THE ECONOMICS OF GLOBAL TIMBER MARKETS

September 2, 1997

Brent Sohngen
Department of Agricultural Economics
The Ohio State University
2120 Fyffe Rd.
Columbus, OH 43220

Robert Mendelsohn
Yale School of Forestry and Environmental Studies
360 Prospect Street
New Haven, CT 06511

Roger Sedjo
Resources For the Future
1616 P Street, NW
Washington, DC 20036

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This research was funded by a grant from the Department of Energy and Resources For the Future. The authors appreciate the advice of Ken Lyon. All views expressed in this paper, however, are those of the authors alone.

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ABSTRACT: This paper develops a global timber market model which captures how timber supply reacts to future predicted increases in the demand for timber. Higher future demand is expected to increase prices, reflecting greater land scarcity. Investments in growing timber are also expected to increase, expanding output and tempering the price response. A greater reliance on plantations in productive regions is predicted to allow large areas of natural forest in low valued regions to remain largely intact. The quantitative results are sensitive to the rate demand increases, the cost of plantations, and access costs of natural forests.

INTRODUCTION

With expanding human population and economic development, natural landscapes have been increasingly manipulated to accommodate the demand for timber and land. For example, models of natural forest ecosystems reveal that forests should stretch over 48% of the terrestrial landscape (Haxeltine and Prentice), but in fact they cover only 27% (FAO, 1995). Most of the lost forest is land that has been converted to grow crops or livestock. Many remaining natural forests, however, have been replaced by managed forests. Older stands have been replaced by younger stands, and low valued species have been replaced by species which yield high timber returns. Thus, despite the large conversion of land from forests to farms, timber supply has expanded.

This paper presents a forward looking dynamic model of global timber markets that builds on earlier efforts by Walker, Sedjo and Lyon, Lyon and Sedjo, Brazee and Mendelsohn, and Sohngen and Mendelsohn. An expanding demand function captures predicted increases in the future demand for timber products. Timber supply is captured with a complex dynamic model which anticipates future demand and makes efficient investments into future timber supplies. This model differs from previous efforts in several ways. First, it models additional global regions to capture essential differences in the ecology and economics of each region. This feature allows the model to balance harvests across inaccessible and managed forests in each region. Second, it endogenizes forest investments for future supplies in all regions. A previous effort by Sedjo and Lyon, for example, left many regions of the globe unresponsive. Third, it captures a complex description of stand ages in order to endogenize standing inventory in forest decisions.

These features allow the model to adapt flexibly to changing conditions following efficient gradual pathways. The model predicts future timber market prices and quantities, investments, and economic wilderness areas. As such, the model is useful not only to participants in the timber market, but also for natural forest conservation since the model predicts how markets are likely to utilize or preserve these forests in the future.

In the next section, we develop the theoretical model. In the third section, we discuss empirical components of the model. In the fourth section, we use the model to describe a baseline timber market scenario. We then vary key model parameters to explore three alternative scenarios. The paper concludes with some general observations.

A MODEL OF GLOBAL TIMBER MARKETS

The demand for timber products is derived from a well behaved utility function over industrial wood and all other goods. A global demand function for industrial timber logs is derived, which is the additive sum of many different regional demand functions. The inverse demand function is:

$$(1) \quad P(t) = D(Q(t), Z(t)),$$

where $Z(t)$ is the vector of all other goods purchased. Demand is expected to shift over time due to population growth and changes in per capita income. The benefits of industrial wood harvests can be found as the area underneath the demand curve, or Marshallian consumer surplus.

$$(3) \quad C_H(Q(t)) = \sum_i c_i^A(q_i(t)) + \sum_i c_i^H(q_i(t)).$$

$c_i^A(q_i(t))$ are the costs of accessing timber stocks and $c_i^H(q_i(t))$ are the costs of harvesting. These costs are expressed as a function of the quantity of timber harvested in each type, $q_i(t)$, in time t . Access costs are important for stocks of natural forests at the economic margin due to the absence of roads and infrastructure. Access costs are assumed to rise as additional land is harvested in this region because the costs of building and maintaining new roads are high in inhospitable regions such as the boreal forests of Canada and the Former Soviet Union. Marginal harvesting costs for other species and regions are assumed to be constant in terms of the quantity of timber harvested. They are applied to all species harvested, regardless of location.

Resources can also be spent regenerating forests after they are harvested. The costs of regenerating timberland, where the annual area regenerated in species i is $G_i(t)$, are:

$$(4) \quad C_G(t) = \sum_i p_{i,m} m_i(t) G_i(t),$$

where $m_i(t)$ is a unit of management intensity purchased at price $p_{i,m}$ (Sedjo and Lyon). Management intensity determined at the time of planting has an effect on the future stock of timber, in that greater (lower) management intensity will enhance (decrease) future yields. The returns to additional units of management are assumed to increase at a decreasing rate (they are concave). In this case, the following two conditions hold,

$$\frac{dV_i(t_{a_i} - t_0)}{dm_i(t_0)} \geq 0, \text{ and } \frac{d^2V_i(t_{a_i} - t_0)}{dm_i(t_0)^2} \leq 0, \text{ where } t_{a_i} \text{ is the time of harvest for species } i, \text{ and}$$

t_0 is the time the land was regenerated.

In some circumstances, such as when future prices are rising rapidly, it may be advantageous to expand the area of forests. Establishing new lands in timber plantations involves additional costs over replanting existing forestlands because the landowner must expend resources finding new lands and preparing it for timber. If new lands in timber plantations are $N_i(t)$, the costs of new land are given as

$$(5) \quad C_N(t) = \sum_i p_{m,i} m_i(t) N_i(t) + \sum_i f_{N,i}(N_i(t)).$$

$f_{N,i}(N_i(t))$ are labor and land conversion costs associated with establishing an additional hectare of land for plantations. These costs are assumed to be an increasing function of the total area of plantations established in type i .

The objective of a social planner (economic efficiency under competition) is to maximize the present value of net benefits:

$$(6) \quad \underset{H_i(t), G_i(t), N_i(t), m_i(t)}{\text{Max}} \quad W = \int_0^{\infty} e^{-rt} \{S(\cdot)\} dt,$$

where r is the interest rate and annual net benefits, $S(\cdot)$, are defined as:

$$(7) \quad S(\cdot) = \int_0^{Q^*(t)} \{D(Q(t), Z(t)) - C_H(Q(t))\} dQ(t) - C_G(t) - C_N(t) - \sum_i R_i(X_i(t))$$

Annually, the net benefits are the gross revenues from harvesting timber less the costs involved with managing and holding timber, where $R_i(t)$ is the annual cost of holding land in timber (land rent), and $X_i(t)$ is the total area of land in timber type i . The model tracks both the total area of land in timber, $X_i(t)$, as well as the age of timber. The age of timber is tracked through the yield function associated with each hectare of land in timber. A social planner must decide how much of the population to harvest, $H_i(t)$, how many of these hectares to regenerate, $G_i(t)$, how many new hectares to plant, $N_i(t)$, and how intensively to regenerate, $m_i(t)$.

The problem is constrained by the stock of land maintained in forests,

$$(8) \quad \dot{X}_i = -H_i(t) + G_i(t) + N_i(t) \quad \forall i$$

This equation expresses the change in the size of the total population of each type of organism in each period; it is the difference between what is harvested and what is regenerated. In addition, initial stocks must be given, and all choice variables are constrained to be greater than or equal to 0:

$$(9) \quad X_i(0) = X_{i,0} \quad \forall i$$

$$(10) \quad X_i(t), H_i(t), G_i(t), N_i(t) \geq 0 \quad \forall i$$

Equation (9) is an initial condition for the stock variable, which defines not only the total quantity of timber harvested, but also the age distribution of the initial stock (through a yield function associated with each hectare of land).

The model above can be solved using the maximum theorem (Pontryagin, et al.). One set of conditions resulting from this model involves harvesting accessible forests. These forests will be harvested according to

$$(11) \quad \dot{P}V_i(a_i(t)) + (P(t) - c_i^H)\dot{V}_i = r(P(t) - c_i^H)V_i(a_i(t)) + R_i(t) \quad \forall i$$

$P(t)$ is the global market clearing price of industrial timber logs, and c_i^H is the marginal cost of harvesting an additional unit of timber. Timber will be harvested along a time path where the marginal benefits of waiting an extra moment to harvest are equated with the marginal costs. The marginal benefits of waiting, the left hand side of (11), arise from additional growth in the organism, $\dot{V}_i$, and changes in price, $\dot{P}$. If prices are declining, the marginal benefits of waiting are reduced. The marginal costs of waiting, the right hand side of (11), include the opportunity costs of delaying harvests and using the land for one more period. For example, if stocks are left intact, $R_i(t)$, is the value of the delay in future rotations.

While condition (11) involves the use of accessible timber stocks, one form of intensifying timberland management is to harvest natural forests at the economic margin more heavily, thereby bringing these forests into the accessible timberland base. In the extensive margin, harvests will occur according to

$$(12) \quad \dot{P} = r(P(t) - c_i^H - c_i^A), \quad \forall i$$

where c_i^A is the marginal access cost. Equation (12) differs from (11) in two distinct ways. First, annual growth ($\dot{V}$) is 0 because these stocks are considered old growth, and as much timber dies in any year as grows. Second, rental costs, $R_i(t)$, are low or nonexistent in this region because there is little competition for land. From this equation, one could see that if all forest land was old growth, then harvests would occur along a path where the rate of growth in net timber price equals r , a condition described by Hotelling (1931).

Along the economic margin, the key issue is whether forests have a net positive value at all. Access costs are high enough that there is little or no incentive to harvest extensive stocks. Because this economic choice is close, harvests of marginal forests are sensitive to world prices. Any public decision which raises these costs, for example, by insisting on planting for regeneration, would reduce the incentive to develop these resources further.

Deciding whether or not to regenerate timberland, $G_i(t)$, once it has been harvested, requires comparing the discounted future marginal benefits with the current marginal costs,

$$(13) \quad (P(t_{a_i}) - c_i^H) V_i(t_{a_i} - t_0) e^{-r(t_{a_i} - t_0)} = p_{m,i} m_i(t_0) + \int_{t_0}^{t_{a_i}} [R_i(z_i) e^{-r(z_i - t_0)}] dz_i, \quad \forall i$$

According to (13), land will be replanted in forests as long as the discounted marginal benefits of the last hectare offsets the current marginal costs. The marginal costs include the costs of regeneration, $p_{m,i}m_i(t_0)$, and the discounted stream of rental costs for maintaining these lands in forests. If prices are expected to remain high in the future, land will remain in forests. If, however, prices are declining relative to other goods in society, some land may flow out of forests and into other uses.

In addition to deciding whether or not to maintain lands in forests, managers must decide on investments in regeneration. In many regions, even if land is left alone, it will regenerate in forests naturally. Foresters, however, control the stocking density of forests according to

$$(14) \quad \left(P(t_{a_i}) - c_i^{H,i} \right) \frac{dV_i(t_{a_i} - t_0)}{dm_i(t_0)} e^{-r(t_{a_i} - t_0)} = p_{m,i} \quad \forall i$$

At the margin, landowners continue investing in management intensity until the discounted marginal benefits just equal the current marginal costs.

Determining the area of new hectares in plantations requires comparing the discounted marginal benefits of one additional hectare of land with the marginal costs of that additional hectare of land,

$$(15) \quad \left(P(t_{a_i}) - c_i^{H,i} \right) V_i(t_{a_i} - t_0) e^{-r(t_{a_i} - t_0)} = p_{m,i} m_i(t_0) + f_{N,i}'(N_i(t_0)) + \int_{t_0}^{t_{a_i}} [R_i(z_i) e^{-r(z_i - t_0)}] dz_i$$

If prices are expected to increase in the future, the marginal benefit of establishing additional plantation lands increases, and new lands flow into plantations.

EMPIRICAL MODEL

The model is programmed and solved using the GAMS programming language and the MINOS solver. Arbitrary terminal conditions are imposed on the system in order to solve the model. The terminal conditions are defined by a steady state that would evolve if demand were held at a constant level at some distant time. By choosing a moment sufficiently far in the future (150 years) in which to stabilize demand, these arbitrary terminal conditions should have little impact on the net present value of the objective.

Global demand for timber logs is assumed to be the linear sum of regional demand functions. The resulting annual global log market demand function is given as

$$(16) \quad P(t) = 140 \cdot \exp(bt) - 0.04 \cdot Q(t),$$

where $Q(t)$ is given in million m^3 , b is the rate of growth in demand, and $P(t)$ is the price per m^3 . As the demand for forest products increases (or decreases), the demand curve will shift out (or in). Under current global prices and consumption, the initial elasticity of demand is approximately 1.0. This is consistent with the empirical results of Sohngen, and the price elasticity used by Sedjo and Lyon. Additional details about functional forms and data are found in the appendix to this paper.

MARKET SCENARIOS

Baseline Case

We assume that global timber demand grows initially at 1.0% annually, declining exponentially to 0.0% annually by 2140. Solving the model under these conditions reveals that real global prices rise from \$72 per m³ to \$135 per m³ over this time period (Figure 1). Prices rise fairly rapidly in early periods when demand growth is highest

Supply responds to these future price increases. Harvests increase from 1.6 billion m³ to 2.5 billion m³ in 2140 (Figure 2). While total harvests rise smoothly, significant variation exists from region to region (Figure 3). The variation in annual harvest arises from shifts in the age class distribution, which alters the quantity of merchantable timber available each year.

Despite the reliance on a single, global market clearing price, regional harvest patterns differ because of regional-specific productivity, and access and harvest costs. Although temperate forests remain the dominant producers, harvests in North America and Europe remain stable. Harvests in the boreal forest decline despite the high stocks in these areas. Harvests specifically decline in the Former Soviet Union because most of the remaining forest is inaccessible (Backman and Waggener). The Chinese and southern subtropical regions experience large increases in harvests as they take advantage of new plantations.

Management intensity is expected to shift in the future. The largest increase in management intensity occurs in the subtropical emerging regions through plantation establishment (Figure 4) and management of existing forests and plantations (Table 2). Due to high productivity and relatively low costs of purchasing land and establishing

plantations, the subtropical areas of Central America, Southern Brazil, Argentina, and Chile, South America experience the greatest gain in plantation lands. Higher future prices, however, result in a slight increase in management intensity in all regions (Table 2).

The baseline results also indicate that optimal forest management should vary substantially across the globe in response to ecological and economic conditions. The most intense forest management should concentrate in productive lands in accessible regions. Forest investments should be lower in less accessible and less productive lands, and the least intense managed forests will be regenerated naturally. Finally, some lands are so unproductive or costly, they remain wilderness.

Fairly large areas of natural forests in the boreal and tropical zones remain economic wilderness in the baseline scenario (Table 3). The net marginal benefit of harvesting these areas declines as price growth tails off and access costs increase. Further, harvesting additional inaccessible forests is not a good investment compared to increasing the area of plantations or increasing management in the temperate and subtropical zone.

High Demand Scenario

While a 1.0% annual increase in timber demand is certainly plausible, population growth rates and economic growth in some regions of the globe is anticipated to expand fairly rapidly in the future. One alternative scenario is that demand for forest products will increase more rapidly at first (1.5% annually) before declining to 0.0% annual growth by 2140.

Under this scenario, prices increase more rapidly (see Figure 1), as do global harvests (Figure 2). Higher prices lead to higher harvests in all regions, greater harvests of inaccessible forests (Table 3), more land in plantations, and greater management of existing forest stocks. The changes vary across the globe, however. Management intensity is boosted initially in regions like North America and China because these regions can respond to higher prices but management intensity is not increased substantially in the Former Soviet Union due to relatively low productivity there. Management intensity in South America increases slowly over time because plantations in that region are short lived, allowing managers to adapt gradually to conditions as they change.

Costly Emerging Region Plantations

There are two important assumptions embedded in $f_{N,i}(N_i(t))$ in the baseline. The first is that new land for plantations is as productive as previous land. Finding new land of the same quality however, may be more costly and require extra resources today. For example, while there have been large successes in plantation establishment in the past 20 years, there have been some large historic failures. In some regions, such as tropical rainforests, exotic plantation species have failed because many exotic mono-cultures are susceptible to bug infestations and other pathogens that are not present in their traditional climates. The second is that it is costly to find and protect these resources against political instability. In this scenario, we explore what would happen if future plantations

turn out to be more expensive to establish than anticipated by exploring a scenario where cost functions for establishing new plantations are doubled across the board.

Such a scenario leads to higher prices (see Figure 1) and less timber production (see Figure 2). While harvests still expand in the emerging region, this region plays a smaller part in the global market, leading to several substitutions. First, additional inaccessible forests are harvested, although the area of land harvested increases only 8% above the baseline (Table 3). Second, the temperate zones respond by harvesting existing stocks more heavily and increasing the intensity of management. Finally, while new emerging region plantations are more costly to establish, management intensity increases on those that have already been established.

Lower Access Costs to Inaccessible Forests

In the baseline scenario, markets harvest some of the large stocks at the economic margin, but incentives to harvest large portions of these regions remain fairly small. While higher demand and lower plantation establishment do increase the incentive to harvest more from these regions, by increasing prices, they do not spur large-scale harvests in these regions. In this scenario, we look at what would happen if the access costs in this region fall in half either because of new technologies or public policy.

Lower access costs result in a small adjustment of both prices and global harvest quantities (see Figures 1 and 2). These adjustments remain small because the low productivity inherent in these regions limit their ability to contribute to supply. The change does cause the natural forest that is accessed for timber to increase by 92%

relative to the baseline case. Thus, lower access costs can increase the incentive to access these regions substantially, but the effect of these changes on the global market is minimal.

In order to assess the relative impact prices have on regional harvests, we calculate the “price elasticity of supply” from these scenarios:

$$(16) \quad \eta_{i,p} = \sum_i \left[\frac{d(\sum_{i \in ext} q_i(t))}{d(P(t))} \frac{P(t)}{\sum_{i \in ext} q_i(t)} \right]$$

The price elasticity of supply is much higher in the northern inaccessible regions, ranging from 1.8 to 2.3 depending on the particular scenario chosen, than in the tropical inaccessible regions, where it is approximately 1.2 for all scenarios. Thus, a 1% increase in prices leads to approximately a 2% increase in harvest from the northern inaccessible regions, and a 1.2% increase in harvests from the tropical inaccessible regions. Although the total volume of timber harvested is low in both northern and tropical regions, small price changes can have a substantial impact on harvest from those regions.

CONCLUSION

This paper presents a dynamic global model of timber markets. Future increases in the demand for timber require forest management to increase future intensity. The model predicts that rising prices will encourage new investments in plantations and management

intensity in the next century. Plantations are expected to increase in warm temperate and subtropical regions. Because of low timber productivity and high access costs, the model predicts economically marginal ecosystems in the boreal and tropical forests will be largely preserved despite large natural stocks of wood.

In the baseline scenario, both prices and harvests are predicted to rise. Forestry becomes more intensive by establishing additional emerging region plantations, and increasing management of existing forest resources. Harvests continue in inaccessible forests, but these harvests amount to only a small percent of global harvests, and they result in only an 8% increase in further harvests of these regions.

Several alternative scenarios are explored where demand increases more rapidly, plantation establishment costs are higher, and access costs to inaccessible forests are lower. These scenarios show that the quantitative results are sensitive to these assumptions. However, the qualitative results are robust. All scenarios predict some increase in the management intensity of low productive forests but most increases in supply are expected from more intensive management of the forests in the warm temperate and subtropical regions.

In addition to explaining the behavior of global timber markets, the model can also serve as an important tool for policy analysis. For example, the model predicts that some areas of the globe are likely to remain as economic wilderness even without explicit protection policies which is important for biological conservation as well as carbon sequestration policy. The model further predicts that any attempt to increase forest conservation will require a system-wide approach as conservation measures in selected places will cause increased harvesting in other areas. Future applications of the global

timber model need to explicitly address the design of global conservation efforts. The model should also be useful for examining environmental impacts on forestry. For example, one application which is underway explores how changes in future climate might impact the global forestry sector.

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APPENDIX

The yield function is expressed as

$$(A1) \quad V_i(a_i) = \exp(\alpha - \beta/a_i).$$

Harvesting costs are assumed to be constant marginal costs per unit of timber harvested, while marginal access costs are assumed to be increasing in the quantity of timber harvested over the time horizon of the model:

$$(A2) \quad c_i^{A'} = \theta_i + \pi_i * (\int_t q_i(t) dt),$$

Marginal plantation establishment costs are assumed to be increasing in the area of land established over the time horizon of the model:

$$(A3) \quad f_{N,i}'(N_i(t)) = \phi_i + \gamma_i (\int_t N_i(t) dt),$$

This paper uses the approach of Sedjo and Lyon to model the relationship between regeneration expenditures and the stocking density. The effective yield of logs from forests is found by rewriting (A1) as:

$$(A4) \quad V_i(a_i)^* = [\delta_i * (m_i(t_0) + 1)^{\eta_i}] * V_i(a_i).$$

Data Sources

Inventory data was obtained from the following sources: US -- John Mills, USDA Forest Service, Portland, Oregon; Canada -- Lowe et al.; Europe -- Kuusela, Bazett; Former Soviet Union -- Backman and Waggener; Oceania -- FAO 1995, and Pandey; China -- Yin, FAO 1993a, Richardson, FAO 1982, and A Working Report on the Forest Inventory in China by the Center for Forest Inventory, Ministry of Forestry, China; South America -- FAO 1993b and Pandey; India -- FAO 1993b and Pandey; Asia Pacific -- FAO 1993b, Pandey, Sedjo and Lyon; Africa -- FAO 1993b and Pandey.

Yield function data was determined in one of two ways. First, where data was available, yield functions were estimated. In some regions, however, data was not available, yield functions of the form given in A1 above were fitted using information on current stocking density and age distribution. Information was obtained from the following sources: Sohngen; Sedjo and Lyon; Backman and Waggener; Kuusela; and Pandey.

Harvesting costs were generally obtained from Sedjo and Lyon. Where harvesting cost data was not available, costs were determined using costs from similar regions in other parts of the globe. Data from US Forest Service was used to develop access cost functions for building roads in different regions of the US. This data was used to estimate cost functions for other regions of the world with similar terrain and access characteristics. Plantation establishment and regeneration costs were obtained from Sedjo, and Sedjo and Lyon.

TABLES

Table 1: Estimates of plantation area in subtropical and tropical emerging regions.

Region	Annual Plantation	
	Establishment	Total Plantation Area
	1980-1990	1990
	1000 hectares	1000 hectares
Central and South America ¹	322	7,765
Africa ¹	158	4,416
Australia and New Zealand ²	50	2,044
Iberia ³	--	6,450
Asia-Pacific ¹	471	9,404
India ¹	1,009	13,230
China ¹	1,140	31,831
Total	3,140	75,140

¹ FAO (1993b); ² Pandey ; ³ Bazett

Table 2: Average mean annual increment in nine global regions in the initial and final steady states for the baseline case. The subtropical emerging regions include only timber plantations.

	Temperate Forests				Emerging Region Plantations				
	NA ¹	Europe	F.S.U. ²	China	SA ³	India	Oceania	A/P ⁴	Africa
Mean Annual Increment (m ³ /ha/year)									
1990	2.22	2.13	0.73	2.03	15.04	2.92	17.40	11.43	13.65
2140	2.44	2.28	0.78	2.10	16.70	3.19	20.11	13.09	15.39
% change	10 %	7 %	6 %	4 %	11 %	9 %	16 %	14 %	13 %

¹ NA = North America; ² F.S.U. = Former Soviet Union; ³ SA = South America; ⁴ A/P = Asia-Pacific Region

Table 3: Total Area of inaccessible forests in 1990 and 2140 under four alternative scenarios.

	North America			Nordic	F.S.U.	China		Tropics	Total
	PNW	Central	Boreal		Siberia	North	South		
Million Hectares									
1990	8.9	22.5	125.2	19.6	321.5	14.4	16.4	826.3	1,355
2140									
Baseline	3.7	1.2	104.3	14.6	306.9	6.7	10.6	752.8	1,201
High Demand	1.5	0.0	95.1	12.6	300.1	3.2	7.8	723.3	1,144
Costly									
Plantations	3.3	0.0	102.6	14.3	337.3	6.1	10.1	746.2	1,188
Low Access									
Cost	0.0	0.0	80.7	9.6	289.1	0.0	3.4	677.0	1,060

FIGURES

Figure 1: Global timber prices in the baseline case and three alternative scenarios

Figure 2: Global total timber harvests under the baseline case and the alternative scenarios.

Figure 3: Regional baseline timber harvests.

Figure 4: Projected area of plantations in the emerging region.