forest Science Monograph No. 18, Society of American Foresters, Washington DC, 1977.

McCarl, B. "Cropping Activities in Agricultural Sector Models: A Methodological Proposal." *Amer. J. Agr. Econ.* 64(1982):768–72.

McCarl, B., C. Chang, J. Atwood, and W. Nayda. "ASM: The U.S. Agricultural Sector Model." Draft report, Dept. of Agr. Econ., Texas A&M University, College Station, 1997.

McCarl, B., and T. Spreen. "Price Endogenous Mathematical Programming as a Tool for Sector Analysis." *Amer. J. Agr. Econ.* 62(1980):87–102.

Meyers, W., A. Womack, S. Johnson, J. Brandt, and R. Young. "Impacts of Alternative Programs Indicated by the FAPRI Analysis." *Amer. J. Agr. Econ.* 69(1987):972–79.

Mills, J., and J. Kincaid. "The Aggregate TimberLand Analysis System—ATLAS: A Comprehensive Timber Projection Model." Gen. Tech. Rep. No. PNW-GTR-281, USDA/ Forest Service, Portland OR, 1992.

Parks, P., and I. Hardie. "Least-Cost Forest Carbon Reserves: Cost-Effective Subsidies to Convert Marginal Agricultural Land to Forests." *Land Econ.* 71(1995):122–36.

Sedjo, R., and K. Lyon. *The Long-Term Adequacy of World Timber Supply.* Washington DC: Resources for the Future, 1990.

Takayama, T., and G. Judge. *Spatial and Temporal Price and Allocation Models.* Amsterdam: North-Holland, 1971.

U.S. Department of Agriculture, Natural Resources Conservation Service. "The 1992 National Resource Inventory in the United States." Unnumbered rep., USDA/NRCS, Washington DC, 1996.

U.S. Department of Agriculture, Soil Conservation Service. "The Second RCA Appraisal: Soil, Water, and Related Resources on Nonfederal Land in the United States—Analysis of Conditions and Trends." Unnumbered rep., USDA/SCS, Washington DC, 1989.

Vesterby, M., R. Heimlich, and K. Krupa. "Urbanization of Rural Land in the United States." Agr. Econ. Rep. No. 673, USDA/Economic Research Service, Washington DC, 1994.