The effects of factor supply assumptions on intertemporal timber supply behavior: the cases of investable funds and land

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Abstract: Intertemporal timber supply models typically assume perfect capital markets and perfectly inelastic supplies of land. Using a dynamic model of U.S. timber and agriculture markets, we examine (*i*) borrowing limits or capital constraints, in which investment in forest management on nonindustrial private ownerships is restricted, and (*ii*) a nonzero elasticity of land supply. Results suggest that alternative treatments of supply conditions for these factors influence the flexibility of the simulated market system to adapt to changes over time and across policy scenarios. Supply restrictions limit adjustment options in management activities and force greater change in other endogenous elements such as price and consumption. Implications drawn from any policy analyses also differ with input supply assumptions. Policy impacts were found to be largely transitory in the cases without investment limits and essentially permanent when limits exist. Recognizing a price-sensitive land supply, at least as this process is represented in the present model, partially compensates for the imposition of borrowing restrictions, moving projections closer to behavior observed in the perfect capital market cases. Access to additional land as potential afforestation investments provides additional private investment flexibility. Typically, however, this linkage is neither explicit nor endogenous in forest sector models.

Résumé : Les modèles d'offre de matière ligneuse à caractère temporel supposent typiquement des marchés de capitaux parfaits et une offre de territoires parfaitement inélastique. À l'aide d'un modèle dynamique des marchés de l'agriculture et des marchés du bois aux États-Unis, nous examinons (*i*) des limites aux emprunts ou des contraintes aux capitaux, dans lesquelles l'investissement en aménagement forestier des propriétés privées non industrielles est restreint et (*ii*) une offre de territoires à élasticité différente de zéro. Les résultats laissent supposer que des traitements alternatifs des conditions d'offre pour ces facteurs, influencent la flexibilité du système de marché simulé pour s'adapter aux changements dans le temps et dans l'ensemble des scénarios de politiques. Les restrictions de l'offre limitent l'ajustement des options dans des activités de gestion et impriment un plus grand changement dans d'autres éléments endogènes tels le prix et la consommation. Les implications découlant de n'importe lesquelles des analyses de politiques diffèrent aussi avec l'introduction d'hypothèses concernant l'offre. Les impacts de politiques se sont avérés largement transitoires, dans les cas sans limites d'investissement, et essentiellement permanentes avec l'existence de limites. L'introduction d'une offre de territoires sensible au prix, du moins comme ce processus est représenté dans le modèle actuel, compense partiellement pour l'imposition de restrictions aux emprunts, rapprochant davantage les projections du comportement observé dans le cas des marchés de capitaux parfaits. L'accès à un territoire additionnel comme des investissements potentiels de reboisement, procure une flexibilité additionnelle pour l'investissement privé. Typiquement, cependant, cette relation n'est ni explicite ni endogène dans les modèles du secteur forestier.
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Introduction

Intertemporal timber supply models, such as those described by Johnson (1973), Walker (1976), Berck (1979), Rahm (1981), Sedjo and Lyon (1990), Brazee and Mendelsohn (1990), and Adams et al. (1996*b*), respond to changes in market conditions or background policy in ways that are partly dictated by assumptions about the supplies of timber production inputs.[2] In most models, factor supplies are assumed to be either perfectly elastic or perfectly inelastic. Treatment of investable capital typically represents one extreme. Studies commonly assume perfect capital markets. For models with

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[2] As used here, an intertemporal timber supply model is one that projects timber harvest and price simultaneously over periods within the time horizon for one or more owners in a market context. Mechanically, harvests (and any other endogenous decisions, such as management investment) are set so as to maximize the present value of producers' plus consumers' surpluses. All future demand relations (or price conditions), the discount rate, and production costs are assumed to be known.

endogenous management investment decisions, there are no limits on the amounts that can be borrowed (no credit rationing) at a fixed interest rate. Land, in contrast, is generally treated as fixed. It may be possible to abandon land in some supply models (that is, not regenerate it by any means), but it is seldom possible to add land, except exogenously, for timber production.

This paper examines the impacts of alternative assumptions about supplies of capital and land as inputs in projections of timber supply and timber market behavior. Using a dynamic model of the U.S. timber and agricultural markets as a vehicle, we focus on the specific cases of (*i*) borrowing limits or capital constraints, in which investment in forest management on nonindustrial private forest ownerships is restricted, and (*ii*) a nonzero elasticity of land supply. The next section reviews past work and the potential effects of the presence or absence of land and capital supply constraints. The third section presents the simulation approach and results. A final section discusses some implications of our findings.

Previous work and theoretical background

Most past studies that have employed optimizing intertemporal harvest models have treated capital markets as perfect and the land input either as strictly fixed or varying according to exogenous rules or considerations. Indeed, with the exception of some recent theoretical and econometric studies, the timber supply implications of these standard assumptions have been given little attention. Using a savings–consumption model and assuming that private owners maximize intertemporal utility, Koskela (1989*a*, 1989*b*) considered the theoretical effects of various taxation schemes when future prices were uncertain, with and without a borrowing limit. Kuuluvainen (1990) and Kuuluvainen and Salo (1991) treated the case of perfect information and provided empirical tests of the notion that credit rationing (or perceived rationing) is a significant determinant of observed harvest behavior. In these studies, however, the land input was fixed and borrowing undertaken only to augment current period consumption. Options to change timber yields through management investment (as another use of current income or borrowed funds) were not considered.

Since capital investment is a key input to timber production, limiting its supply (or linking interest rates to amounts borrowed) would have an impact on optimal harvest timing of existing and future stands, aggregate timber output, and (in the market context) timber prices. The detailed nature of these effects would vary with the specific conditions. If investment in management were extensive in the absence of capital limitations, however, it is likely that borrowing limits would act to reduce harvest volumes in the long-term and raise prices in the face of reduced timber yields.

The potential effects of abandoning assumptions of a fixed or exogenous land base are somewhat more complex. In the simplest case, the land input could be made variable by positing a land supply function with prices representing the (rising) opportunity costs of returns foregone in other uses, such as agriculture, as do Richards et al. (1993) and Parks and Hardie (1995). Land movement is unidirectional, from other uses to forests, and owners must determine the optimal amounts by which to augment the initial forest land base. The impacts of such an option could act to expand potential supply and lower prices; though the extent and timing of impacts would vary with the specific case.

A more realistic extension would allow bidirectional movement of land, from other uses to forestry or the reverse, as relative returns dictate. Historical experience in the United States and elsewhere clearly indicates that changes in relative land rents over time can be large enough to cause some land to move back and forth between agricultural and forest uses. Often this involves concurrent movement of lands of different qualities and productive potential between the two sectors. With bidirectional movement, harvest and price effects would depend on the net shift of land into (out of) the forest sector.

With perfectly inelastic supplies of either land or capital, it is also likely that the projected responses of timber markets to changes in policy or other external conditions will vary from cases where supplies are price sensitive or perfectly elastic. Since constraints of this sort act to limit options for market (timber owner) adjustment, price and harvest reactions to policy changes may well be exaggerated compared with unconstrained cases.

But while the general directions of potential market and model response to changes in land and capital supplies seem clear enough, the extent and timing are uncertain and, to the authors' knowledge, have not been explored in past timber supply studies. Do changes in these elements produce any significant variation in projections or in the interpretation of scenario simulation results? Or can we employ the traditional assumptions with impunity? The present study offers an empirical assessment of these questions in the context of a specific model.

Simulation methods

To examine the intertemporal harvest effects of alternative assumptions on the supplies of capital and land, we conducted a set of simulation experiments with the forest and agriculture sectors optimization model (FASOM, Adams et al. 1996*a*). FASOM is a multiperiod, price-endogenous, spatial and temporal equilibrium market model of the U.S. forest and agricultural sectors. It simulates production, consumption, and investment decisions in the two sectors consistent with intertemporal welfare maximization. The two sectors are linked both in the joint objective function, which comprises the present value of producers' and consumers' surpluses in the markets of the two sectors, and through constraints on the availability of land and its transfer between sectors. A model solution gives prices, production, consumption, and management actions in both sectors for the full projection period. In management and investment decisions, producers are assumed to have full knowledge of current and future market conditions. Simulations proceed on a decade time step with a 9-decade time horizon to accommodate treatment of terminal inventories. Analysis focuses on the first five decades of the projection (1990 to 2040) as the period of primary interest for purposes of most policy analyses. The model employs nine geographic regions in the United States.

The forest sector module, described by Adams et al. (1996*b*), treats only the market for logs, differentiated by hardwood and softwood species and sawlog, pulpwood, and fuelwood products. Empirical demand functions for logs were derived from solutions of the TAMM and NAPAP models

(Adams and Haynes 1996; Ince 1994) together with cost data on transportation and harvesting. Capacity to process logs is limited, and decisions to purchase additional capacity are endogenous. Substitution of roundwood between product categories (sawlogs for pulpwood, pulpwood for fuelwood) and between residue generated in sawlog processing and pulpwood is permitted. Log trade with regions outside the United States is recognized via price-sensitive, product-specific export demand and import supply relations.

The model of private harvest and management follows the "linear forest" form of Johansson and Löfgren (1985) or "model II" of Johnson and Scheurman (1977). Timberland is differentiated by two owner classes (industrial and nonindustrial), forest type, site productivity, management form or intensity, suitability for transfer to agriculture, and age-class.[3] Decisions on harvest age, management intensity, and postharvest forest type are endogenous. Public log supply is treated as exogenous.

The agricultural sector module was adapted from an earlier equilibrium model described by Chang et al. (1992). As in the forestry case, its objective maximizes the present value of consumer willingness-to-pay net of the costs of intermediate and primary factors and transportation. Production activities comprise more than 200 potential budgets, representing different types of crops, cropping methods, and options for secondary processing. Some 36 primary crops and livestock commodities and 39 secondary or processed products are considered, including field crop, livestock, and tree crop production. At the regional level, crops compete for price-sensitive labor and irrigation water supplies and a land base (which includes areas converted from forests).

Land movements between the sectors occur through the nonindustrial private forest ownership. This is the only group that holds both forest and agricultural lands in the same ownership and has historically been the pathway for virtually all of the land-use transfers between sectors. Forest industry land holdings are treated as exogenous in the present analysis. Suitable nonindustrial private land can move, after timber harvest in the case of timberland conversion, between forest and agricultural use based on considerations of intertemporal profitability and subject to the availability of other resources. Limits on the area of convertible forest land were derived from the National Resources Inventory and the Second RCA Appraisal (USDA Soil Conservation Service 1989; USDA National Resources Conservation Service 1996). Area estimates for agricultural land suitable for conversion to forests were drawn from Moulton and Richards (1990). A summary of total U.S. land areas involved is given in Table 1.

A highly condensed mathematical description of the model, emphasizing the sectoral land linkages, is given in the Appendix. Endogenous variables in forestry are forest harvest volume (H in the Appendix notation) and the area of harvesting and regeneration of existing (X) and newly created forest stands (N) over time, and the intensity of management (M) applied to the latter. In the agriculture sector, the model determines agricultural output (Q), primary (crop or livestock) and secondary production (C and S) and use of price-sensitive agricultural inputs (W, comprising irrigation water and labor). Land movements between sectors are represented by the variables L2A, land from forest to agriculture, and LFA, land from agriculture to forests. Given the model's detailed treatment of the land base, both L2A and LFA may be nonzero in any given period. Shadow prices of Appendix constraints [A2] and [A4] give equilibrium prices in the forest and agriculture product markets. Relations [A3], [A5], [A7], and [A8] regulate the movement of land between sectors. In the forest sector, land can move to agriculture if the opportunity costs of diversion from forestry plus any conversion costs (C_L) plus any rents to conversion limits [A7] are less than its value in agriculture. This is the shadow price of Appendix relation [A3]. If land is converted from agriculture to forestry, subject to limitations in [A8], the shadow price of relation [A5] can be interpreted in a similar way for the agriculture sector.

The model treats the process of forest management as if it were a decision made solely at time of stand initiation (regeneration) with perfect foresight. Stands cannot change management class or management intensity until harvested. We simulate the effects of investment (capital) borrowing limits for nonindustrial private forest owners by adding a set of investment cost constraints to the FASOM structure (relations [A9] in the Appendix).[4] The sum of regeneration costs in each period is restricted to be no larger than a prespecified real dollar bound, K_t. Bounds vary across regions but we did not change them over time. They were based on estimates of total nonindustrial planting area for 1993 derived from U.S. Forest Service planting reports (USDA Forest Service 1994) and authors' estimates of per-acre planting costs.[5]

The effects of varying the elasticity of land supply were examined by manipulating FASOM's land base interface. Land may move to either use depending on its relative returns. When FASOM is run with this linkage intact, the forest sector effectively faces a rising supply curve for its land input. This supply relation will vary over time and with any changes in the simulation conditions. When the linkage is eliminated (dropping activities L2A and LFA and constraints [A7] and [A8]), the sectors operate independently and the land supply for forestry is fixed.

Finally, as noted above, it is likely that alternative land and capital supply assumptions will modify the impacts of changes in externally imposed simulation conditions. To illustrate this prospect we examine three scenarios:
(1) A "base" case that follows general timber market conditions

[3] Four management intensity classes are used: passive (effective abandonment after harvest with limited natural regeneration and reduced yields), low (natural regeneration), medium (planting), and high (planting with improved stock, intermediate treatments such as fertilization or thinning). Basic inventory and timber yield information were derived from data collected for *The 1993 RPA Timber Assessment Update* (Haynes et al. 1995), Moulton and Richards (1980), and Birdsey (1992). The largest part of the timber management cost data were developed from regional input and price data by the authors.

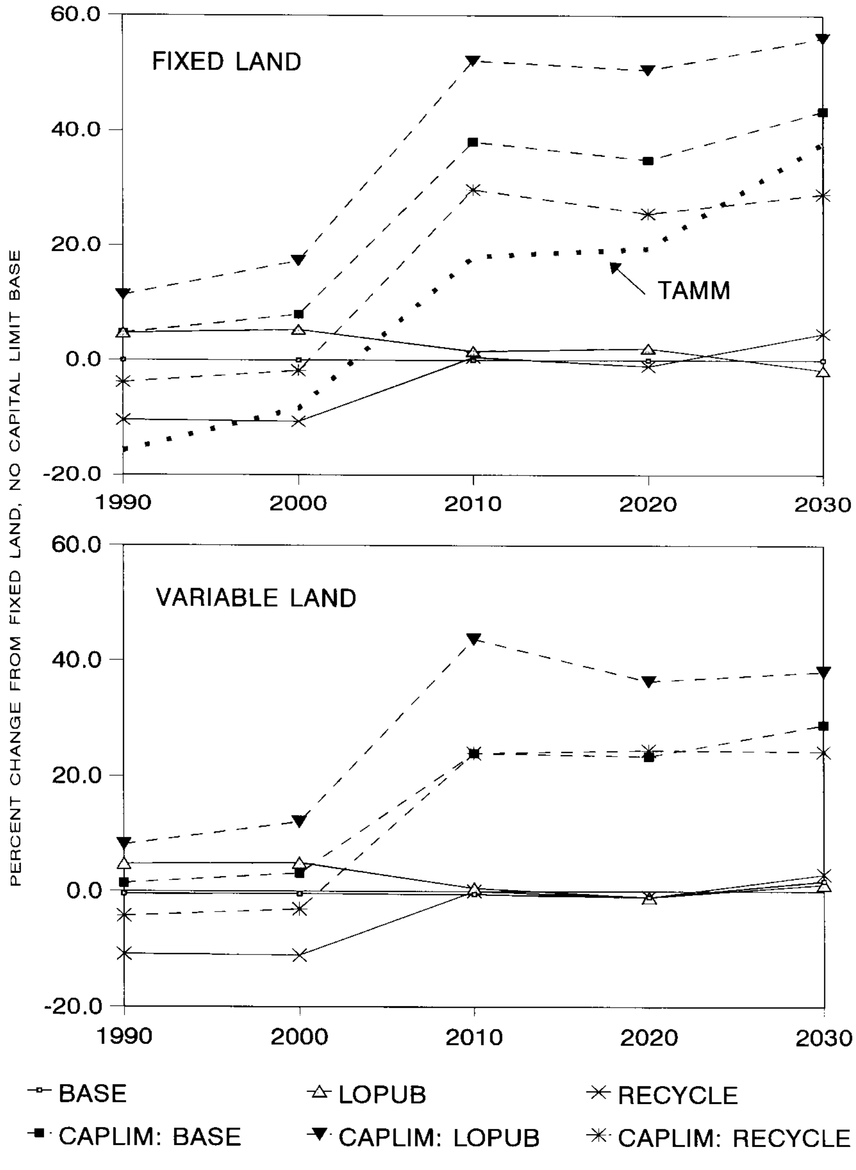
[4] Industrial owners may face similar restrictions, but we do not examine them here.

[5] So that model investment might resemble observed investment behavior as closely as possible in all its dimensions, we also limit both the mix of afforestation and reforestation and the total area of planting to 1993 levels. In all cases, the investment, mix, and area constraints are simultaneously binding in the solutions. This approach adds a further element of realism to the capital limitation and has no impact on the general nature of our results or the conclusions that we draw from the analysis.

Table 1. Areas ($\times 10^6$ ha) of agricultural land, timberland by owner, and lands convertible between uses in the United States, 1990 (see comments in text for sources).

	Timberland by owner			Agricultural lands
	Nonindustrial	Industrial	Other	
Total area	116.4	28.5	53.2	309.3
Timberland suitable for agricultural	15.5	—	—	—
Agricultural land suitable for timberland	—	—	—	89.2

Fig. 1. U.S. softwood sawtimber prices under alternate capital and land supply assumptions, expressed as percent changes from the fixed land base, no capital limit case.

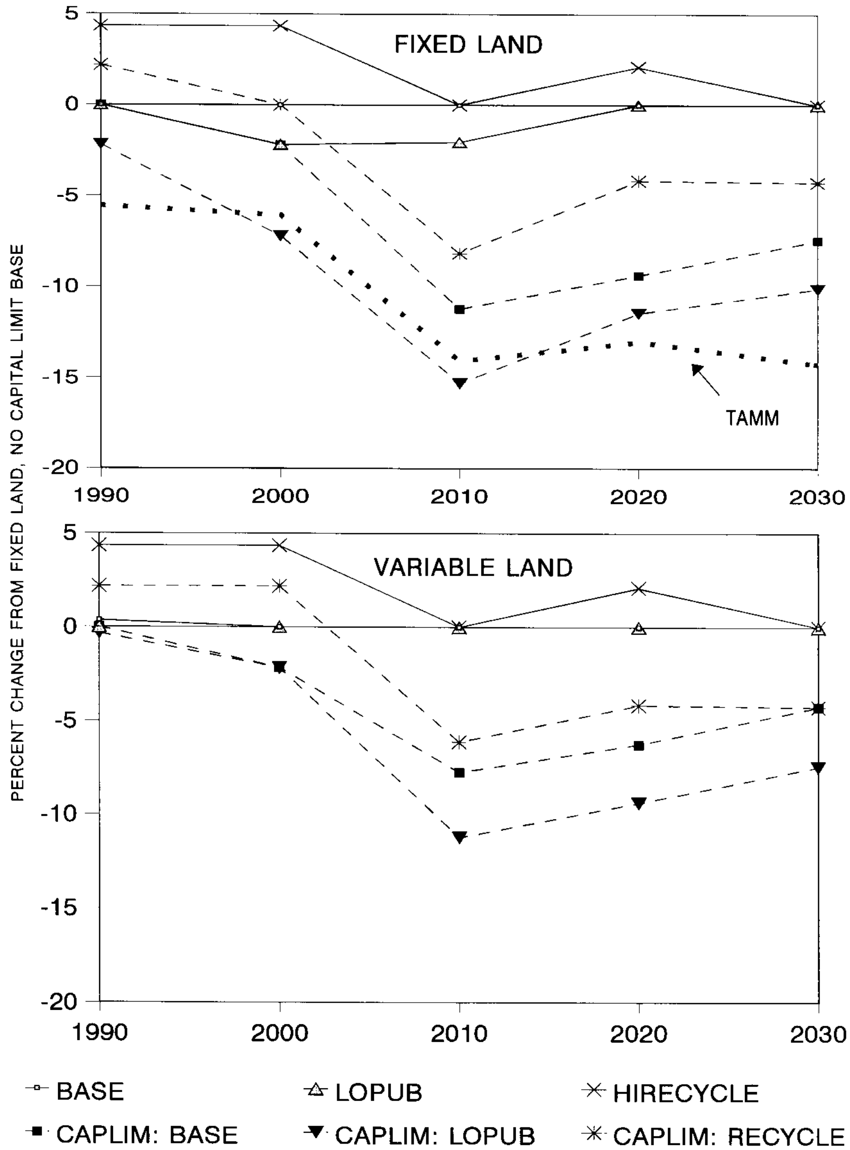


described in Haynes et al. (1995) and agriculture market conditions as in Chang et al. (1992).[6]

(2) A "high recycling" outlook, in which we allow wastepaper utilization rates in the United States to reach 60% by 2010 in contrast with 45% by 2040 in the base case (see Haynes et al. (1995) for further details of this case). This scenario

[6] Base case assumptions for the 1990–2040 period include (1) construction: new residential housing starts average 1.7 million units (all types) per year with a declining trend, residential upkeep and repair expenditures grow at 1.4% per year, and value of nonresidential construction put-in-place rises at 0.8% per year; (2) manufacturing: real GDP grows at 2.7% per year, the index of manufacturing production grows at 3.6% per year; (3) shipping: pallet production roughly doubles by 2040; energy costs: real world oil prices roughly triple by 2040; technology: technical improvement in processing and wood utilization efficiency in consumption change in response to endogenous price signals and assumed trends as described in Haynes et al. (1995).

Fig. 2. U.S. softwood sawtimber consumption under alternative capital and land supply assumptions, expressed as percent changes from the fixed land base, no capital limit case.



(RECYCLE) reduces demand for both softwood and hardwood pulpwood relative to the base case, with greatest changes in the South.

(3) A "reduced public timber harvest" outlook (LOPUB), where harvests from national forests in all regions are reduced by 50% from the base and cut from all other public lands is reduced by 25%. This represents a reduction in public cut from an annual average of 62.2 to 45.3×10^6 m^3, relative to an annual total harvest of roughly $628.3 \times$ m^3. In contrast with the reduced demand conditions of the RECYCLE case, this scenario represents a reduction in supply, primarily of softwood sawtimber in the West.

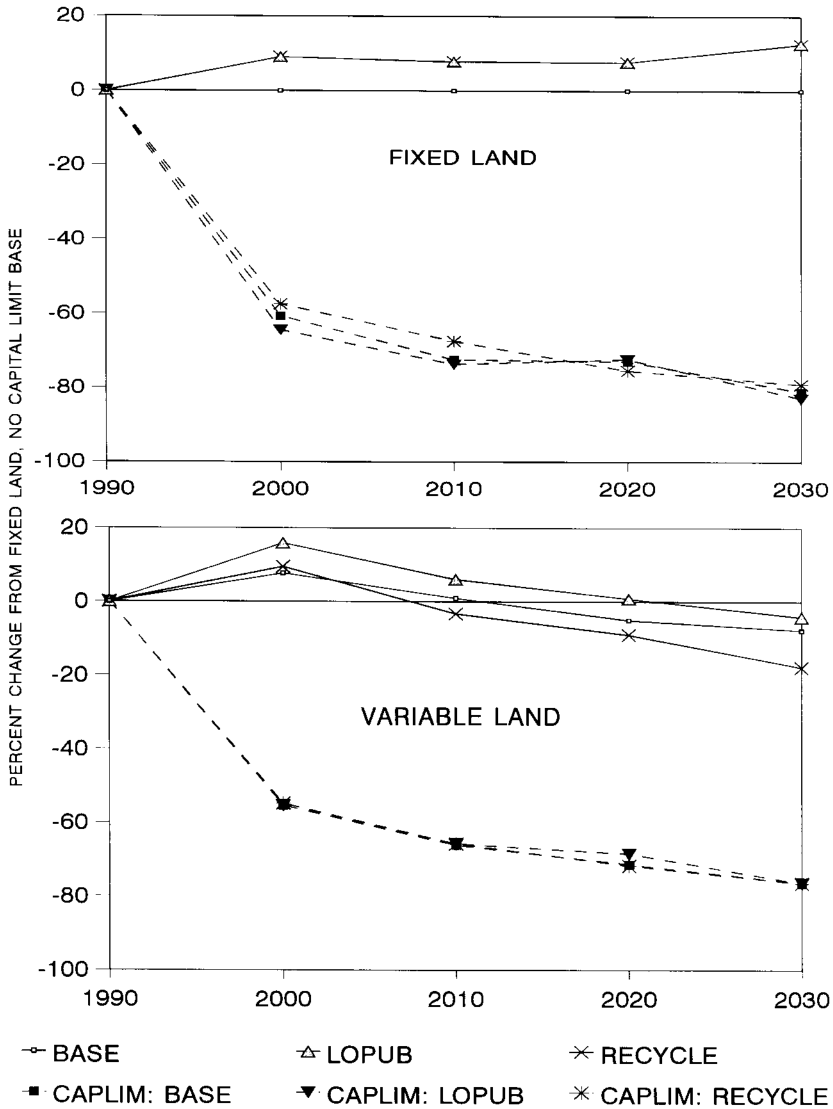
Simulation results

Results are illustrated in Figs. 1–4 for softwood sawtimber prices and consumption, nonindustrial private plantation area in the South and total U.S. private softwood inventory. Projections labeled CAPLIM refer to the case of limited investment funds. The upper portions of the figures (labeled FIXED LAND) show the results of fixed land base runs, those in which agriculture–forestry land movements were restricted. The lower parts (labeled VARIABLE LAND) show results where endogenous land exchange between the sectors was allowed and land supply for forestry is price sensitive. In all cases the figures show the percent deviation from the case most commonly assumed in timber supply studies, that of a fixed land base and unlimited access to capital.

Limited capital

Regardless of the scenario or land supply mechanism, constraining nonindustrial private planting investment raises the time path of sawtimber prices (Fig. 1) and reduces consumption (Fig. 2). These shifts are limited in the 1990s and 2000s and expand thereafter. The initial lag in response reflects the time required from planting to first merchantability for softwood

Fig. 3. Area of softwood plantations on Nonindustrial private land in the U.S. South, expressed as percentage changes from the fixed land base, no capital limit case.



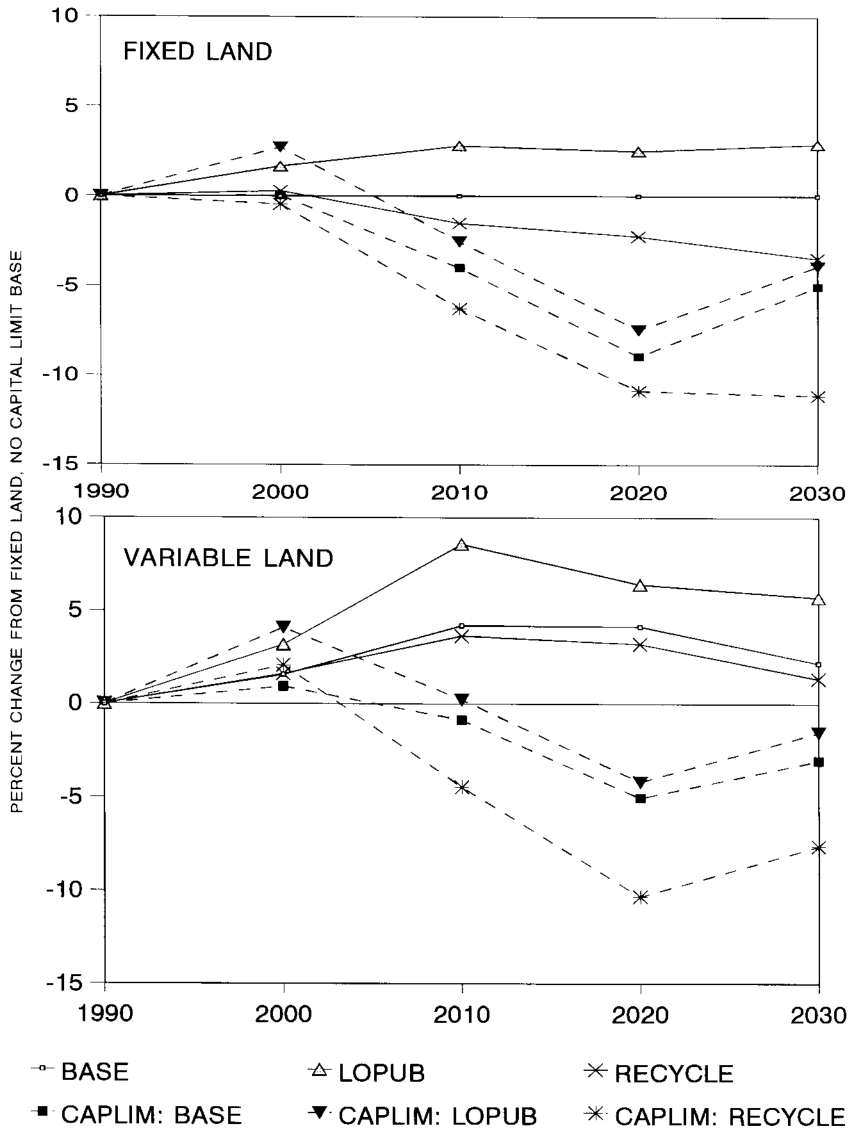
plantations. Harvest responses during this interval are based on inventory existing at the start of the projection. Reductions in the area of new plantations, as in the CAPLIM case, are reflected in merchantable inventory in later periods.

Prices rise and consumption falls because the area of planted softwood forests, and hence the growth and inventory of harvestable softwood timber, in the CAPLIM runs declines relative to the unconstrained cases. Figure 3 shows total area of plantations in the southern nonindustrial private ownership. In the FIXED LAND runs, these plantations are reduced 60 to 80% (16.2 to 24.3 × 10^6 ha) in the long-term by imposing investment limitations.[7] And while industrial ownerships respond by expanding plantations, the industrial land base is too small to fully compensate. As a consequence southern and total U.S. private softwood inventories are lower in the CAPLIM runs as shown in Fig. 4.

The response of softwood prices and consumption to the high recycle and low public cut scenarios differs markedly between CAPLIM and unrestricted runs. In the CAPLIM cases, prices and consumption (Figs. 1 and 2) depart from base levels for the entire projection. The unrestricted cases differ in the first two decades (again reflecting the minimum time for maturation of new stands) then converge to roughly similar time paths, suggesting that it is optimal (in terms of the model objective) to return to the base case price and volume trajectories as soon as possible after an initial disturbance and adjustment. This is realized by modifying management investment. Figure 3 indicates, however, that the restricted runs have little latitude to affect such adjustments. The planting investment restrictions are binding in all periods, and planted area is rising as rapidly as constraints will allow. Restricted scenarios have no means to attain the unrestricted production trajectories.

[7] In the CAPLIM cases these areas are regenerated after harvest using one of the less costly natural regeneration management classes rather than by planting.

Fig. 4. Total U.S. private softwood timber inventory, expressed as percent changes from the fixed land base, no capital limit case.



Price-sensitive land supply

The VARIABLE LAND projections, shown in the lower parts of the figures, allow lands that are suitable for either forestry or agriculture to move between the two sectors, as market forces dictate. In the no capital limit, VARIABLE LAND case, for example, the net land exchange involves the movement of some 1.6×10^6 ha of agricultural land (mostly pasture in the South) into forestry during the first 5 decades. In the CAPLIM, VARIABLE LAND run, in contrast, there is a net movement of nearly the same area in the opposite direction (from forestry to agriculture). In this instance, the gross area moving to agriculture is actually lower than in the no CAPLIM case. But the CAPLIM restriction sharply reduces the transfer from agriculture to forestry, yielding a net flow to agriculture.

Under FIXED LAND there is a greater dispersion of the scenario results for price and consumption around the base case compared with VARIABLE LAND for either treatment of capital (see Figs. 1 and 2). With a fixed land base, timber owners can adapt to the scenario changes only by shifting harvest levels and investment. As a result, market changes (prices and consumption) provide a greater portion of the overall adjustment. A fixed land base also affects the differences between the CAPLIM and no CAPLIM cases (contrast comparable pairs of broken and solid lines within the upper and lower panels of the figures). Imposition of the CAPLIM leads to greater increases in price and losses in consumption in the FIXED LAND runs. The drop in plantation establishment between free and limited investment in Fig. 3 is also larger in the fixed land case. Since the CAPLIM forces near equality in plantation responses between fixed and variable land cases, the main difference between the upper and lower panels in the figure is in the no CAPLIM cases. Here the higher forestry prices in the FIXED LAND runs encourage more planting than the VARIABLE land cases. For timber inventory in Fig. 4, in constrast, a smaller forest land base and inventory in the FIXED LAND case yields a smaller inventory drop between no CAPLIM and CAPLIM than for VARIABLE LAND.

Discussion

The simulation results suggest that perfect capital market and fixed land supply assumptions employed in many timber supply studies may have important effects on both basic projections and the outcomes of policy analysis. Using the FASOM model, we find that the land supply assumption has small, but discernible, impacts on measures of softwood sawtimber consumption and prices. In contrast, the CAPLIM restriction produces substantial changes, shifting both base and scenario results by 5–15% in the case of consumption and 20–40% or more for prices, depending on the time period within the projection. Applied jointly, interaction of the two restrictions further exaggerates impacts.

Alternative treatments of supply conditions for land and capital influence the flexibility of the simulated market system to adapt to changes over time and across scenarios. Constrained supplies, as in the CAPLIM and FIXED LAND cases, limit adjustment options in management activities and force greater change in other endogenous elements such as price. Projections of price and consumption from FASOM with the CAPLIM restriction more closely resemble those from market models such as TAMM (Adams and Haynes, 1996) that are not set in an intertemporal optimization context and use fixed, exogenous forest management (investment) assumptions. This is suggested in Figs. 1 and 2, where we have added the analogous TAMM projections from the most recent U.S. Forest Service Timber Assessment Update (Haynes et al. 1995).

Implications drawn from any policy analyses would also differ between CAPLIM and unrestricted runs. The CAPLIM projections of the RECYCLE and LOPUB scenarios show distinct price, consumption, and inventory patterns over time, with none of the tendency toward convergence of the unrestricted cases. Policy impacts are transitory (to a degree dependent on the earliest ages of merchantability of plantations) in the unrestricted case and essentially permanent in the other. Again, use of the TAMM model for policy analysis shows results very similar to this latter, restricted case (see Haynes et al. 1995, pp. 50–64, for examples of this behavior).

Recognizing a price-sensitive land supply, at least as this process is represented in FASOM, partially compensates for the imposition of borrowing restrictions, moving projections somewhat closer to behavior observed in the perfect capital market cases. Access to agricultural lands as potential afforestation investments provides a significant expansion in nonindustrial private investment flexibility. Typically, however, this linkage is neither explicit nor endogenous in forest sector models.

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Appendix

Table A1. Condensed mathematical description of forest and agriculture sector optimization model.

[A1]	Max	$\sum_{t=0}^{T} (1+r)^{-t} \Big[\int D_{\mathrm{F}}(H_t)\, \mathrm{d}H_t - F(X_t, N_t, M_t) - C_{\mathrm{L}}(\mathrm{L2A}_t)$	$+ \int D_{\mathrm{A}}(Q_t)\, \mathrm{d}Q_t - A(C_t, S_t) - \int S_{\mathrm{W}}(W_t)\, \mathrm{d}W_t \Big]$		
[A2]	subject to	$H_t \quad - h(X_t, N_t, M_t)$		$\leq$	0
[A3]		$R(X_t, N_t, M_t) \quad - \mathrm{L2A}_t + \mathrm{LFA}_t$		$\leq$	E_{F}
[A4]			$Q_t \quad - Y(C_t, S_t)$	$\leq$	0
[A5]		$\mathrm{L2A}_t - \mathrm{LFA}_t$	$+ a(C_t)$	$\leq$	E_{A}
[A6]			$w(C_t) \quad - W_t$	$\leq$	0
[A7]		$\mathrm{L2A}_t - \mathrm{LFA}_t$		$\leq$	SFA
[A8]		$- \mathrm{L2A}_t + \mathrm{LFA}_t$		$\leq$	SAF
[A9]		$P(N_t, M_t)$		$\leq$	K_t

Note: Time subscripts suppressed on functions, where (in alphabetical order) $A(C_t, S_t)$, costs of producing, processing, and shipping agricultural products determined by crop–livestock and secondary product output; $a(C_t)$, land use in crop–livestock production; $C_{\mathrm{L}}(\mathrm{L2A}_t)$, cost of converting forest land to agricultural use; C_t, crop and livestock production; $D_{\mathrm{A}}(Q_t)$, demand for domestic agricultural products; $D_{\mathrm{F}}(H_t)$, net demand for products from the domestic forest sector; E_{F}, E_{A}, initial endowments of forest and agricultural land; $F(X_t, N_t, M_t)$, management (for regeneration and other activities varying with M), harvest, and log shipment costs; H_t, harvest volume from forest sector in period t, determined as a function, h, of areas of existing (X) and replanted (N) stands and their management intensity (M), K_t, upper bound on capital available for investment in management; $\mathrm{L2A}_t$, land moved from forest to agricultural use; LFA_t, land moved from agricultural to forest use; M_t, forest management intensity (comprising four classes); N_t, area of new forest stands created since the start of projection (differentiated at each time t by date of planting and date of harvest); $P(N_t, M_t)$, management costs (planting and any subsequent treatments) on regenerated areas (N) varying with management intensity; Q_t, production of domestic agricultural products; $R(X_t, N_t, M_t)$, regeneration of forest X and N areas at various management intensities, M; SFA, SAF, area (maximum net shift) of land in forests suitable for agriculture and land in agriculture suitable for forest; S_t, secondary agricultural processing; $S_{\mathrm{W}}(W_t)$, supplies of price-sensitive inputs used in crop and livestock production (irrigation water and labor); W_t, use of price-sensitive inputs in agricultural production determined as a function, w, of crop–livestock production (C); X_t, area of forest stands that existed at the start of the projection (differentiated at each time t by initial age and date of harvest); $Y(C_t, S_t)$, yield of agricultural products from crop–livestock and secondary processing. The model is structured as a nonlinear programming problem and solved using MINOS within the GAMS programming system (Brooke et al. 1992).