Forestry Sequestration of CO_2 and Markets for Timber

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Abstract

Forestry has been considered to have potential in reducing the atmospheric concentration of carbon dioxide by sequestrating carbon in above-ground timber and below-ground roots and soil. This potential has been noted in the Kyoto Protocol, which identified specific forestry activities for which carbon sequestration credits could be obtained. To date, a few forestry efforts have been undertaken for carbon purposes, but most of these efforts have been on a small scale. Proposals have been under discussion, however, that would result in the creation of very large areas of new forest for the purpose of offsetting some of the additional carbon that is being released into the atmosphere. Concerns are expressed, however, that large-scale sequestration operations might have impacts on the world timber market, affecting timber prices and thereby reducing the incentives of traditional suppliers to invest in forest management and new timber production. Such a "crowding out" or "leakage" effect, as it is called in the literature, could negate much or all of the sequestered carbon by the newly created sequestration forests. Accordingly, the purpose of this study is to examine and assess the interactions between carbon sequestration forestry, particularly, newly created carbon forests, and the markets for timber.

The approach of this study involves utilizing an existing Dynamic Timber Supply Model (DTSM) to examine the interactions between newly created sequestration forests and the markets for timber. This model has been used to examine global timber supply and, more recently, has been modified to include carbon considerations. This study suggests that even without any specific sequestration efforts, commercial forestry offers the potential to sequester substantial volumes of carbon, approaching ten gigatons (Gt) (or petagrams (Pg)), in vegetation, soils and market products over the next century. At current rates of atmospheric carbon build up this is equal to about three years of net carbon releases into the atmosphere. This volume of carbon sequestration could be increased 50–100% by 50 million hectares (ha) of rapidly growing carbon-sequestering plantation forests, even given the anticipated leakages due to market price effects. Finally, the projections suggest that the amount of crowding out and carbon leakages are likely to be very modest. The 50 million ha of carbon plantations are projected to reduce land areas in industrial plantations, that is, crowd out, only from 0.2 to 7.8 million ha over the 100-year period. The addition of carbon sequestration forests offers the potential to increase the carbon sequestration of the forest system more than 50%, up to 5.7 Gts, above that already captured from market activity. This estimate assumes that crowding out and associated projected leakages will occur. At current rates of atmospheric carbon buildup, about 2.8% of the expected total buildup in atmospheric carbon over the next century could be offset by 50 million ha of carbon plantations.

Key Words: carbon, forests, sequestration, leakages, timber, markets, prices, models

JEL Classification Numbers: Q10, Q15, Q21, Q23, Q24

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1. Introduction

Forestry has been considered to have potential in reducing the atmospheric concentration of carbon dioxide by sequestrating carbon in above-ground timber and below-ground roots and soil. This potential has been noted in the Kyoto Protocol, which identified forestry activities for which carbon sequestration credits could be obtained. Some forestry efforts have been undertaken, but most forestry efforts to date have been undertaken on a small scale. (For a discussion of some of the project scale issues facing forestry and carbon sequestration, see Sedjo et al. 1997). Proposals have been considered that would result in large areas of new forest, primarily for carbon sequestration purposes, which could offset some of the additional carbon that is being released into the atmosphere. Concerns are expressed, however, that large-scale sequestration operations might have impacts on the world timber market, affecting traditional suppliers of timber and reducing their incentive to invest in forest management and new production. Such a "crowding out" or "leakage" effect, as it is called in the literature, could negate all or a portion of the carbon sequestered by the newly created sequestration forest. Accordingly, the purpose of this study is to examine and assess the interactions between carbon sequestration forestry and the markets for timber.

Fig. A describes the flows from the raw wood resource. Some of the wood succumbs to various forms of natural mortality such as fire and infestation. Humans harvest wood for use both for fuel and for industrial wood (i.e., wood that is processed into wood materials and woodpulp for paper). This study is concerned with the approximately 50% of raw wood that is harvested worldwide for use as industrial wood.

2. Project Approach

Overview—The approach of this study involves utilizing an existing Dynamic Timber Supply Model (DTSM) to examine the interactions between newly created sequestration forests and the markets for timber. There are two other large regional models of which we are

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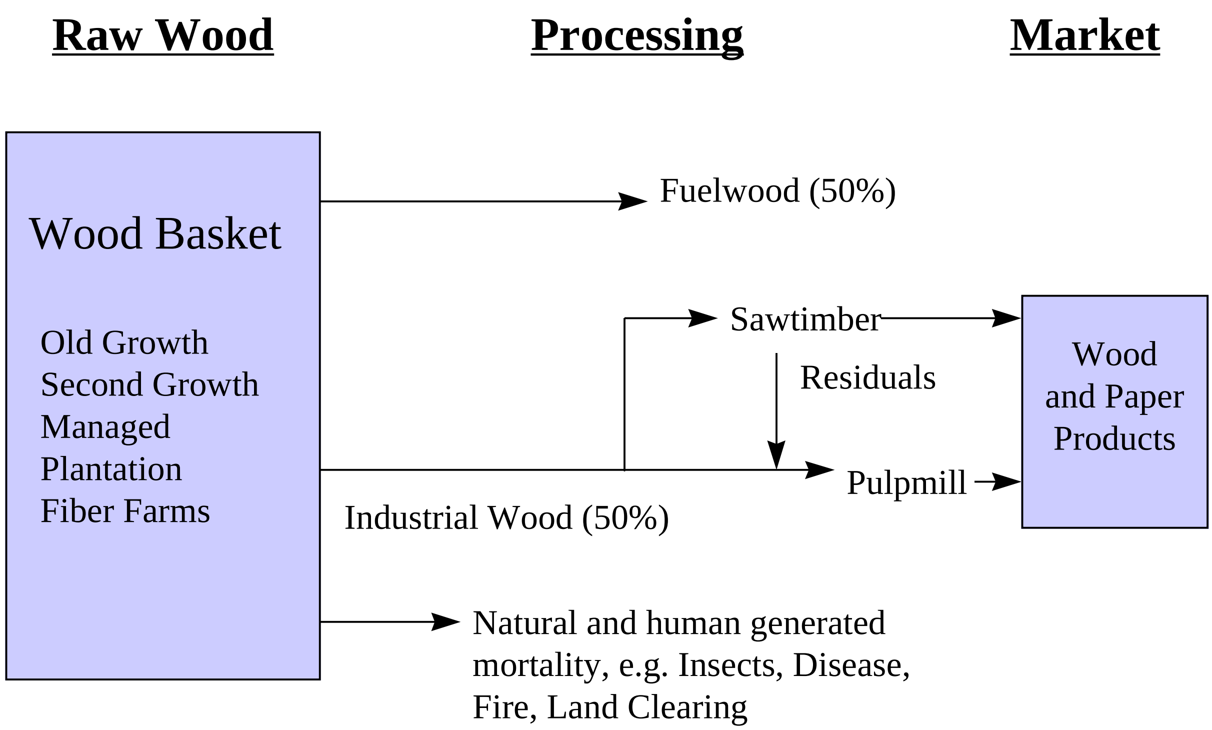
aware that can examine carbon sequestration and forests. These are the Forest and Agricultural Sector Optimization Model (FOSUM) (Adams et al. 1994) and the Cintrafor Global Trade Model (CGTM) (Perez-Garcia et al. 1997). However, since the FOSUM covers only the United States, it cannot deal comprehensively with global issues. The CGTM is similar in some respects to our DTSM, but, not being a optimal control model, it lacks the ability of the DTSM to carefully monitor timber inventories and is also limited in its ability to endogenously add or subtract forest land areas from the timber base. Both of these factors are important for assessing the impact of markets on the timber base and thus on the amount of carbon sequestered.

Figure A. Wood Flows and Uses



The DTSM has been used to examine global timber markets and industrial wood markets, including both solidwood (e.g., sawtimber) and also pulpwood. The model is an optimizing model. It is forward looking in that it assumes that economic actors anticipate the future effects of various current actions. Thus, the establishment of large areas of carbon sequestration forests that are not precluded from harvesting will be anticipated to depress future timber prices compared to what they would be in the absence of the carbon forest and, thus, will influence current investment actions.

The original DTSM has been modified to allow it to examine the issue of carbon stocks and changes as well as traditional timber markets. The focus of the projections and scenarios is on the carbon sequestered (or released). The model uses a 5% real discount rate throughout. Of course, other discount rates could also be used. The approach involves developing a base case scenario with an analysis of that base case, focusing especially on deviations from that base as provided by alternative scenarios. The base case assesses the interactions between forest sequestration and the markets for timber based on a business-as-usual assumption. This involves projections of future industrial wood demand and supply over a 100-year period. Projected supply comes from natural, managed, and plantation forests on the basis of maximizing the present value of the industrial wood using a 5% discount rate. Future supply sources include growth and regeneration of natural forests, as well as new supplies generated from projected newly created artificially planted forests. These new industrial commercial forests are assumed to be created in response to market forces on the basis of economic calculations. The model is discussed in greater technical detail in Appendix C.

Problem Statement

The basic problem addressed in this study is that of assessing the effects on the industrial timber market of the imposition of the addition of a large number of tree plantations that are established primarily to sequester carbon. Although these carbon plantations are established primarily to sequester carbon, they may at some future time be used as industrial timber. However, if timber producers recognize the carbon plantations as potential future competitors in the industrial wood market, the plantations' establishment would have impacts on future industrial wood prices and, hence, on investment decisions regarding the establishment of industrial commercial plantations. The various scenarios examine the question of the impacts of the carbon forests on the total forest and on industrial plantation investment decisions and the associated implications of these investment decisions on the overall sequestration of carbon. The scenarios present alternative ways of viewing the carbon plantations.

Carbon plantations would probably be established either by direct government forest planting activities, on the basis of some type of forest subsidy paid to the landowner/grower to establish trees, or by credits earned on the basis of the carbon sequestered by the forest. The two approaches have the potential to dramatically alter the current market situation of growing forests. Direct tree planting by governments will surely affect private tree-planting investment decisions, especially if the government planting is done at locations where harvests are economic. Forest subsidies would also affect industrial forest planting decisions.

The direction of the effect would depend on whether industrial firms were eligible for the subsidies and under what conditions (i.e., joint returns). Payment for the carbon sequestration services of planted trees would also influence investment and forest management decisions, again based on eligibility and other details of the program. Large forest companies are already speculating about the repercussions of various forest carbon policies in terms of their likely effects on land prices. The companies are extending rotation lengths or even abandoning harvesting of plantations due to their increased value of the forest on the ground in the event of carbon credit payments.

This study, however, does not examine the precise incentive system used to establish the additional forests. Rather, we take as given that the carbon forests would be established roughly in accordance with their financial potential as industrial wood enterprises. An example would be if governments simply undertook public sector projects using tax monies either to directly plant additional forests or to subsidize private entities to establish carbon forests on lands not already established in commercial forests. Since it is assumed that the industry has already placed suitable land into commercial forests given anticipated prices, the lands now used for carbon forests would be inferior for commercial forest operations.

Furthermore, the study does not examine the implications of a situation where carbon offsets receive explicit financial credits, either from the government or in a market for sequestration offsets. However, since the carbon forests are established by moving upon the underlying commercial forest cost curves, the approach of this study could readily be adapted to estimate forest carbon supply curves. Elements of this issue are explicitly examined in Sedjo 1999. However, in this report no explicit value has been estimated for the incremental carbon sequestered.

The Major Elements

The approach is first to outline the model. Next, the base case is developed and run. Some of the important base case information is reported. Then, the various scenarios are developed on the assumption that carbon sequestration plantation wood is harvested and sold into the global timber market. This first set of scenarios is called Case 1. Next, Case 2 is developed under the assumption that the wood from the carbon sequestration plantations is not harvested on a financially optimal rotation. Either the wood is assumed never to be harvested or it is assumed to be harvested on a longer, nonfinancial rotation. These runs are only applied to a subset of the scenarios, those that appear to have the largest impact on carbon implications. In Section 6, (summary of scenario results), the carbon implications of the changed harvesting rules are then examined and compared to the results of that same scenario in Case 1. Next, the results and the details of the various scenarios and sub-scenarios are presented, discussed, and analyzed. A number of importance issues are then raised and discussed. Finally, a summary of the important findings and conclusions of the study are presented.

The Scenarios: The scenarios developed consist of a base case (Scenario 1) and four other scenarios with a number of variations. The scenarios and variations are:

Scenario 2: Creation of carbon sequestration plantations: high levels of establishment

a. High sequestration plantation establishment: establishment of 50 million ha of sequestration plantations in North American and Europe over a 30-year period.

b. High sequestration plantation establishment: Establishment of 50 million ha of sequestration plantations in the subtropics over a 30-year period.

Scenario 3: Creation of carbon sequestration plantations: low levels of establishment

a. Low sequestration plantation establishment: establishment of 10 million ha of sequestration plantations in North American and Europe over a 30-year period.

b. Low sequestration plantation establishment: establishment of 10 million ha of sequestration plantations in the subtropics over a 30-year period.

Scenario 4: Ultimate fate of sequestrated forests

a. Add 50 million ha of sequestrated forests in 30 years to the base case with financially optimal harvesting and replanting.

b. Add 50 million ha of sequestrated forests in 30 years to the base case without harvesting.

c. Add 50 million ha of sequestrated forests in 30 years to the base case with long-rotation harvesting and replanting.

Scenario 5: Substitution effects

a. Low demand elasticity with no carbon plantations

b. Low demand elasticity with high carbon plantations in subtropical regions (plantations established as in Scenario 2 above)

3. The Model

To assess the potential future supply of global timber and its implications on forest carbon stocks, we adapted a recent modeling effort by Sohngen et al. (1999) to also account for carbon stocks and changes in those stocks (see Sohngen and Sedjo, 2000). The 1999 effort built a dynamic timber market model of the world (DTMW) and follows the work of Sedjo and Lyon (1990, 1996), but expands their earlier model in four important ways.

First, the dynamic model incorporates a broader diversity of forests and of geographic regions, including 46 timber types in nine geographic regions across the globe. Second, unlike the earlier models where the level of commercial timber plantations is determined outside the model, in this model commercial plantation establishment is determined endogenously, within the model, based upon generating an acceptable financial return. Third, the model predicts the area of marginal economic forest that will be accessed for industrial wood market needs. In this way, the model efficiently trades off harvests today from existing, multiple types of forest management and species across the globe for investments in future forests. Finally, the dynamic timber market model is modified to include a carbon inventory system with estimates of forest ecosystem carbon and market carbon, that is, carbon captured in long-lived wood products (adjusted for decomposition and destruction) and changes in that carbon. The figures provided build on and extend the 1990 estimates for carbon in market products, with pulp products having fairly short lives while solidwood products have much longer average lives.

Although some variants of this model are exploring ways to introduce the ecological changes on forests and forest growth (e.g., the fertilization effects) that would accompany global warming, the model variant used in this project does not consider changes in growth or yields or changes in forest areas that might occur in a warming world. The model used in this paper is more fully developed in Appendix C and in the cited literature.

Furthermore, it should be noted that the model does not have a component to adjust global forests for the anticipated continuation of tropical deforestation, that is, tropical forestland conversion to other uses such as croplands or grazing areas, that are not driven by timber markets. Thus, the projections focus on the changes in timber and the carbon sequestration that occurs due the interactions between sequestration forestry and the markets for timber. Most analysts believe that tropical deforestation is driven primarily by desired-for land-use conversion, primarily to agriculture. Often, in these cases the timber is ignored or burned as part of the clearing operation and thus has little effect on global timber markets. This model assumes that the stock of tropical forests remains unchanged except to the extent that commercial logging changes the age, and thus biomass, of the forest. Thus the results reflect interactions between the global timber market and sequestration forests and do not consider changes in carbon stocks driven by forestland conversion to nontimber uses. The influence of land-use changes could be added to the model by incorporating existing deforestation forecasts. However, we have left this non-timber market influence external to our market model and its explorations.

The model presents results for nine regions, each of which has different growing conditions. The timber production of each region contributes to the global total of timber, as do the carbon changes. It should be noted that the timber price, which represents the delivered price of raw wood at the mill gate, is treated as identical throughout the global market. Although clearly a simplification (wood quality often differs and is reflected in prices), this treatment is consistent with viewing the global market as a single market in which the "law of one price" applies. This treatment can also be interpreted as viewing the price as an index of global log prices, recognizing that the prices vary with species, quality, etc. A single global price also treats trade restrictions of industrial wood as nonexistent. This simplifying assumption has become less accurate as new restrictions have been coming into effect in recent years. However, it should not distort our global results substantially, because, although some of the regional projections could be distorted, such distortions would be greatest at the disaggregated level and smallest when dealing with global averages—as we are throughout this paper.

4. The Base Case Scenario

Scenario 1—Base Case: Projection of timber outputs and prices over time with some regional detail. We begin the base case projections with the initial 1995 situation, including the timber inventories for and growth conditions appropriate to the timber types and conditions associated with the 46 regions.

Harvest levels are determined by intertemporal profitability. Harvests occur when financially optimal, and investments in replanting occur if financially warranted. Similarly, the level of plantation establishment is determined endogenously within the model by financial considerations. Although human planting does not take place after harvest in many situations, for most timber types natural regeneration is expected in the absence of artificial regeneration. Harvesting costs, including transport costs, are estimated using the best available data, which may vary by region and timber type.

As prices rise, a summation of the underlying costs of production of the various regions provides the estimate of aggregate global supply. Global timber demand is projected beginning with the actual 1990 level and is assumed to increase at 0.75% per year initially, declining exponentially to 0.0% per year by 2190.

Any assumption about growth rates over periods of centuries is highly problematic. Other assumptions about future growth could be used. The growth rate used is roughly consistent with that experienced globally for industrial wood over the past 25 years. Furthermore, the actual growth rate has been declining. For example, total industrial wood production and consumption was roughly the same in 1997 as in 1984. Although some of this stagnation can be attributed to the dramatic decline in industrial wood production and consumption in the former states of the Soviet Union after its dissolution, global long-term wood production and consumption were recognized as increasing only very slowly even earlier (e.g., see Sedjo and Lyon 1990). The usual explanation for the very slow growth is the substitution of nonwood materials for wood in both the solidwood and fiber uses, including paper. For example, various materials can be substituted in construction, including bricks, concrete, and steel. In packaging there has been a shift from paper and paperboard to the use of plastics, containers, and other materials. In communications, newspaper production is stagnate in many parts of the world, and there are concerns that electric information flows have or will impact negatively on paper use generally. The results are given for the years 1995–2105. If demand were to continue increasing indefinitely, this would have little effect on our projections of the next several decades and constitute the base with which the various scenarios are compared and contrasted.

Some Base Case Information:

- Average carbon density per hectare of forest is given in the following table. These results are consistent with the published literature.

Table 1: Average Carbon Density per Hectare in Vegetation and Soil by Region

	Vegetation	Soil (one meter)	Total
Region	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}
Temperate			
North America	63	146	209
Europe	70	127	197
Former Soviet Union	73	198	271
China	81	157	238
Emerging and Tropical			
Oceania	50	95	145
South America	130	117	247
India	14	112	126
Asia-Pacific	166	126	292
Africa	107	116	223

• Growth in forests is projected to generate the following average carbon yields per hectare per year between 1995 and 2105:

Temperate forests: 1.94 metric tons (Mg) of carbon per year with soil carbon
1.62 metric tons (Mg) of carbon per year without soil carbon

Subtropical Plantations: 2.4 metric tons (Mg) of carbon per year with soil carbon.
2.1 metric tons (Mg) of carbon per year without soil carbon.

Note that we distinguish between numbers with soil carbon and without (see below)

• Soil carbon is a difficult issue to address. The additional soil carbon in new plantations is calculated here as net of the soil carbon that is presumed to have existed on the land previously. While the previous use affects the level of carbon initially found in the soil, it does not affect the rate of new accumulation. Note that soil carbon on previous land can be low if intensive agriculture was used. If, however, the lands are marginal grazing lands, soil carbon may be quite large. We have used conservative estimates of the additional soil generated by forests throughout this analysis.

• Industrial plantation establishment: The base case begins with 41 million ha already in industrial plantations as of the initial year, 1995. This figure climbs to 65.4 million ha by 2045 and 73 million ha by 2105, for increases of 24.4 million ha by 2045 and a total increase of 32.0 million ha by 2105.

5. Model Run Description

Case 1. Timber harvesting allowed

1. Baseline scenario: no carbon plantations

2. Scenario 2a: high carbon plantations in temperate region (50 million ha total)

    Pacific Northwest (PNW): 1 million ha
    Southern soft and hardwood: 30 million ha
    Temperate deciduous: 5 million ha
    Nordic: 2 million ha
    Central European soft and hardwood plantations: 6 million ha
    Southern European soft and hardwood plantations: 6 million ha

3. Scenario 2b: high carbon plantations in subtropical regions (50 million ha total)

    South America softwood: 15 million ha
    South America hardwood (eucalyptus): 10 million ha
    Oceania softwood (Douglas fir): 2.5 million ha
    Oceania hardwood (eucalyptus): 2.5 million ha
    Asia-Pacific mixed: 10 million ha
    Africa softwood: 5 million ha
    Africa hardwood: 5 million ha

4. Scenario 3a: low carbon plantations in temperate regions (10 million ha total)

    Pacific Northwest: 0.2 million ha
    Southern soft and hardwood: 6 million ha
    Temperate deciduous: 1 million ha
    Nordic: 0.4 million ha
    Central European soft and hardwood: 1.2 million ha
    Southern European soft and hardwood: 1.2 million ha

5. Scenario 3b: low carbon plantations in subtropical regions (10 million ha total)

    South America softwood: 3 million ha
    South America hardwood (eucalyptus): 2 million ha
    Oceania softwood (Douglas fir): 0.5 million ha
    Oceania hardwood (eucalyptus): 0.5 million ha
    Asia-Pacific mixed: 2 million ha
    Africa softwood: 1 million ha
    Africa hardwood: 1 million ha

Note: Scenario 4 is covered in Case 2 below.

6. Scenario 5a: low demand elasticity with no carbon plantations

7. Scenario 5b: low demand elasticity with high carbon plantations in subtropical regions (plantations established as in scenario 2b above)

Case 2. No timber harvesting allowed

Description: Planting scenario 4b is presented.

6. Summary of Scenario Results

Some general results that follow in the tables below:

Notes related to the tables that follow:

1. These results are total carbon storage given by the year. These results are total carbon storage given by the year;

2. Each column represents a different scenario;

3. Timber plantations are established endogenously within the model and are dependent upon future prices; and

4. Plantation establishment discussed below generally refers to carbon sequestration plantations, which are established by a decision external to the model (e.g., exogenously). These must be distinguished from industrial commercial plantations, which are endogenously determined within the model based on profitability criteria.

Table A.• Total carbon in sequestration plantation establishment scenarios with timber harvest

		High Plantation		Low Plantation		Low Elasticity	Low Elasticity
Year	Base	Temperate	Subtropical	Temperate	Subtropical	Base	Plantation
				Petagrams			
2045	7.14	11.48	11.38	8.09	8.50	7.69	11.71
2105	9.40	14.81	15.10	10.59	10.91	12.32	17.62

Table B. • Carbon gain relative to baseline in the plantation establishment scenarios with timber harvest
(The low-elasticity case carbon gain is calculated relative to the low-elasticity baseline.)

	High Plantation		Low Plantation		Low Elasticity
Year	Temperate	Subtropical	Temperate	Subtropical	Plantation
			Petagrams		
2045	4.34	4.24	0.95	1.36	4.01
2105	5.41	5.70	1.19	1.51	5.31

Table C.• Total area of industrial plantations with timber harvest
(Area of industrial plantations (millions of hectares))

		High Plantation		Low Plantation	
Year	Base	North America/ European Union]	Subtropical	North America/ European Union	Subtropical
2045	65.4	64.7	59.7	65.3	63.9
2105	73.0	71.9	65.1	72.8	71.2

Table D. • Difference in total plantation area from baseline (millions of hectares)

	High Plantation		Low Plantation	
Year	North America/ European Union	Subtropical	North America/ European Union	Subtropical
2045	–0.7	–5.6	–0.1	–1.4
2105	–1.1	–7.8	–0.2	–1.7

Table E. • Total incremental carbon above that of the base case in carbon plantation establishment scenarios with no timber harvest

	High Plantation		Low Plantation	
Year	Temperate	Subtropical	Temperate	Subtropical
	Petagrams			
2045	3.72	8.14	0.74	1.62
2105	8.92	12.06	1.78	2.41

Table F. • Total gain in carbon storage between 1995 and the year given in plantation establishment scenarios with timber harvest for three scenarios

(Optimal refers to financial optimal harvest rotation. Long Rotation refers to the extended rotation in excess of the financial optimal)

		High Plantation			Low Plantation	
Year	Base Optimal	Temperate Optimal	Subtropical Optimal	Subtropical Long Rotation	Temperate Optimal	Subtropical Optimal
				Petagrams		
2045	7.14	11.48	11.38	13.05	8.09	8.50
2105	9.40	14.81	15.10	19.54	10.59	10.91

Table G. • Total carbon gain relative to baseline in the plantation establishment scenarios with timber harvest
(The low-elasticity case carbon gain is calculated relative to the low-elasticity baseline.)

	High Plantation			Low Plantation	
Year	Temperate Optimal	Subtropical Optimal	Subtropical Long Rotation	Temperate Optimal	Subtropical Optimal
	Petagrams				
2045	4.34	4.24	5.90	0.95	1.36
2105	5.41	5.70	10.14	1.19	1.51

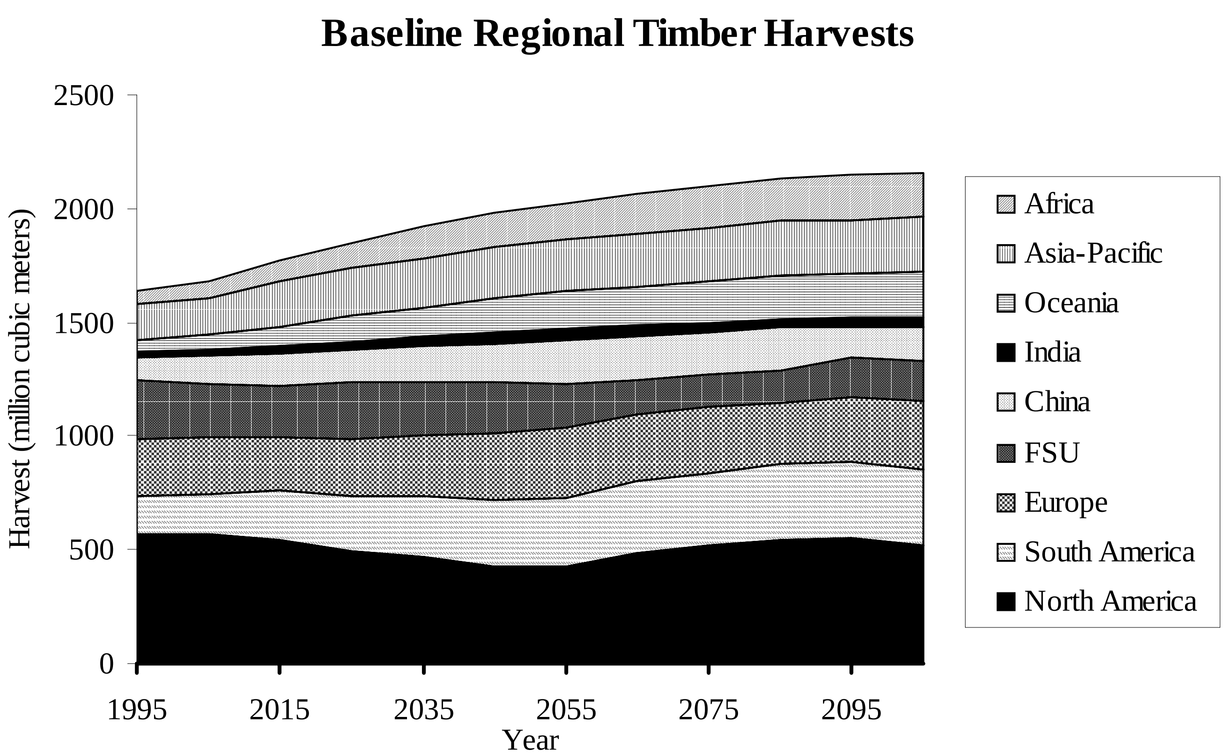
Table H. • Crowding out: a comparison of the area of land in industrial subtropical plantations in the year given
(These figures do not include the land planted for carbon sequestration purposes. All scenarios begin with 41 million hectares in plantations in 1995.)

		High Plantation			Low Plantation	
Year	Base Optimal	Temperate Optimal	Subtropical Optimal	Subtropical Long Rotation	Temperate Optimal	Subtropical Optimal
	Millions of hectares					
2045	65.4	64.7	59.7	60.3	65.3	63.9
2105	73.0	71.9	65.1	66.0	72.8	71.2

7. Discussion and Details

These projections provide estimates of annual changes in timber production and in timber prices. Fig. 1 presents the baseline regional timber harvest projections.

Figure 1. Baseline regional timber harvests.



In addition, seven tables are generated for the base case and for each scenario. The tables are in Appendix B. These are:

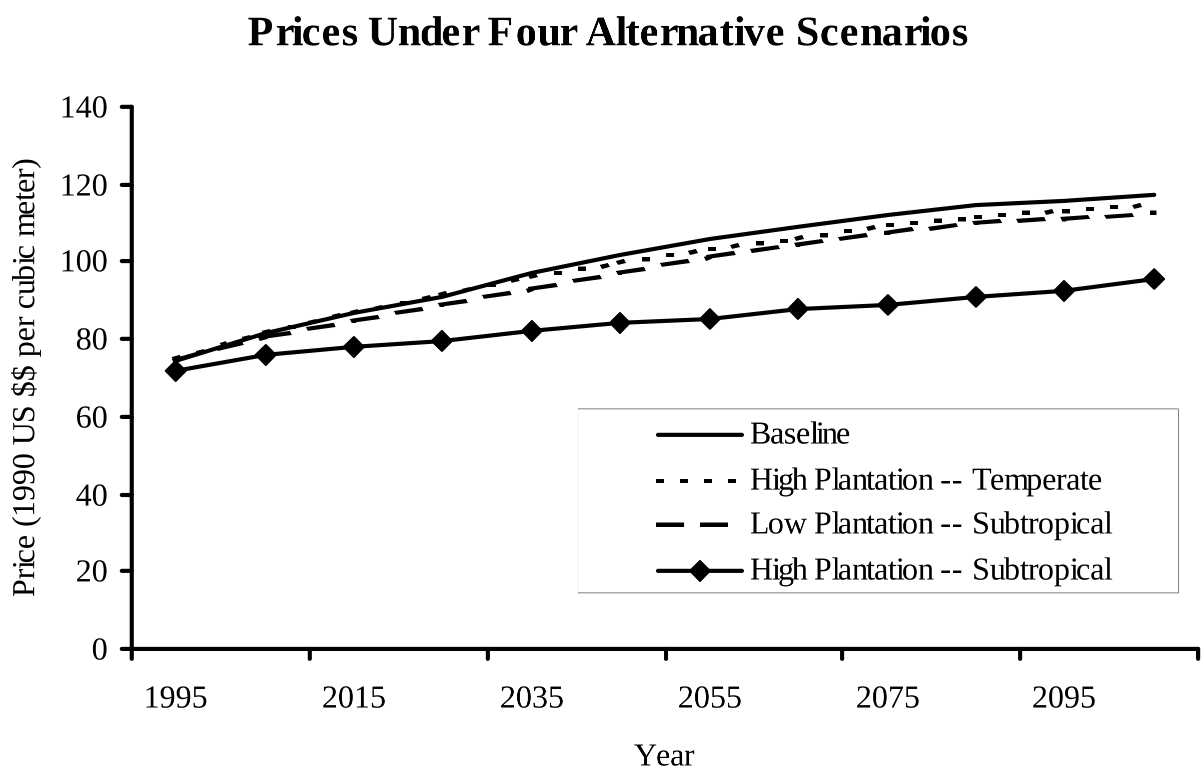
Table 1. Global price, regional and global timber harvest volumes for an approximately 100- year period
Table 2. Global carbon pool by region
Table 3. Tree carbon
Table 4. Forest floor carbon
Table 5. Soil carbon
Table 6. Market carbon (carbon tied up in market products since 1990)
Table 7. Regional carbon fluxes

Discussion

Fig. 1 shows global harvests rising, but only gradually, throughout the more than 100-year period. Traditional producing regions such as North America, Europe and the Former Soviet Union (FSU) show stagnate or declining harvest levels. By contrast, increased harvests are found in most of the other regions, especially South America. These increases are driven by commercially planted forests, and harvests are projected to increase from 1,641 million cubic meters in 1995 to 2,157 million cubic meters after the year 2100, or about 31%. Most of the increased volume comes from South America, Oceania, Asia-Pacific and Africa. Additionally, to meet this demand, a total of 32 million ha of new industrial plantations are established. When combined with the existing 41 million ha of industrial plantations in the initial period, this generates a total of 73 million ha worldwide of intensively managed industrial plantations.

Fig. 2 presents the price projections for the various high sequestration plantation scenarios. Projections from low sequestration temperate plantation establishment are not shown, but they are not very different from the baseline scenario prices or harvests. Prices are somewhat lower and harvests slightly higher. In the case of temperate sequestration forests, some of the higher cost commercial plantations are crowded out by the somewhat lower prices anticipated by the harvests of the sequestration plantations. In contrast, the establishment of a high number of sequestration plantation starts in the subtropical region and crowds out some commercial plantations. However, due to their high productivity, they still generate a fairly large increase in total harvest and a significant decrease in price.

Figure 2. Prices under four alternative scenarios



Scenario One—Base Case:

Fig. 3 compares annual carbon fluxes in North America and Europe with those of the rest of the world and the global total for the base case. Forest carbon consists of carbon in the forest biomass, both above and below ground; carbon in forest soils; carbon in the forest understory and forest litter; and carbon in the stock of long-lived forest products. Soil carbon increases depend on the stock of carbon in the soil initially, and soil carbon radual (logistic) build-up as the carbon approaches the soils' carrying capacity. The carrying capacity is dependent, in part, on the land's previous use.

Total carbon in the forest ecosystem increases only modestly, by about 9.4 Gt. Much of this increase comes from the storage in long-lived wood products. Soils are a source of carbon in early decades, because harvests from older northern and boreal forests, which release more carbon, are a little heavier in carbon at that time. Vegetation carbon rises as plantations are established and temperate forests are managed more heavily.

The base case results also comport reasonably well with a priori evidence from the initial period (fig. 3). In the first part of the 21st century in North America, Europe, and the FSU, carbon increases only modestly, at about 0.25 Gt annually, or about one-half of the 0.5 Gt per year increase in forest carbon sequestration estimated currently by the Intergovernmental Panel on Climate Change (IPCC). Our results reflect our expectation that the U.S. South's wood basket, and more generally North America, will function like a silo. For the past 75–100 years, forest stocks have been rising as former agricultural lands have reverted to forest and young forests mature to older forests. Our projections anticipate that, for a period of three to four decades, the financially mature timber will be drawn down as it matures and is intensively harvested. Thus, the first part of the 21st century should see increased harvests and decreased forest and carbon inventories for the U.S. South and elsewhere in North America. Subsequently, toward the middle of the 21st century, inventory rebuilding will again proceed and then decline again toward the end of the century.

Figure 3. Annual carbon flux in selected regions for the baseline case

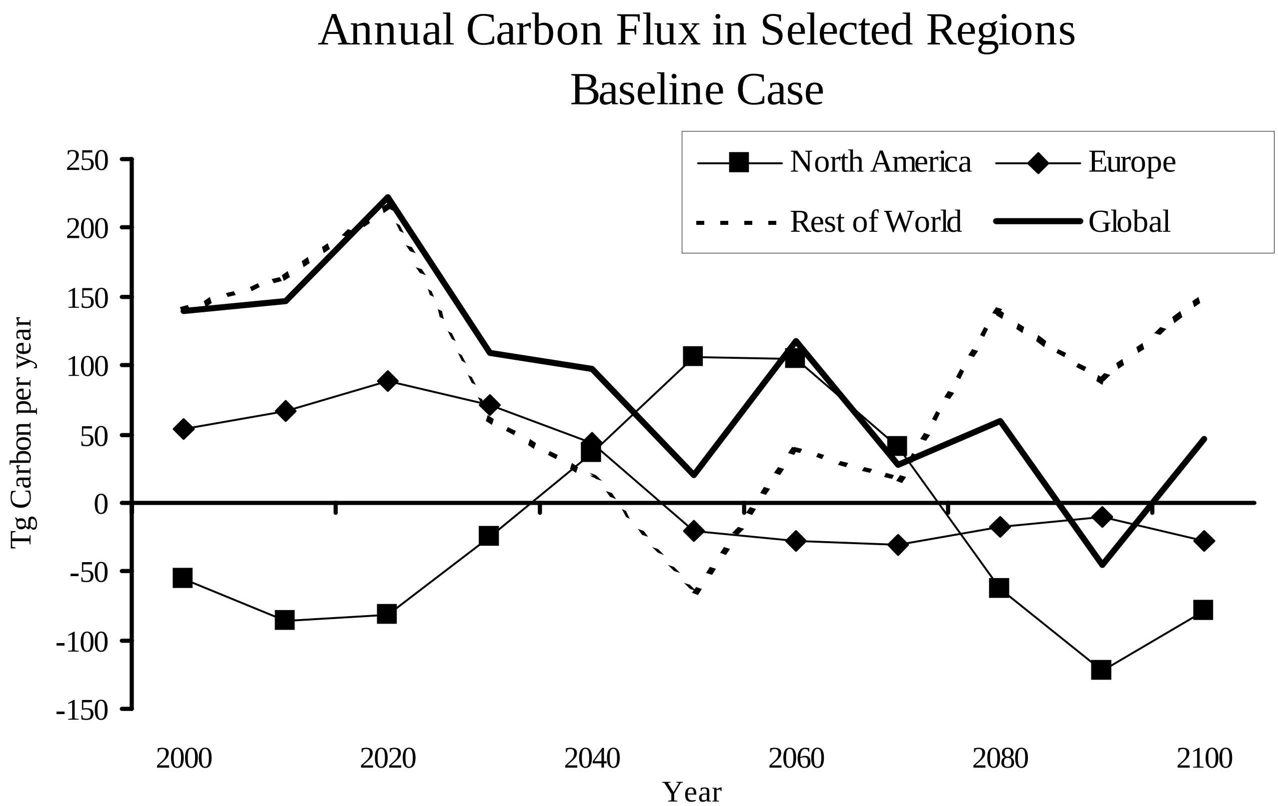
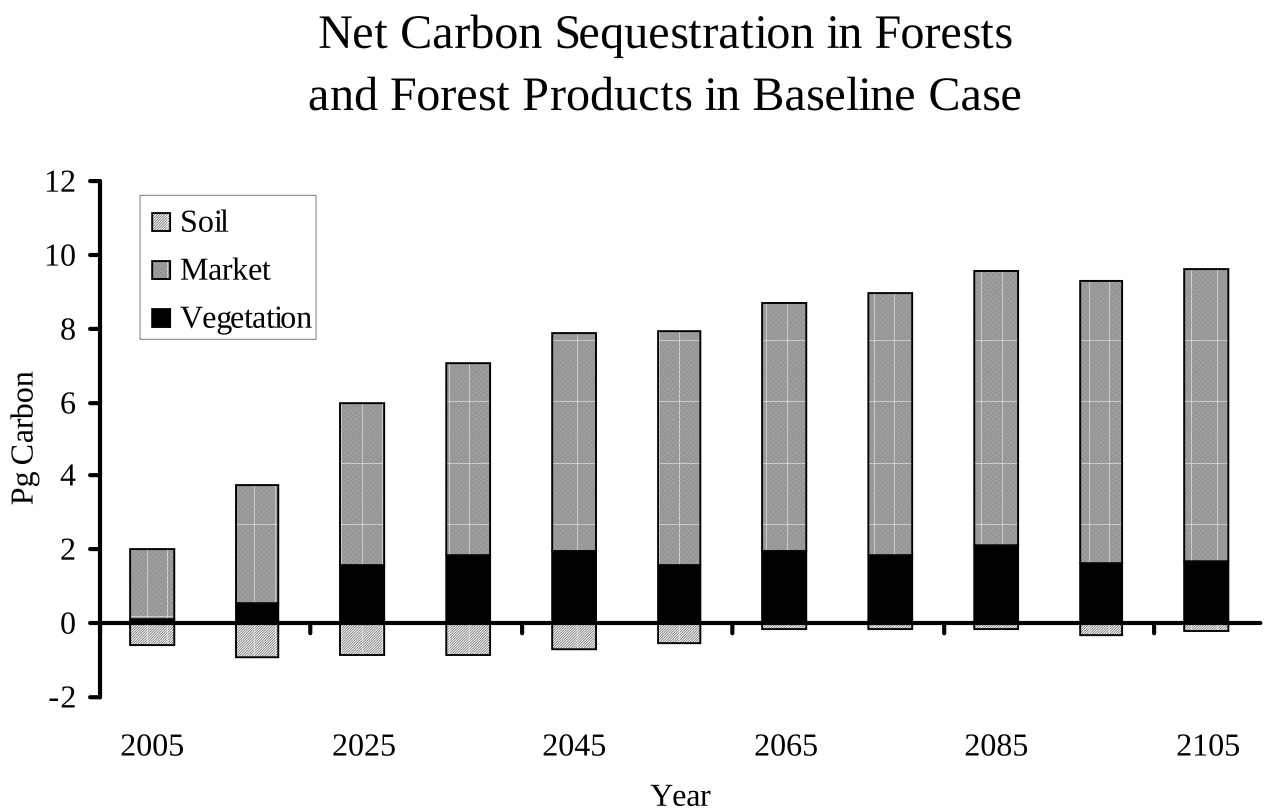


Fig. 4 shows how additional carbon storage is allocated among components, including market carbon. Markets capture most of the additional carbon sequestered. Soils are a source of carbon release in early decades, because harvests are drawn heavily from northern and boreal forests, where soil carbon losses associated with harvests are larger. Vegetative carbon rises as plantations are established and temperate forests are managed more heavily.

Figure 4. Net carbon sequestration in forests and forest products in the baseline case



One finding of our model is that for the short rotation, (e.g., the intensively managed industrial forest plantations used in our model), the relationship between harvests and carbon stocks in the remaining stands is generally much weaker than for second-growth forests, (natural forests that have regenerated after a harvest of the old-growth forest) with longer rotations. For example, for a regulated forest with equal proportions of the various age classes, the sustainable harvest at 100 years would be one one-hundredths of the total stand volume, the ratio of remaining forest biomass to harvest is in the order of ninety-nine-to-one.

By contrast, for a ten-year short-rotation industrial plantation, the remaining stand has only 90% of the biomass of the 10% area harvested, thus the ratio is about nine-to-one. Thus, for example, where most of the increased harvests come from short rotation plantations, the increase in carbon stocks in the biomass would be modest. The base case predicts that industrial forest plantations will expand from 41 million hectares to 73 million hectares in emerging regions by the year 2105 as the result of market forces. Over the long run (approximately 150 years), each new hectare of emerging region plantations provides approximately 400 Mg carbon per hectare of total additional carbon storage in the forest ecosystem and in marketed products (note that this number includes the storage of carbon in market products for some existing plantations. However, eliminating the market-stored products would not reduce the total carbon storage substantially). Carbon sequestration associated with the base case alone generates approximately 9.4 additional Gt of carbon storage, a number that is consistent with the changes shown in the tables on baseline carbon in Appendix B for South America, India, Oceania, Asia-Pacific, and Africa. This amounts to a 1.3% increase in the global atmospheric carbon pool.

Alternatively, harvests (production) on emerging-region plantations rise from 8.9 cubic meters per hectare per year to 12.8 cubic meters per hectare per year, on average, as management intensity rises to meet higher prices. The 32 million new hectares in plantations, therefore, provide approximately 410 million cubic meters per year of additional wood products in the long run. This is an increase in future harvests of 25% over harvests in 1995. Plantations have a much greater impact on markets than on carbon stocks, however, although their effect on carbon stocks is helpful because it is growth that is anticipated to be a byproduct of economically efficient, not subsidized, plantations.

Finally, it should be noted that our projections do not include estimates of the carbon losses due to tropical deforestation. Thus, our projections will not comport with those of, for example, the IPCC, which estimates a decrease of 1.6 Gt in carbon sequestrated in the tropical forest. That estimate depends on assuming some continuing rate of tropical deforestation, which our model does not do. We could do this by simply adding in the estimates of others to our model.

Scenario 2

Scenario 2 involves the creation of large areas of carbon sequestration plantations (high establishment), (e.g., the establishment of 50 million ha of sequestration plantations over a 30-year period). One alternative establishes these in the regions with slower tree growth of North America and Europe, while the other alternative assumes that the 50 million ha of sequestration plantations are established in the fast-growing subtropics over a 30-year period. Also, there is a low plantation alternative for both North America and the subtropics.

The largest impact is projected from the high establishment of carbon sequestration plantations in the subtropics. In this case, despite the crowding-out effect on commercial plantations that reduces the total industrial area in the year 2105 by 7.8 million ha below the area in the base case, total production expands rapidly and prices rise only 33% over the 110-year period from 2000 to 2110, as compared to 57% in the base case. Harvests rise from 1,712 million cubic meters to 2,717 million cubic meters annually (59% over this period) well above the 37% harvest increase of the base case. Importantly, additional net carbon sequestered increased to 15.1 Gt over the period to 2105 (61% more than the base case of 9.40 Gt).

The creation of carbon sequestration plantations in North America and Europe results in a similar amount of carbon being sequestered in the period 1995 to 2105, a total of 14.81 Gt (57% over the base case). However, the time profiles of the additional carbon sequestered are quite different (see fig. 5), with the temperate forests adding more carbon in the earlier part of the period, less in the later part of the period due to their different growth cycles combined with harvesting (which is assumed to occur on carbon plantations as well as industrial).

While the addition of carbon plantations adds to total industrial wood harvest over time, the impact of temperate carbon plantation on industrial harvests is only modest, while that of subtropical carbon harvests is large, due to the higher productivity of subtropical plantations. Thus, the effect of subtropical carbon plantations in depressing timber price is much larger than that of the plantations in temperate regions.

While crowding-out effects or leakages do occur, they tend to be relatively modest. The higher leakages are associated with the high establishment of carbon plantations in the subtropics. This is due to the substantially higher productivity from subtropical carbon plantations depressing the market price and thus crowding out some commercial plantations that would have been established. However, output effect of rapidly growing carbon plantations in the subtropics tends to overwhelm the crowding-out effect, thereby resulting in substantial global output increases and price declines. We should note that much of the crowding out is cross regional. For example, the depressed price, which is caused by the establishment of carbon plantations in the subtropics, causes commercial plantation reductions in the temperate regions as well as in the subtropics. However, total carbon sequestration increases due to the carbon plantation bring about an addition 5.7 Gt of carbon over the period, about a 60% increase in carbon sequestered above that of the base case.

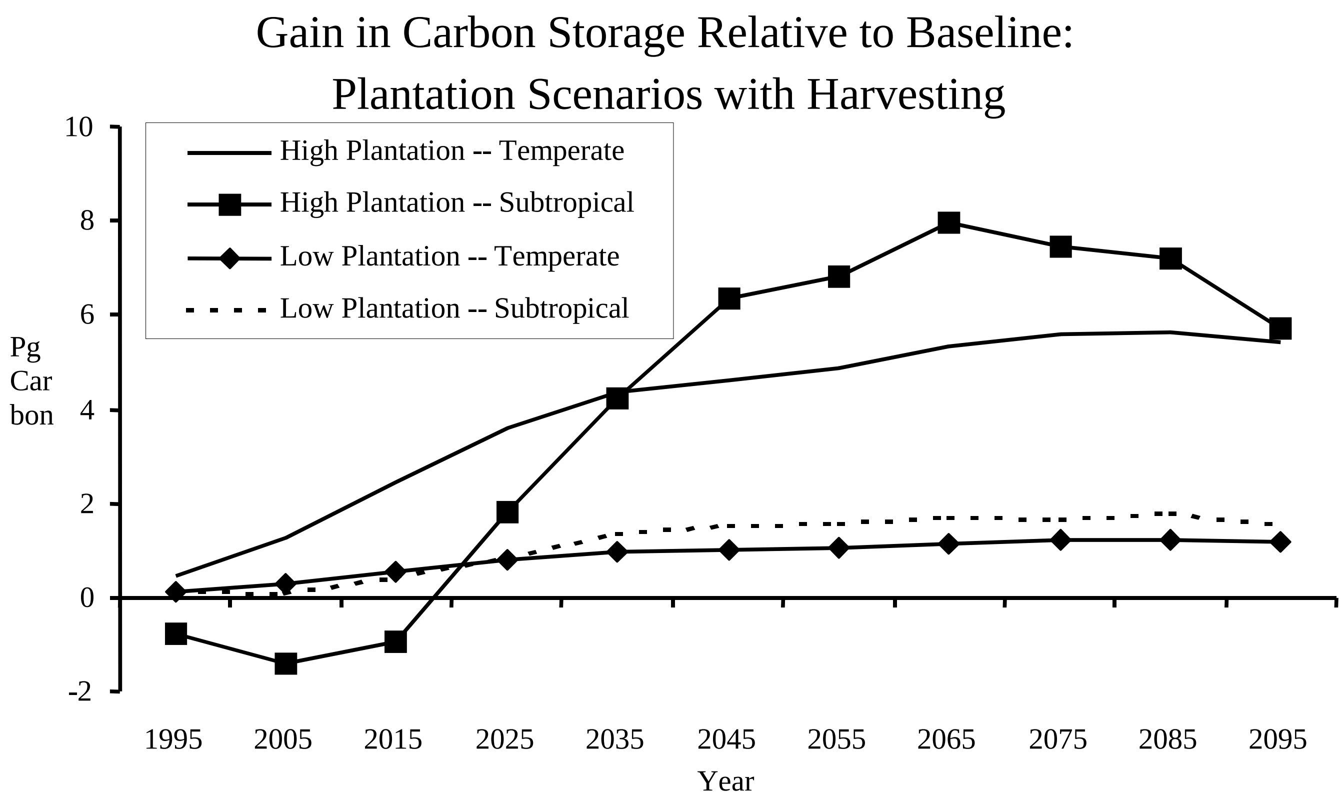
Scenario 3

Scenario 3: involves the creation of a much lower level of carbon sequestration plantations (low establishment), specifically the establishment of 10 million ha of sequestration plantations over a 30-year period in both North America and Europe and in the subtropical region. The effects of the establishment in North America and Europe are barely different for price, total harvest, and additional carbon storage from that of the base case. For low carbon sequestration establishment in the subtropics, the price and harvest effects are somewhat larger, but the carbon effect is small.

Fig. 5 shows how much additional storage would be expected when carbon sequestration plantations are established in our four cases. This measures additional carbon storage relative to the baseline that assumes no exogenous plantation establishment. Total carbon storage is considered here, which includes vegetation, markets, and soil storage.

Fig. 5 also highlights the distortions caused by the high plantation subtropical region scenario. While forests are still sequestering additional carbon in that scenario, they are sequestering much less carbon than the baseline case, as shown by the negative number for the high plantation–subtropical scenario. This occurs because forests in temperate regions are harvested more heavily in early periods, because of the lower future prices which are expected to result from these additional plantations.

Figure 5. Gain in carbon storage relative to baseline under the plantation scenarios, with harvesting



Scenario 4—Ultimate fate of sequestration forests

In scenario 2, we examined the effect of high carbon sequestration plantation establishment in the subtropics on the assumption that the carbon plantations can also be harvested for timber. In this scenario, Scenario 4, we examine the effect on carbon sequestration with no harvest of these forests.

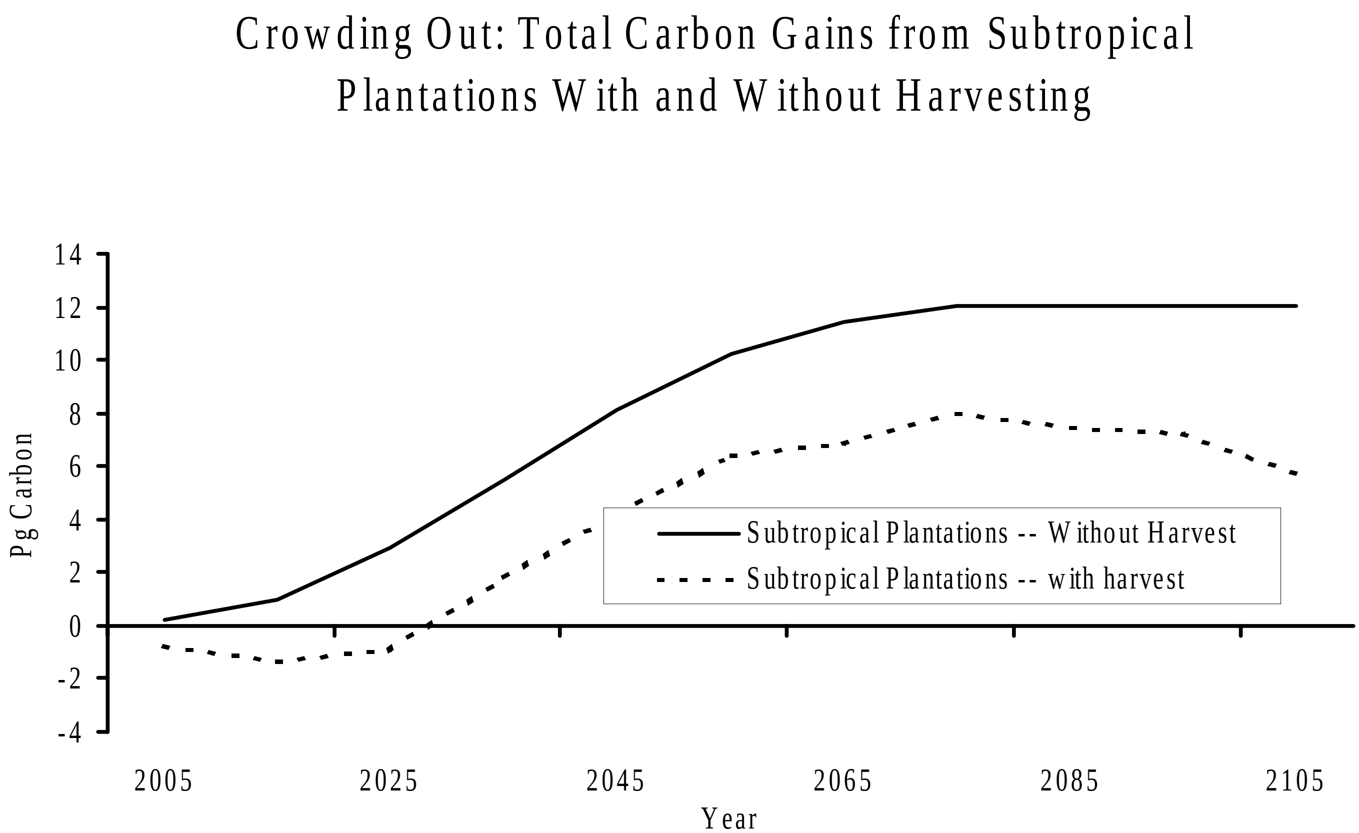
a. Add 50 million ha of sequestrated forests in 30 years to the base case with harvesting and replanting.

b. Add 50 million ha of sequestrated forests in 30 years to the base case without harvesting.

c. Add 50 million ha of sequestered forests in 30 years to the base case. Allow harvesting with replanting but with a longer-than-financial-optimum-harvest rotation period.

Fig. 6 is used to show the effect of harvest restrictions on carbon plantations and on total carbon sequestered over that of the base case when it is anticipated that future harvests from the sequestration plantations will be forbidden. Because under this scenario the carbon sequestration plantations are not expected to produce industrial wood, their creation does not discourage other wood-oriented forest management and plantation establishment. By contrast, if it is expected that the wood of carbon plantations is to be harvested, commercial plantations and forest management activities are crowded out. Thus, less carbon is obtained when these forests enter the market and are harvested at their optimal rotation ages. Additionally, the carbon forests are allowed to add biomass beyond the normal rotation period, thus further contributing to total biomass and related sequestered carbon.

Figure 6. Crowding out: total carbon gains from subtropical plantations with and without harvesting

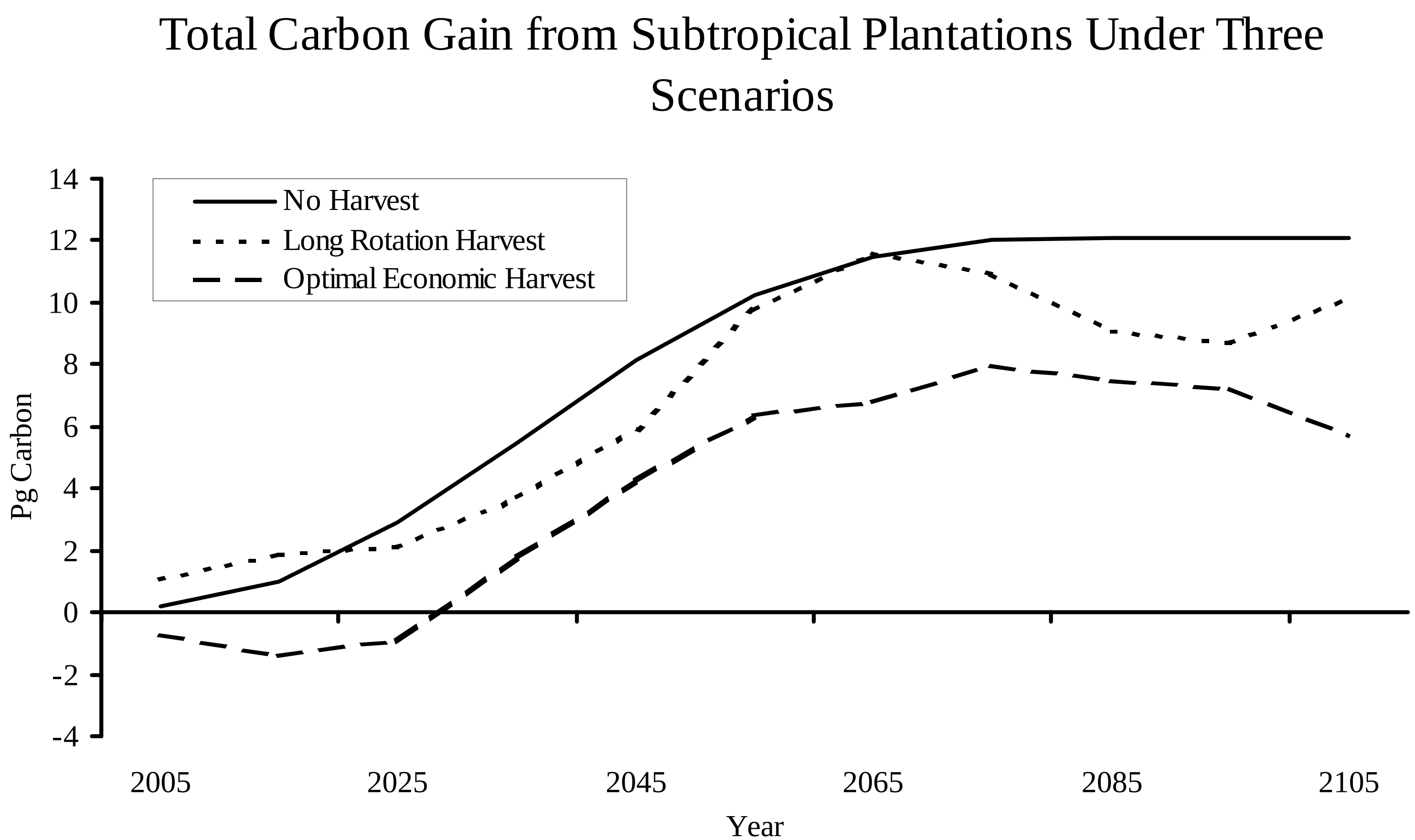


Scenario 4c—Long rotations (LR) for carbon plantations

In this scenario carbon plantations are added, but the harvest rotation is changed from a financial rotation to a long rotation. As before, it was assumed that one-third of the plantations were added each decade, beginning in the first decade. Additionally, it was assumed that softwood species were harvested in 50 years and hardwood species in 30 years. This compares to the typical industrial rotation age of 20–30 years for softwoods and 10 years for hardwoods. This method of harvesting these forests, subtropical LR harvests, leads to additional carbon sequestration, but the result is, not surprisingly, between our original harvest and no-harvest scenarios.

In fig.7 below, the LR harvest carbon is presented together with that of the optimum financial rotation and that of the no-harvest scenario. As intuition would suggest, the longer rotation provides for more sequestered carbon than with the financial rotation, but less than in the no-harvest situation. The total carbon gain is about 4.44 Gts in year 2105 over what would occur in the shorter rotation case—or about twice the incremental carbon sequestered in the optimal rotation case. The components of the difference in the gain in carbon storage for the optimal economic harvest and LR scenarios for 50 million subtropical plantations in year 2005 is given in Table 3 of Appendix B.

Figure 7. Total carbon gain under three scenarios, including the addition of the long rotation forest



Scenario 5—Substitution effects

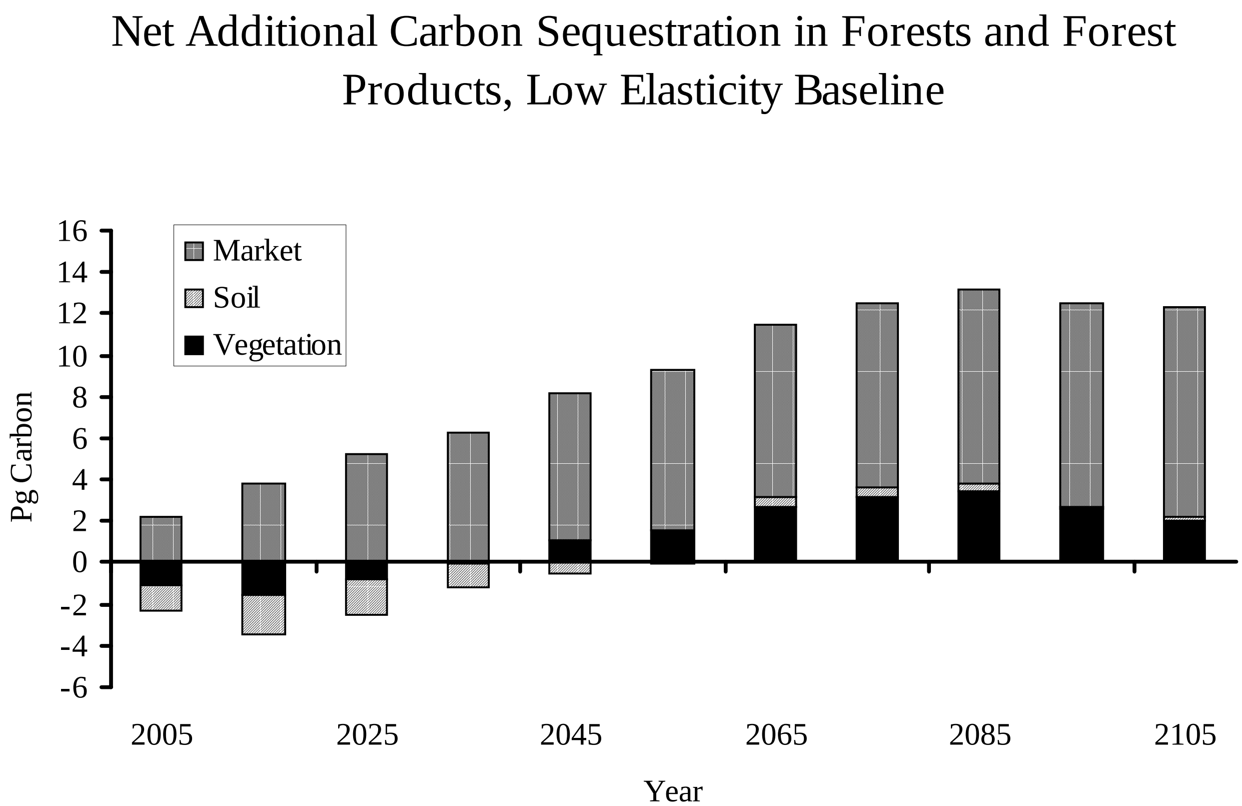
Over time it is expected that nonwood materials can substitute and replace wood material, at least to some extent. For example, in many uses wood as a material can be replaced by cement, steel, and so forth. On the pulp side, processes that are highly intensive in power (e.g., the groundwood process) increase their utilization of wood fiber, but at the cost of high power usage. Additionally, technology can play a major role. For example, forecasters have predicted the large-scale substitution of electronic media for paper for the past several decades. However, thus far, paper production still continues its overall increase in worldwide production and consumption.

In a market model this anticipated substitution from wood to other materials and the reverse is captured in the price elasticity of the demand curve. As price rises, consumers shift away from the higher price commodity and substitute a now relatively lower-priced good. Thus, the price of wood vis-à-vis all other goods has a mechanism for including the substitution of all other goods. A price-inelastic demand curve indicates there is little potential for substitution in use, while a price-elastic demand curve indicates greater substitution possibilities. In general, short-run curves tend to be more inelastic than long-run curves, because more substitution adaptations can be made over the longer period. Furthermore, the cross-price elasticities may be important in some uses, for example, lumber and steel. If the price of one rises, it can affect the consumption of the other, even if all other prices are unchanged. However, because the commodity of interest here is industrial wood, even if steel were highly substitutable for lumber in some markets, the overall effect of this one substitute on all industrial wood worldwide would, likely, be very small. Furthermore, most empirical data suggest that these cross elasticities (e.g., steel and concrete) are very small (Spelter 1985).

The basic DTSM uses a demand curve with a unitary price elasticity, that is, -1.0, a fairly responsive elasticity. However, if price changes only a small amount, the magnitudes of the substitution will be small.

The substitution scenario involves the introduction of the price elasticity used in a recent U.N. Food and Agriculture Organization (FAO) study (Brooks et al. 1996). Using cross-section samples that include 97 countries that account for more than 80% of the world's population and 81% of industrial roundwood consumption, the FAO estimated the global price elasticity of industrial wood to be –0.686. We build this alternative elasticity into the base case model and apply it to the scenario that generates the largest output forecast.

Figure 8. Net additional carbon sequestration in forests and forest products in the low-elasticity baseline case



Using the FAO elasticity, Scenario 5 picks up global wood-nonwood substitution that is consistent with recent experience. This can then be compared with a situation where no substitution occurred or where substitution is more fluid, as in the original elasticity used in the DTSM.

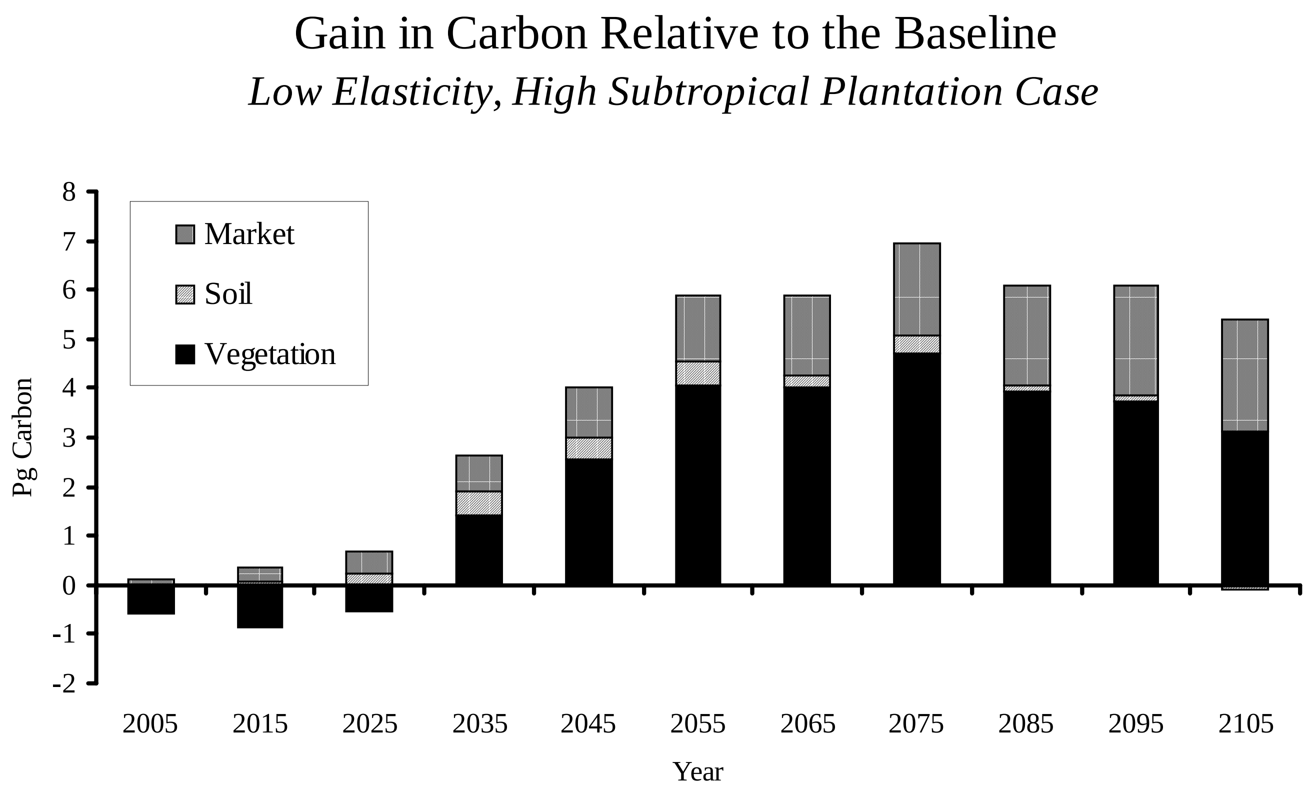
Fig. 8 shows where the additional carbon from forest management accumulates for the low-elasticity case. This case suggests that there are fewer substitution possibilities than the baseline case. This means that harvests rise to higher levels than the baseline but also that prices rise more rapidly. More harvests imply that product storage increases, which can be seen by comparing this to fig. 4 above.

Vegetation storage initially declines, which means that forests themselves are emitting more carbon. This occurs because harvests are heavy in early periods in the northern and boreal forest when the forests are limited to their initial inventories. Over time, vegetation begins to sequester additional carbon when management intensification can have an effect. This increased management results from the higher prices. Higher prices lead to greater management intensity in temperate forests and additional plantation establishment.

Higher elasticity means slightly more storage than the baseline, but most of this accrues to storage in market products. It actually means less storage of carbon in vegetation in early periods. Vegetation storage rises above the baseline in later periods because of increased management of forests and increased plantation area.

Fig. 9 shows the gain in carbon relative to the baseline for the high-elasticity case, with high plantation establishment in the subtropical regions. Breaking the gains or losses into categories allows one to see that most of the gains occur in vegetation carbon. This same effect occurs for the baseline case with the addition of plantations. While most of the carbon stored in the model accumulates to vegetation carbon, most of the gains in carbon storage when plantations occur accrue to vegetation components.

Figure 9. Gain in carbon for low-elasticity, high subtropical plantation case



Compared to the baseline case, however, when plantations are added to the low-elasticity model, the proportion of total storage that accumulates to market components is higher. This occurs because there is less substitution with other products. In 2105, 47% of the additional storage is market storage in the low-elasticity case, compared to 43% for the baseline case.

For comparative purposes, fig. 10 presents the gain in carbon relative to the baseline for the high subtropical plantation case, with the normal, that is, not inelastic, elasticity.

Figure 10. Gain in carbon relative to the baseline–normal-elasticity, high subtropical plantation case

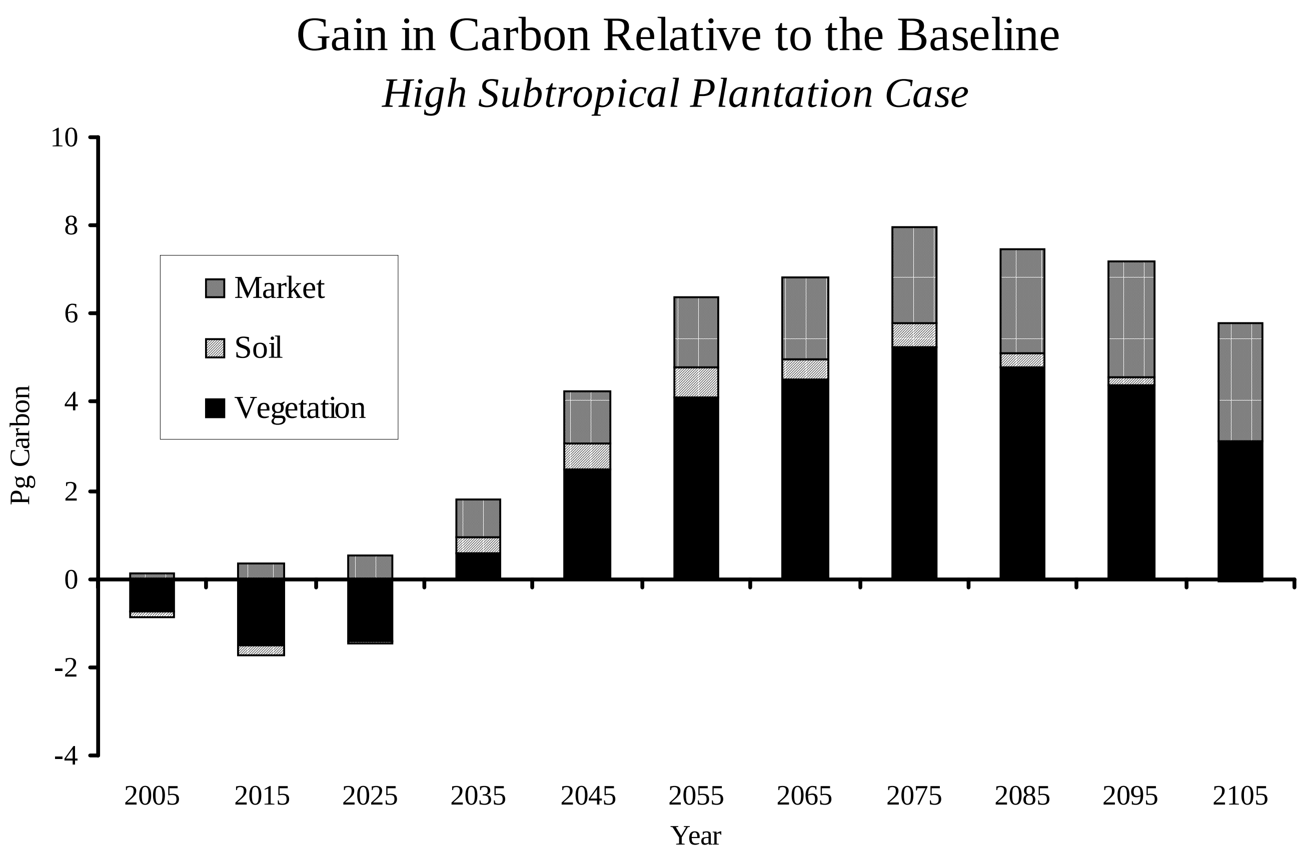
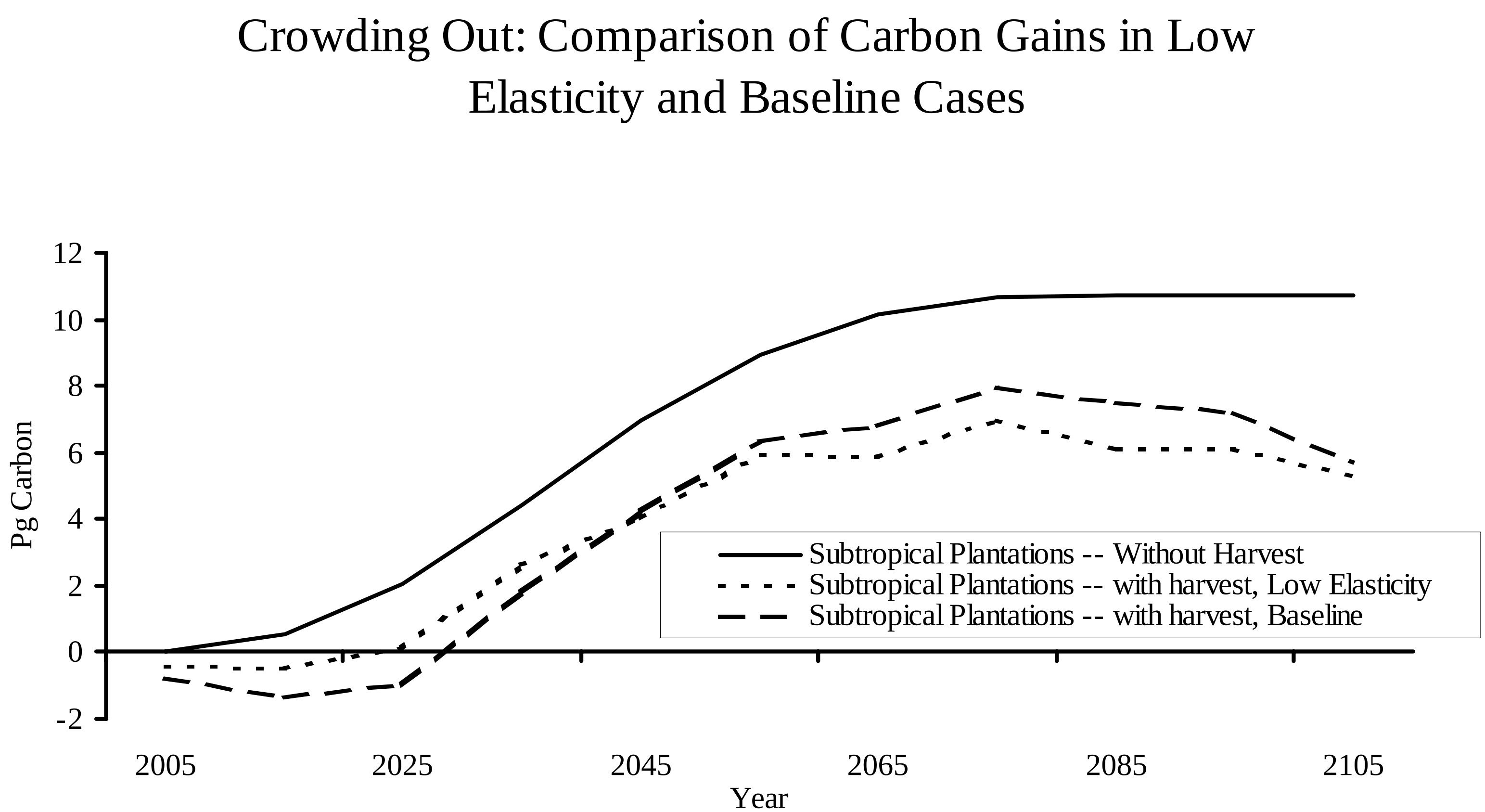


Fig. 11 examines the extent to which crowding out occurs in the baseline and low-elasticity cases. The projections show that more crowding out occurs in the early period with the low-elasticity case, although these results are reversed over the longer period.

Figure 11. Crowding out



8. Further Issues

Lands to be Forested: Although one might believe that the lands going into carbon plantations would simply occupy the next best forestlands after those already claimed by the commercial forest industry, this is not what appears to be planned in many developing countries. For example, work in Argentina suggests that the Argentine government is looking to the establishment of carbon sequestration plantations in Patagonia, clearly not the best forest sites not already claimed by commercial forest interests available in Argentina. The rationale appears to be to use sequestration plantations as a vehicle for the development of some of the more economically backward regions of the country. Similarly in Colombia, the goal appears to be to reforest badly degraded tropical wastelands with carbon sequestration forests as a land rehabilitation scheme. A similar approach may occur in Indonesia. Again, these would be high-cost lands that would typically be ignored by the industry.

Additionally, there appears to be a strong reluctance by environmental groups to agree to provide industry with carbon credit payments for planting trees on lands that industry might plant without the carbon sequestration considerations. However, a country could receive credit toward its carbon targets under the Kyoto Protocol. Thus, lands at the commercial lands' margin might not be eligible for carbon sequestration payments even as the carbon sequestered in these forests is counted toward meeting a country's obligations. Many of these issues remain to be worked out, but it seems clear that it is unlikely that carbon sequestration forests will simply be the extension of additional forests onto the best remaining marginal forest lands.

These considerations suggest that growth on the carbon plantations may be less rapid than assumed throughout our analysis, and the carbon build-up may also be less rapid than estimated throughout our model.

A Forward-looking Model: The question of the extent to which the industry actually takes account of the activities of others, including government sequestration programs, is an open question. Our DTSM assumes that industry is, on the average, forward-looking. Discussions with industry firms and associations, for example, the American Forest & Paper Association in Washington, D.C., reveal the industry is keenly interested in the sources of future timber supplies. Numerous timber-forecasting activities are undertaken by firms, consultants, and public agencies such as the U.S. Forest Service and the FAO.

Industries regularly schedule meetings to discuss future demand and supply of wood resources. There is growing recognition by associations and firms that climate change and carbon sequestration forests may play a major role in future timber supplies. Firms indicate that much of their planting is aimed at meeting very specific future wood requirements. Planting locations and species types are adapted for those anticipated future needs. The industry has followed the climate debate very closely, including discussion about forest sinks and sources, and these considerations apparently are included in industry's strategic production plans. Thus, an analysis that assumes forward-looking economic agents appears to be very sensible.

9. Summary and Conclusions

This study uses a global timber market model, the Dynamic Timber Supply Model (DTSM) to examine the effects of introducing noncommercial carbon sequestration forests to the global timber production system, with the focus on the effects of the carbon sequestration forests on total forest carbon. A baseline case is constructed and compared to a number of alternative scenarios that introduce noncommercial carbon sequestration forests. Because the distribution of any likely global approach to carbon sequestration forests is unknown, for the analysis they were introduced into the northern developed countries and then into the subtropical southern countries. Furthermore, the costs of the carbon sequestration plantations are unknown.

A number of conclusions flow from this study:

1. Even without any specific sequestration efforts, commercial forestry offers the potential to sequester substantial volumes of carbon, approaching 10 Gts., in vegetation, soils, and market products over the next century. At current rates, this is roughly about 3 years' worth of net carbon additions into the atmosphere. This volume of carbon sequestration could be increased by 50 to 100% with 50 million ha of rapidly growing plantation forests.

2. The projections suggest that the amount of crowding out and carbon leakages is likely to be very modest. The 50 million ha of newly established carbon plantations are projected to reduce land areas in industrial plantations by only 0.2 to 7.8 million ha over the 100-year period.

3. The addition of carbon sequestration forests offer the potential to increase the carbon sequestration of the forest system over 50%, up to 5.7 Gts., above that already captured from market activity. This estimate assumes that crowding out and associated leakages projected will occur. At current rates of atmospheric carbon build-up, about 2.8% of the expected total build-up in atmospheric carbon over the next century could be offset by 50 million ha of carbon plantations.

4. If the industrial wood from carbon sequestration plantations is kept out of the industrial wood basket, the potential forest carbon sequestration almost doubles for the high plantation scenario, from 5.7 Gts in the base case to about 11 Gts after 100 years. This is because the carbon plantations are allowed to approach maturity, which involves higher biomass and soil carbon. This amount of carbon is over 5% of the build-up of atmosphere carbon at current rates over 100 years. However, in this case, the financial costs probably rise, because the financial returns of the timber are not realized.

5. If carbon plantations are harvested, but put on a longer rotation, an intermediate amount of carbon would be sequestered, about 8–10 Gts. over that of the base case, or about 4% of the expected buildup of atmospheric carbon over the next 100 years.

6. To the extent that demand is less elastic, for example, nonwood materials are limited in their substitutability for wood, the commercial system will increase the amount of carbon sequestration. In our example, the inelastic demand gives a base case increase of about 40% over the initial base case result, from 9.7 to about 14 Gts., in an approximately 100-year period. It should be noted here that this estimate does not consider the comparative fossil fuel carbon releases associated with using wood and nonwood materials.

7. Commercial forest activities plus the high carbon sequestration forest alternative (even allowing for short rotation harvests of sequestration plantations) can capture about 15–20 Gts. of carbon over the next 100 years or about 7–10% of the current net carbon build-up in the atmosphere of about 3.0–3.5 Gts per year.

References

Adams, D., R. Alig, J.M. Callaway, and B. McCarl. 1994. *Forest and Agricultural Sector Optimization Model: Model Description*. Final Report to the Climate Change Division, Environmental Protection Agency, Washington, D.C. Variously numbered.

Brooks, David, Heikki Pajulja, Tim Peck, Birger Solberg, and Philip Wardle. 1996. *Long-term Trends and Prospects in the Supply and Demand for Timber and Implications for Sustainable Forest*. Rome: U.N. Food and Agriculture Organization.

Perez-Garcia, J. L. A. Joyce, C. S. Binkley, and A. D. McGuire. 1997. Economic Impacts of Climatic Change on the Global Forest Sector: An Integrated Ecological/Economic Assessment. In *Economics of Carbon Sequestration in Forestry*, edited by Roger Sedjo, R. Neil Sampson, and Joe Wisniewski. Boca Raton, FL: Lewis Publishers.

Sedjo, Roger A. 1983. *The Comparative Economics of Plantation Forestry*, Resources for the Future, Washington D.C.

Sedjo, Roger A. 1999. Potential for Carbon Forest Plantation in Marginal Timber Forests: The Case of Patagonia, Argentina. Discussion paper 99-27. Washington, D.C.: Resources for the Future. *

Sedjo, Roger A. and Kenneth. S. Lyon. 1990. *The Long Term Adequacy of the World Timber Supply*. Washington, D.C.: Resources for the Future. *

Sedjo, Roger A. and Kenneth S. Lyon. 1996. Timber Supply Model 96: A Global Timber Supply Model with a Pulpwood Component. Discussion paper 96-15. Washington, D.C.: Resources for the Future. *

Sedjo, Roger A., R. Neil Sampson, and Joe Wisniewski, editors. 1997. *Economics of Carbon Sequestration in Forestry*. Boca Raton, FL: Lewis Publishers. Also in *Critical Reviews in Environmental Science and Technology* 27:1–364, Special Issue.

Sohngen, Brent, Robert Mendelsohn, and Roger A. Sedjo. 1999. Forest Management, Conservation, and Global Timber Markets. *American Journal of Agricultural Economics* 81 (February):1–13.

Sohngen, Brent and Roger A. Sedjo. 2000. Potential Carbon Flux From Timber Harvest and Management in the Context of A Global Timber Market. *Climatic Change* 44:151–172.

Spelter, Henry. 1985. A Product Diffusion Approach to Modeling Softwood Lumber Demand. *Forest Science* 31(3).

*Resources for the Future Discussion Papers are available on the RFF Web site, www.rff.org, or by mail from Resources for the Future, 1616 P St. N.W., Washington, D.C. 20036.

Appendix A: The Data

Timber Data and Inventory

Inventory data used was obtained from the following sources: U.S. — John Mills, USDA Forest Service, Portland, Ore.; Canada — Lowe et al. (1994); Europe – Kuusela (1994), Bazett (1993); Former Soviet Union — Backman and Waggener (1991); Oceania — FAO (1995) and Pandey (1992); China – Yin (1995), FAO (1993a), Richardson (1990), FAO (1982), and Center for Forest Inventory, "A Working Report on the Forest Inventory in China," Ministry of Forestry, China; South America — FAO (1993b) and Pandey (1992); India — FAO (1993b) and Pandey (1992); Asia Pacific — FAO (1993b), Pandey (1992), Sedjo and Lyon (1990); Africa — FAO (1993b) and Pandey (1992).

Yield function data were determined in one of two ways. First, where data were available, yield functions were estimated. In some regions, however, data were not available, so yield functions were fitted using information on current stocking density and age distribution. Information was obtained from the following sources: Sohngen (1996); Sedjo and Lyon (1990); Backman and Waggener (1991); Kuusela (1994); and Pandey (1992) .

Harvesting costs were generally obtained from Sedjo and Lyon (1990). Where harvesting cost data was not available, costs were determined using costs from similar regions in other parts of the globe. Data from the U.S. Forest Service (1996) was used to develop access cost functions for building roads in different regions of the U.S. These data were 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 (1983), and Sedjo and Lyon (1990).

Carbon Model Data

The main source of information on tree carbon storage in temperate forests was Birdsey (1992). These estimates were extrapolated to regions where similar species or ecosystem types exist in the Temperate Zone. A uniform assumption that the proportion of carbon per unit of biomass of 0.5 was used for all species.

Tree carbon in emerging plantation forests was estimated by assuming that the ratio of total tree to merchantable tree components is 1.6, because many softwood plantations in the subtropical emerging region utilize species similar to southern pines. In Oceania, however, species native to the U.S. Pacific Northwest are often used, suggesting that parameter values for those forests should be used. Hardwood plantations are often composed of eucalyptus, which are assumed to have 470 kg of carbon per cubic meter of wood.

Forest floor carbon and soil carbon are estimated from a database obtained from Kristina Vogt, Yale School of Forestry The soil component values were compared to those in Post et al. (1982), and several small adjustments were made. Average carbon storage in forests for our inventories are similar to the estimates made by Dixon et al. (1994).

Appendix B: The Tables

(1) Baseline Case

Table B.1 Price and Harvest

Year	Price Real 1995 $/cub mt]	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
		Million m^3 per year									
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	75	571	161	257	255	101	27	49	161	59	1641
2010	82	568	180	250	231	123	29	62	166	76	1685
2020	87	541	217	234	228	142	31	84	200	94	1771
2030	91	490	247	252	251	138	33	116	209	115	1852
2040	97	470	269	267	232	160	36	132	217	142	1925
2050	102	429	286	297	222	174	47	153	222	153	1983
2060	106	427	300	311	191	192	48	168	228	161	2027
2070	109	489	311	299	143	195	49	172	231	178	2068
2080	112	516	320	295	139	183	48	184	234	181	2100
2090	114	547	328	268	148	188	38	192	236	184	2129
2100	116	556	334	281	173	138	39	192	238	197	2147
2110	117	516	339	298	181	149	41	199	238	196	2157

Table B.2 Baseline Total Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	164.9	229.5	38.5	212.9	31.7	1.5	22.3	88.8	123.0	913.1
2005	164.3	229.5	39.0	212.4	32.7	1.6	22.9	89.0	123.0	914.5
2015	163.5	229.6	39.7	212.4	33.6	1.6	23.5	88.9	123.1	916.0
2025	162.6	229.9	40.6	212.4	34.3	1.7	24.1	89.2	123.3	918.2
2035	162.4	230.2	41.3	211.3	34.9	1.9	24.5	89.3	123.5	919.3
2045	162.8	230.4	41.7	209.8	35.4	2.0	24.9	89.7	123.6	920.2
2055	163.8	230.6	41.5	208.8	35.3	1.9	25.1	89.7	123.8	920.5
2065	164.9	230.7	41.3	209.4	34.2	1.8	25.2	90.3	123.9	921.6
2075	165.3	230.8	40.9	210.2	33.4	1.8	25.3	90.3	124.0	921.9
2085	164.7	230.9	40.8	210.8	33.6	1.8	25.4	90.5	124.0	922.5
2095	163.4	231.0	40.7	211.3	33.8	1.9	25.4	90.5	124.1	922.0
2105	162.7	231.0	40.4	211.3	34.5	2.0	25.5	91.0	124.1	922.5

Table B.3 Baseline Tree Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	29.6	74.4	9.4	29.8	7.5	0.1	7.0	46.4	36.8	241.0
2005	29.1	74.5	9.7	29.3	8.2	0.1	7.5	46.3	36.9	241.5
2015	28.3	74.6	10.1	29.3	8.7	0.2	7.9	46.2	37.0	242.2
2025	27.6	74.7	10.7	29.3	9.2	0.2	8.2	46.2	37.1	243.3
2035	27.4	74.7	11.3	28.5	9.7	0.3	8.5	46.2	37.2	243.8
2045	27.7	74.8	11.6	27.5	10.1	0.4	8.7	46.2	37.2	244.1
2055	28.5	74.8	11.5	26.7	10.0	0.3	8.7	46.1	37.2	243.9
2065	29.4	74.8	11.3	27.2	9.1	0.2	8.7	46.3	37.3	244.2
2075	29.8	74.9	11.1	27.7	8.4	0.2	8.7	46.2	37.3	244.2
2085	29.4	74.9	11.0	28.2	8.5	0.2	8.8	46.3	37.3	244.5
2095	28.6	74.9	10.9	28.6	8.7	0.3	8.7	46.2	37.3	244.1
2105	27.9	74.9	10.6	28.7	9.3	0.3	8.8	46.3	37.3	244.2

Table B.4 Baseline Floor and Understory Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.3	46.4	4.0	27.1	3.3	0.1	0.6	3.9	22.0	126.7
2015	19.1	46.3	4.1	27.0	3.3	0.1	0.7	3.8	22.0	126.4
2025	19.0	46.3	4.2	27.0	3.4	0.1	0.7	3.8	22.0	126.4
2035	18.9	46.3	4.2	26.8	3.4	0.1	0.7	3.8	22.0	126.2
2045	18.9	46.3	4.2	26.6	3.4	0.1	0.7	3.8	22.0	126.0
2055	19.0	46.2	4.2	26.4	3.4	0.1	0.7	3.8	22.0	125.8
2065	19.1	46.2	4.1	26.5	3.3	0.1	0.7	3.8	22.0	125.8
2075	19.0	46.2	4.1	26.6	3.2	0.1	0.7	3.8	22.0	125.7
2085	18.9	46.2	4.1	26.7	3.2	0.1	0.7	3.8	22.0	125.7
2095	18.7	46.2	4.0	26.7	3.2	0.1	0.7	3.8	22.0	125.6
2105	18.7	46.2	4.0	26.8	3.3	0.1	0.7	3.8	22.0	125.6

Table B.5 Baseline Soil Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	114.2	108.2	24.4	155.4	20.7	1.3	14.6	38.1	64.0	540.9
2005	113.8	108.1	24.5	155.3	21.0	1.3	14.6	37.9	63.9	540.3
2015	113.5	108.0	24.6	155.3	21.1	1.3	14.7	37.9	63.8	540.0
2025	113.3	108.0	24.7	155.2	21.1	1.3	14.8	37.9	63.8	540.0
2035	113.3	108.1	24.7	154.9	21.1	1.3	14.8	37.9	63.9	540.0
2045	113.4	108.1	24.7	154.7	21.2	1.3	14.9	37.9	63.9	540.2
2055	113.6	108.2	24.6	154.7	21.1	1.3	14.9	37.9	64.0	540.3
2065	113.7	108.2	24.6	154.9	21.0	1.3	15.0	38.0	64.0	540.7
2075	113.6	108.2	24.5	155.1	21.0	1.3	15.0	38.0	64.0	540.8
2085	113.4	108.2	24.5	155.2	21.1	1.4	15.0	38.0	64.1	540.8
2095	113.1	108.2	24.5	155.2	21.1	1.4	15.0	37.9	64.1	540.6
2105	113.1	108.3	24.5	155.1	21.1	1.4	15.0	38.1	64.1	540.7

Table B.6 Baseline Market Storage

	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
Year					Petagrams carbon					
1995	1.5	0.3	0.7	0.6	0.3	0.1	0.1	0.4	0.2	4.1
2005	2.1	0.6	0.8	0.8	0.4	0.1	0.2	0.9	0.2	6.0
2015	2.5	0.8	1.0	0.9	0.5	0.1	0.3	1.0	0.3	7.3
2025	2.7	0.9	1.1	1.0	0.6	0.1	0.4	1.3	0.4	8.5
2035	2.8	1.1	1.1	1.0	0.6	0.1	0.5	1.5	0.4	9.3
2045	2.8	1.2	1.2	1.0	0.7	0.2	0.6	1.7	0.5	10.0
2055	2.7	1.3	1.3	0.9	0.8	0.2	0.7	1.9	0.6	10.4
2065	2.7	1.4	1.3	0.8	0.8	0.2	0.8	2.1	0.6	10.8
2075	2.8	1.5	1.3	0.8	0.8	0.2	0.9	2.3	0.6	11.2
2085	3.0	1.6	1.3	0.7	0.8	0.2	0.9	2.5	0.7	11.5
2095	3.0	1.6	1.3	0.7	0.8	0.2	1.0	2.6	0.7	11.8
2105	3.0	1.6	1.3	0.7	0.7	0.2	1.0	2.7	0.7	12.0

Table B.7 Baseline Average Annual Carbon Flux by Decade

	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
Years					Petagrams carbon					
1995—2005	–56	0	54	–47	106	5	59	17	1	140
2005–2015	–85	15	67	2	84	8	59	–10	8	147
2015—2025	–81	27	88	–3	71	10	58	34	19	223
2025—2035	–24	27	71	–111	57	13	45	12	19	109
2035–2045	36	21	43	–153	52	12	34	35	16	97
2045—2055	106	18	–21	–99	–10	–5	18	2	12	20
2055–2065	105	12	_27	64	–111	–8	15	58	10	118
2065–2075	41	12	–31	76	–78	–9	8	1	8	27
2075–2085	–62	7	–18	67	16	7	10	26	7	60
2085–2095	–123	8	–10	45	24	9	4	–6	5	-–45
2095–2105	78	4	–28	5	70	11	7	51	4	46

(2) Temperate High Plantation

Table B.8 Price and Harvest

Year	Price Real 1995 $/cub mt	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
		Million m^3 per year									
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	75	571	161	256	256	101	27	47	161	58	1638
2010	82	569	180	249	233	123	29	60	165	74	1681
2020	87	541	217	234	226	143	31	85	200	91	1767
2030	91	492	247	259	249	143	33	112	209	112	1855
2040	96	492	268	274	229	157	36	131	216	138	1942
2050	100	488	284	286	218	170	47	154	222	148	2016
2060	103	511	296	300	190	188	48	162	227	155	2078
2070	106	586	307	289	142	186	48	169	230	171	2129
2080	109	594	315	292	138	192	47	182	233	174	2167
2090	112	614	322	301	147	179	38	185	234	176	2197
2100	113	626	328	305	173	132	39	187	236	189	2215
2110	115	593	333	303	182	153	41	197	237	188	2228

Table B.9 Temperate High Plantation Total Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	164.8	229.5	38.5	212.9	31.7	1.5	22.4	88.8	123.0	913.0
2005	164.8	229.5	39.0	212.4	32.7	1.6	22.9	89.0	123.1	914.9
2015	164.7	229.7	39.7	212.3	33.6	1.6	23.5	88.9	123.2	917.1
2025	165.0	229.9	40.7	212.3	34.3	1.7	24.1	89.2	123.4	920.6
2035	166.0	230.2	41.5	211.2	34.6	1.9	24.5	89.3	123.5	922.8
2045	167.0	230.4	41.9	209.8	35.2	2.0	24.9	89.7	123.7	924.5
2055	168.1	230.6	42.0	208.8	35.1	1.9	25.0	89.7	123.8	925.0
2065	168.7	230.7	42.1	209.4	34.2	1.9	25.2	90.2	123.9	926.4
2075	169.0	230.8	42.3	210.2	33.5	1.8	25.3	90.3	124.0	927.1
2085	168.8	230.9	42.3	210.9	33.4	1.8	25.4	90.5	124.1	928.0
2095	167.8	230.9	42.0	211.3	33.6	1.9	25.4	90.5	124.1	927.6
2105	166.9	231.0	41.8	211.4	34.2	2.0	25.5	91.0	124.1	927.8

Table B.10 Temperate High Plantation Tree Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	29.6	74.4	9.4	29.8	7.5	0.1	7.0	46.4	36.8	241.0
2005	29.3	74.5	9.6	29.3	8.1	0.1	7.5	46.3	36.9	241.7
2015	29.1	74.6	10.1	29.2	8.7	0.2	7.9	46.2	37.0	242.8
2025	29.0	74.7	10.7	29.2	9.2	0.2	8.2	46.2	37.1	244.6
2035	29.6	74.7	11.3	28.5	9.5	0.3	8.5	46.2	37.2	245.7
2045	30.3	74.8	11.5	27.5	9.9	0.4	8.6	46.2	37.2	246.4
2055	31.0	74.8	11.6	26.7	9.8	0.3	8.7	46.1	37.2	246.4
2065	31.6	74.8	11.7	27.2	9.1	0.2	8.7	46.3	37.3	247.0
2075	31.9	74.9	12.0	27.7	8.5	0.2	8.7	46.2	37.3	247.3
2085	31.8	74.9	12.0	28.3	8.4	0.2	8.7	46.3	37.3	247.8
2095	31.1	74.9	11.8	28.6	8.6	0.3	8.7	46.1	37.3	247.5
2105	30.3	74.9	11.6	28.7	9.1	0.3	8.8	46.3	37.3	247.4

Table B.11 Temperate High Plantation Floor and Understory Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.5	46.4	4.1	27.0	3.3	0.1	0.6	3.9	22.1	126.9
2015	19.5	46.3	4.2	27.0	3.3	0.1	0.7	3.8	22.0	126.9
2025	19.5	46.3	4.3	27.0	3.4	0.1	0.7	3.8	22.0	127.0
2035	19.5	46.3	4.3	26.8	3.4	0.1	0.7	3.8	22.0	127.0
2045	19.6	46.3	4.4	26.6	3.4	0.1	0.7	3.8	22.0	126.9
2055	19.7	46.2	4.4	26.4	3.4	0.1	0.7	3.8	22.0	126.7
2065	19.7	46.2	4.4	26.5	3.3	0.1	0.7	3.8	22.0	126.7
2075	19.7	46.2	4.4	26.6	3.2	0.1	0.7	3.8	22.0	126.7
2085	19.6	46.2	4.3	26.7	3.2	0.1	0.7	3.8	22.0	126.7
2095	19.4	46.2	4.3	26.8	3.2	0.1	0.7	3.8	22.0	126.6
2105	19.3	46.2	4.3	26.8	3.3	0.1	0.7	3.8	22.0	126.6

Table B.12 Temperate High Plantation Soil Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	114.2	108.2	24.4	155.4	20.7	1.3	14.6	38.1	64.0	540.9
2005	113.9	108.1	24.5	155.3	21.0	1.3	14.6	37.9	63.9	540.3
2015	113.7	108.0	24.5	155.2	21.1	1.3	14.7	37.9	63.8	540.2
2025	113.7	108.0	24.7	155.2	21.1	1.3	14.8	37.9	63.9	540.5
2035	114.0	108.1	24.7	154.9	21.1	1.3	14.8	37.9	63.9	540.8
2045	114.2	108.1	24.8	154.7	21.1	1.4	14.9	37.9	64.0	541.1
2055	114.4	108.2	24.8	154.7	21.1	1.3	14.9	37.9	64.0	541.3
2065	114.3	108.2	24.8	155.0	21.0	1.3	15.0	38.0	64.1	541.6
2075	114.2	108.2	24.7	155.1	21.0	1.3	15.0	38.0	64.1	541.6
2085	114.0	108.2	24.7	155.2	21.0	1.4	15.0	38.0	64.1	541.6
2095	113.9	108.3	24.6	155.2	21.0	1.4	15.0	37.9	64.1	541.4
2105	113.8	108.3	24.6	155.1	21.1	1.4	15.0	38.1	64.1	541.5

Table B.13 Temperate High Plantation Market Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	1.5	0.3	0.7	0.6	0.3	0.1	0.1	0.4	0.2	4.1
2005	2.1	0.6	0.8	0.8	0.4	0.1	0.2	0.9	0.2	6.0
2015	2.5	0.8	1.0	0.9	0.5	0.1	0.3	1.0	0.3	7.3
2025	2.7	0.9	1.1	1.0	0.6	0.1	0.4	1.3	0.4	8.5
2035	2.8	1.1	1.1	1.0	0.6	0.1	0.5	1.5	0.4	9.3
2045	2.9	1.2	1.2	1.0	0.7	0.2	0.6	1.7	0.5	10.1
2055	3.0	1.3	1.2	0.9	0.8	0.2	0.7	1.9	0.5	10.6
2065	3.1	1.4	1.3	0.8	0.8	0.2	0.8	2.1	0.6	11.1
2075	3.2	1.5	1.3	0.8	0.8	0.2	0.8	2.3	0.6	11.5
2085	3.4	1.5	1.3	0.7	0.8	0.2	0.9	2.5	0.6	11.8
2095	3.4	1.6	1.3	0.7	0.7	0.2	0.9	2.6	0.6	12.1
2105	3.4	1.6	1.3	0.7	0.7	0.2	1.0	2.7	0.7	12.4

Table B.14 Temperate High Plantation Average Annual Carbon Flux by Decade

Years	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995_2005	–6	0	54	–50	106	5	56	17	4	186
2005–2015	–6	15	72	-6	84	8	59	–10	10	226
2015–2025	28	27	100	–3	71	11	58	34	19	344
2025–2035	99	27	78	–107	36	13	44	12	19	221
2035–2045	107	21	40	–144	52	12	34	34	16	171
2045–2055	106	17	5	–98	–8	–5	18	1	12	49
2055–2065	63	11	16	66	–86	-8	14	58	10	144
2065–2075	30	11	19	77	–73	-9	8	0	8	71
2075–2085	–24	7	3	67	–13	6	10	26	6	88
2085–2095	–98	8	–33	45	26	8	4	–6	5	–42
2095–2105	–92	4	–20	1	58	10	7	51	4	24

(3) High Plantations in Subtropical Regions

Table B.15 Price and Harvest

Year	Price Real 1995 4/cub mt	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
						Million m^3 per year					
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	72	577	179	287	274	103	27	46	154	65	1712
2010	76	547	250	253	243	140	28	65	179	90	1794
2020	78	509	359	230	226	123	30	105	233	139	1952
2030	80	434	487	217	193	119	31	154	282	192	2109
2040	82	424	563	195	163	136	34	189	311	242	2259
2050	84	374	619	222	156	142	44	225	336	270	2389
2060	85	419	628	240	137	175	45	232	341	276	2493
2070	88	456	635	275	139	164	45	235	343	289	2581
2080	89	494	642	276	141	174	44	245	345	288	2649
2090	91	528	648	274	166	159	35	248	347	291	2695
2100	93	514	653	275	200	141	35	249	348	303	2719
2110	96	481	660	264	189	177	37	258	350	301	2717

Table B.16 Subtropical Region High Plantation Total Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	164.7	229.5	38.4	212.8	31.7	1.5	22.4	88.8	123.0	912.7
2005	163.5	230.2	38.5	211.4	32.6	1.6	23.1	89.3	123.3	913.4
2015	162.5	231.0	38.8	210.5	32.8	1.7	23.8	89.4	123.7	914.2
2025	161.9	232.1	39.2	209.8	33.6	1.8	24.6	89.8	124.1	916.9
2035	162.1	232.8	40.1	209.5	34.2	1.9	25.2	90.4	124.5	920.7
2045	162.5	233.3	40.7	209.1	35.3	2.0	25.6	90.8	124.7	924.1
2055	164.0	233.5	41.0	209.5	34.9	1.9	25.8	91.0	124.8	926.4
2065	164.6	233.9	41.1	210.3	33.9	1.8	26.0	91.5	125.0	928.1
2075	165.3	233.9	40.9	211.2	33.5	1.8	26.1	91.9	125.0	929.5
2085	164.1	234.1	40.6	211.8	33.9	1.8	26.2	92.0	125.1	929.6
2095	163.5	234.1	40.2	211.5	34.2	1.9	26.2	92.1	125.1	928.8
2105	162.5	234.3	40.1	210.5	34.5	2.0	26.3	92.5	125.2	927.8

Table B.17 Subtropical Region High Plantation Tree Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	29.4	74.4	9.3	29.6	7.5	0.1	7.0	46.4	36.8	240.4
2005	28.4	74.9	9.2	28.6	8.0	0.1	7.5	46.5	37.0	240.2
2015	27.6	75.4	9.3	27.8	8.1	0.2	8.1	46.5	37.3	240.2
2025	27.0	75.8	9.5	27.2	8.7	0.2	8.6	46.6	37.5	241.3
2035	27.1	76.0	10.3	27.1	9.3	0.3	8.8	46.8	37.7	243.3
2045	27.5	76.1	10.7	26.9	10.1	0.4	9.0	46.8	37.7	245.3
2055	28.6	76.0	11.1	27.1	9.8	0.3	9.0	46.7	37.8	246.5
2065	29.2	76.2	11.2	27.8	9.0	0.2	9.1	46.8	37.8	247.2
2075	29.7	76.1	11.1	28.5	8.6	0.1	9.1	46.9	37.8	247.8
2085	28.9	76.2	10.8	29.0	8.8	0.2	9.1	46.8	37.8	247.7
2095	28.4	76.1	10.5	28.9	9.1	0.2	9.1	46.8	37.8	247.0
2105	27.7	76.2	10.4	28.1	9.4	0.3	9.1	46.9	37.8	246.0

Table B.18 Subtropical Region High Plantation Floor and Understory Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.3	46.5	4.0	26.9	3.2	0.1	0.7	3.9	22.1	126.6
2015	19.1	46.5	4.0	26.8	3.3	0.1	0.7	3.9	22.1	126.4
2025	18.9	46.5	4.1	26.7	3.3	0.1	0.7	3.9	22.1	126.4
2035	18.9	46.5	4.2	26.7	3.4	0.1	0.8	3.9	22.1	126.6
2045	19.0	46.5	4.2	26.6	3.4	0.1	0.8	3.9	22.1	126.7
2055	19.1	46.5	4.2	26.6	3.4	0.1	0.8	3.9	22.1	126.7
2065	19.2	46.5	4.2	26.7	3.3	0.1	0.8	3.9	22.1	126.8
2075	19.2	46.5	4.1	26.8	3.2	0.1	0.8	3.9	22.1	126.8
2085	19.0	46.5	4.1	26.9	3.3	0.1	0.8	3.9	22.1	126.7
2095	18.9	46.5	4.0	26.8	3.3	0.1	0.8	3.9	22.1	126.5
2105	18.8	46.5	4.0	26.7	3.3	0.1	0.8	3.9	22.1	126.3

Table B.19 Subtropical Region High Plantation Soil Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	114.2	108.3	24.4	155.4	20.7	1.3	14.6	38.1	64.0	541.0
2005	113.7	108.1	24.5	155.1	20.9	1.3	14.7	37.9	63.9	540.3
2015	113.4	108.1	24.6	155.0	20.9	1.3	14.8	37.9	63.9	539.9
2025	113.3	108.2	24.6	154.9	21.0	1.3	14.9	37.9	64.0	540.1
2035	113.4	108.2	24.7	154.9	21.0	1.4	14.9	37.9	64.0	540.5
2045	113.6	108.3	24.7	154.9	21.1	1.4	15.0	37.9	64.1	540.9
2055	113.8	108.3	24.7	155.0	21.0	1.4	15.0	37.9	64.1	541.1
2065	113.8	108.4	24.6	155.1	20.9	1.4	15.0	38.0	64.1	541.3
2075	113.7	108.4	24.6	155.3	21.0	1.4	15.0	38.0	64.2	541.4
2085	113.4	108.4	24.5	155.2	21.0	1.4	15.0	38.0	64.2	541.2
2095	113.3	108.4	24.5	155.1	21.1	1.4	15.0	37.9	64.2	540.9
2105	113.2	108.4	24.5	154.9	21.1	1.4	15.1	38.0	64.2	540.8

Table B.20 Subtropical Region High Plantation Market Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	1.5	0.3	0.7	0.6	0.3	0.1	0.1	0.4	0.2	4.2
2005	2.0	0.7	0.9	0.8	0.4	0.1	0.2	0.9	0.2	6.2
2015	2.4	1.1	1.0	0.9	0.5	0.1	0.3	1.1	0.3	7.7
2025	2.5	1.5	1.0	0.9	0.5	0.1	0.5	1.5	0.5	9.1
2035	2.6	2.0	1.0	0.9	0.5	0.1	0.7	1.8	0.6	10.2
2045	2.5	2.3	1.0	0.8	0.6	0.2	0.9	2.2	0.7	11.2
2055	2.5	2.6	1.0	0.7	0.7	0.2	1.0	2.5	0.8	12.1
2065	2.5	2.8	1.1	0.7	0.7	0.2	1.1	2.8	0.9	12.8
2075	2.7	2.9	1.1	0.7	0.7	0.2	1.2	3.0	0.9	13.4
2085	2.8	3.0	1.2	0.7	0.7	0.2	1.2	3.3	1.0	14.0
2095	2.8	3.1	1.2	0.7	0.7	0.2	1.3	3.5	1.0	14.5
2105	2.8	3.1	1.2	0.8	0.7	0.2	1.3	3.7	1.0	14.8

Table B.21 Subtropical Region High Plantation Average Annual Carbon Flux by Decade

Years	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995–2005	–119	64	17	–139	96	6	68	49	23	64
2005–2015	–103	85	33	–86	21	8	78	9	39	84
2015–2025	–58	108	37	–75	75	10	80	43	45	267
2025–2035	22	66	87	–24	63	12	58	62	38	384
2035–2045	43	59	56	–39	112	12	41	37	20	340
2045–2055	145	17	34	33	–46	–6	18	20	15	232
2055–2065	66	37	10	82	–101	–9	18	48	11	163
2065–2075	69	1	–22	92	–40	–10	6	37	8	141
2075–2085	–119	25	–32	57	40	5	12	16	6	10
2085–2095	–63	–7	–35	–26	37	7	1	9	4	–72
2095–2105	–99	21	–12	–103	28	9	9	39	4	–103

(4) Low Plantations in Temperate

Table B.22 Price and Harvest

Year	Price Real 1995 $/cub mt	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Million m^3 per year						
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	75	570	161	257	255	101	27	49	161	58	1639
2010	82	568	180	250	231	123	29	62	165	74	1683
2020	87	541	217	234	228	142	31	84	200	91	1768
2030	91	490	247	255	251	138	33	116	209	113	1851
2040	97	475	269	267	232	160	36	132	217	139	1926
2050	102	441	286	295	222	173	47	153	222	150	1988
2060	106	445	299	308	191	192	48	167	228	158	2036
2070	108	508	310	296	143	195	49	172	231	175	2078
2080	111	532	319	296	139	183	48	183	234	177	2111
2090	114	562	327	272	148	188	38	191	236	179	2141
2100	115	570	333	291	173	135	39	190	237	192	2161
2110	117	534	338	297	180	152	41	198	238	192	2170

Table B.23 Temperate Low Plantation Total Carbon

	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
Year					Petagrams carbon					
1995	164.9	229.5	38.5	212.9	31.7	1.5	22.3	88.8	123.0	913.1
2005	164.4	229.5	39.0	212.4	32.7	1.6	22.9	89.0	123.1	914.6
2015	163.7	229.6	39.7	212.4	33.6	1.6	23.5	88.9	123.2	916.3
2025	163.1	229.9	40.6	212.4	34.3	1.7	24.1	89.2	123.3	918.7
2035	163.1	230.2	41.3	211.3	34.9	1.9	24.5	89.3	123.5	920.1
2045	163.6	230.4	41.8	209.8	35.4	2.0	24.9	89.7	123.7	921.2
2055	164.7	230.6	41.6	208.8	35.3	1.9	25.1	89.7	123.8	921.4
2065	165.6	230.7	41.5	209.4	34.2	1.8	25.2	90.3	123.9	922.6
2075	166.0	230.8	41.2	210.2	33.4	1.8	25.3	90.3	124.0	923.0
2085	165.5	230.9	41.1	210.8	33.5	1.8	25.4	90.5	124.1	923.7
2095	164.3	231.0	41.0	211.3	33.7	1.9	25.4	90.5	124.1	923.2
2105	163.5	231.0	40.7	211.3	34.5	2.0	25.5	91.0	124.2	923.7

Table B.24 Temperate Low Plantation Tree Carbon

	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
Year					Petagrams carbon					
1995	29.6	74.4	9.4	29.8	7.5	0.1	7.0	46.4	36.8	241.0
2005	29.1	74.5	9.7	29.3	8.2	0.1	7.5	46.3	36.9	241.6
2015	28.5	74.6	10.1	29.3	8.7	0.2	7.9	46.2	37.0	242.4
2025	27.9	74.7	10.7	29.3	9.2	0.2	8.2	46.2	37.1	243.6
2035	27.8	74.7	11.3	28.5	9.7	0.3	8.5	46.2	37.2	244.2
2045	28.2	74.8	11.6	27.5	10.1	0.4	8.7	46.2	37.2	244.6
2055	29.0	74.8	11.5	26.7	10.0	0.3	8.7	46.1	37.2	244.4
2065	29.8	74.8	11.4	27.1	9.1	0.2	8.7	46.3	37.3	244.8
2075	30.2	74.9	11.3	27.7	8.4	0.2	8.7	46.2	37.3	244.9
2085	29.9	74.9	11.2	28.2	8.5	0.2	8.8	46.3	37.3	245.2
2095	29.1	74.9	11.1	28.6	8.7	0.3	8.7	46.2	37.3	244.9
2105	28.4	74.9	10.8	28.7	9.3	0.3	8.8	46.3	37.3	244.9

Table B.25 Temperate Low Plantation Floor and Understory Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.4	46.4	4.0	27.1	3.3	0.1	0.6	3.9	22.1	126.7
2015	19.2	46.3	4.1	27.0	3.3	0.1	0.7	3.8	22.0	126.6
2025	19.1	46.3	4.2	27.0	3.4	0.1	0.7	3.8	22.0	126.5
2035	19.0	46.3	4.2	26.8	3.4	0.1	0.7	3.8	22.0	126.4
2045	19.0	46.3	4.3	26.6	3.4	0.1	0.7	3.8	22.0	126.2
2055	19.1	46.2	4.2	26.4	3.4	0.1	0.7	3.8	22.0	126.0
2065	19.2	46.2	4.2	26.5	3.3	0.1	0.7	3.8	22.0	126.0
2075	19.2	46.2	4.1	26.6	3.2	0.1	0.7	3.8	22.0	126.0
2085	19.0	46.2	4.1	26.7	3.2	0.1	0.7	3.8	22.0	125.9
2095	18.9	46.2	4.1	26.8	3.2	0.1	0.7	3.8	22.0	125.8
2105	18.8	46.2	4.1	26.8	3.3	0.1	0.7	3.8	22.0	125.8

Table B.26 Temperate Low Plantation Soil Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	114.2	108.2	24.4	155.4	20.7	1.3	14.6	38.1	64.0	540.9
2005	113.8	108.1	24.5	155.3	21.0	1.3	14.6	37.9	63.9	540.3
2015	113.5	108.0	24.6	155.2	21.1	1.3	14.7	37.9	63.8	540.1
2025	113.4	108.0	24.7	155.2	21.1	1.3	14.8	37.9	63.9	540.1
2035	113.5	108.1	24.7	154.9	21.1	1.3	14.8	37.9	63.9	540.2
2045	113.6	108.1	24.7	154.7	21.2	1.3	14.9	37.9	64.0	540.4
2055	113.8	108.2	24.7	154.7	21.1	1.3	14.9	37.9	64.0	540.6
2065	113.8	108.2	24.6	154.9	21.0	1.3	15.0	38.0	64.0	540.9
2075	113.7	108.2	24.6	155.1	21.0	1.3	15.0	38.0	64.1	541.0
2085	113.5	108.2	24.5	155.2	21.1	1.4	15.0	38.0	64.1	541.0
2095	113.3	108.2	24.5	155.2	21.1	1.4	15.0	37.9	64.1	540.8
2105	113.2	108.3	24.5	155.1	21.1	1.4	15.0	38.1	64.1	540.9

Table B.27 Temperate Low Plantation Market Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	1.5	0.3	0.7	0.6	0.3	0.1	0.1	0.4	0.2	4.1
2005	2.1	0.6	0.8	0.8	0.4	0.1	0.2	0.9	0.2	6.0
2015	2.5	0.8	1.0	0.9	0.5	0.1	0.3	1.0	0.3	7.3
2025	2.7	0.9	1.1	1.0	0.6	0.1	0.4	1.3	0.4	8.4
2035	2.8	1.1	1.1	1.0	0.6	0.1	0.5	1.5	0.4	9.3
2045	2.8	1.2	1.2	1.0	0.7	0.2	0.6	1.7	0.5	10.0
2055	2.8	1.3	1.3	0.9	0.8	0.2	0.7	1.9	0.5	10.4
2065	2.8	1.4	1.3	0.8	0.8	0.2	0.8	2.1	0.6	10.9
2075	2.9	1.5	1.3	0.8	0.8	0.2	0.9	2.3	0.6	11.2
2085	3.0	1.6	1.3	0.7	0.8	0.2	0.9	2.5	0.6	11.6
2095	3.1	1.6	1.3	0.7	0.8	0.2	0.9	2.6	0.7	11.8
2105	3.1	1.6	1.3	0.7	0.7	0.2	1.0	2.7	0.7	12.1

Table B.28 Temperate Low Plantation Average Annual Carbon Flux by Decade

Years	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995–2005	–47	0	54	–47	106	5	59	17	4	152
2005–2015	–69	15	68	2	84	8	59	–10	10	165
2015–2025	–58	27	90	–3	71	10	58	34	19	248
2025–2035	0	27	71	–111	57	13	45	12	19	133
2035–2045	49	21	45	–153	51	12	34	35	16	111
2045–2055	107	18	–16	–99	–10	–5	18	2	12	26
2055–2065	96	12	–15	65	–111	–8	15	58	10	121
2065–2075	41	12	–23	76	–76	–9	8	1	8	36
2075–2085	–55	7	–14	67	13	7	10	26	6	67
2085–2095	–118	8	–9	45	20	9	4	–6	5	–44
2095–2105	–81	4	–30	4	72	11	7	51	4	43

(5) Low Plantations in Subtropical Regions

Table B.29 Price and Harvest

Year	Price Real 19995 4/cub mt	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
		Million m^3 per year									
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	75	569	165	260	258	101	27	49	160	59	1648
2010	81	566	194	244	241	123	28	63	169	77	1704
2020	85	537	246	234	220	142	31	88	207	101	1806
2030	89	484	295	247	242	136	32	124	224	128	1913
2040	93	466	328	265	220	156	35	143	236	159	2009
2050	97	420	353	303	203	172	46	166	245	174	2082
2060	101	425	365	308	190	191	47	180	251	181	2139
2070	104	477	376	307	142	194	48	184	254	198	2181
2080	107	519	385	289	138	184	47	195	257	200	2214
2090	110	556	393	267	147	176	38	203	259	203	2242
2100	111	555	399	277	175	140	38	203	260	215	2263
2110	113	518	404	286	192	147	40	210	261	215	2273

Table B.30 Subtropical Regions Low Plantation Total Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	164.8	229.5	38.5	212.9	31.7	1.5	22.3	88.8	123.0	913.0
2005	164.2	229.6	39.0	212.3	32.7	1.6	23.0	89.0	123.1	914.5
2015	163.4	229.9	39.7	211.9	33.6	1.6	23.6	89.0	123.3	916.0
2025	162.6	230.4	40.6	211.9	34.3	1.7	24.2	89.4	123.5	918.5
2035	162.4	230.7	41.4	210.9	34.8	1.9	24.7	89.5	123.7	920.0
2045	162.7	231.0	41.8	209.8	35.4	2.0	25.0	89.9	123.9	921.5
2055	163.9	231.2	41.5	208.9	35.3	1.9	25.2	90.0	124.0	921.9
2065	164.9	231.3	41.2	209.6	34.2	1.9	25.4	90.5	124.1	923.1
2075	165.6	231.4	40.9	210.3	33.3	1.8	25.4	90.6	124.2	923.5
2085	164.8	231.5	40.7	211.0	33.5	1.8	25.5	90.8	124.3	924.1
2095	163.6	231.6	40.6	211.5	33.9	1.9	25.6	90.8	124.3	923.7
2105	162.5	231.7	40.4	211.4	34.6	2.0	25.7	91.3	124.4	923.9

Table B.31 Subtropical Regions Low Plantation Tree Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	29.6	74.4	9.4	29.8	7.5	0.1	7.0	46.4	36.8	240.9
2005	29.0	74.6	9.6	29.2	8.1	0.1	7.5	46.3	36.9	241.5
2015	28.3	74.8	10.1	28.9	8.7	0.2	7.9	46.2	37.1	242.1
2025	27.6	74.9	10.7	28.9	9.2	0.2	8.3	46.3	37.2	243.3
2035	27.4	75.0	11.3	28.2	9.7	0.3	8.6	46.3	37.3	244.0
2045	27.6	75.1	11.6	27.5	10.1	0.4	8.7	46.3	37.3	244.7
2055	28.5	75.1	11.5	26.8	10.0	0.3	8.8	46.2	37.3	244.5
2065	29.4	75.1	11.2	27.2	9.1	0.2	8.8	46.4	37.4	244.9
2075	30.0	75.1	11.0	27.8	8.4	0.2	8.8	46.3	37.4	244.9
2085	29.5	75.2	10.9	28.4	8.4	0.2	8.8	46.4	37.4	245.2
2095	28.6	75.2	10.8	28.8	8.8	0.3	8.8	46.3	37.4	244.9
2105	27.8	75.2	10.6	28.8	9.4	0.3	8.8	46.5	37.4	244.8

Table B.32 Subtropical Regions Low Plantation Floor and Understory Carbon

	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
Year					Petagrams carbon					
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.3	46.4	4.0	27.0	3.3	0.1	0.6	3.9	22.1	126.7
2015	19.1	46.3	4.1	27.0	3.3	0.1	0.7	3.9	22.1	126.5
2025	19.0	46.3	4.2	26.9	3.4	0.1	0.7	3.9	22.1	126.4
2035	18.9	46.3	4.2	26.8	3.4	0.1	0.7	3.8	22.1	126.3
2045	18.9	46.3	4.2	26.6	3.4	0.1	0.7	3.8	22.1	126.2
2055	19.0	46.3	4.2	26.5	3.4	0.1	0.7	3.8	22.1	126.0
2065	19.1	46.3	4.1	26.5	3.3	0.1	0.7	3.9	22.1	126.0
2075	19.1	46.3	4.1	26.6	3.2	0.1	0.7	3.8	22.1	126.0
2085	18.9	46.3	4.1	26.7	3.2	0.1	0.7	3.8	22.1	125.9
2095	18.8	46.3	4.0	26.8	3.3	0.1	0.7	3.8	22.1	125.8
2105	18.7	46.3	4.0	26.8	3.3	0.1	0.7	3.9	22.1	125.8

Table B.33 Subtropical Regions Low Plantation Soil Storage

	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
Year					Petagrams carbon					
1995	114.2	108.2	24.4	155.4	20.7	1.3	14.6	38.1	64.0	540.9
2005	113.8	108.1	24.5	155.2	20.9	1.3	14.7	37.9	63.9	540.3
2015	113.5	108.0	24.6	155.2	21.1	1.3	14.7	37.9	63.8	540.0
2025	113.3	108.0	24.7	155.1	21.1	1.3	14.8	37.9	63.9	540.1
2035	113.3	108.1	24.7	154.9	21.1	1.3	14.8	37.9	63.9	540.2
2045	113.5	108.2	24.7	154.7	21.2	1.4	14.9	37.9	64.0	540.4
2055	113.7	108.2	24.6	154.7	21.1	1.3	14.9	37.9	64.0	540.5
2065	113.7	108.2	24.6	155.0	21.0	1.3	15.0	38.0	64.1	540.9
2075	113.7	108.2	24.5	155.1	21.0	1.3	15.0	38.0	64.1	540.9
2085	113.4	108.3	24.5	155.2	21.0	1.4	15.0	38.0	64.1	540.9
2095	113.2	108.3	24.5	155.2	21.1	1.4	15.0	37.9	64.1	540.7
2105	113.1	108.3	24.5	155.1	21.1	1.4	15.0	38.1	64.1	540.7

Table B.34 Subtropical Regions Low Plantation Market Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	1.5	0.3	0.7	0.6	0.3	0.1	0.1	0.4	0.2	4.1
2005	2.1	0.6	0.8	0.8	0.4	0.1	0.2	0.9	0.2	6.0
2015	2.5	0.8	1.0	0.9	0.5	0.1	0.3	1.0	0.3	7.4
2025	2.7	1.1	1.0	1.0	0.6	0.1	0.4	1.3	0.4	8.6
2035	2.8	1.3	1.1	1.0	0.6	0.1	0.5	1.6	0.5	9.5
2045	2.7	1.5	1.2	1.0	0.7	0.2	0.7	1.8	0.5	10.3
2055	2.7	1.6	1.3	0.9	0.8	0.2	0.8	2.0	0.6	10.8
2065	2.7	1.7	1.3	0.8	0.8	0.2	0.9	2.2	0.6	11.3
2075	2.8	1.8	1.3	0.7	0.8	0.2	0.9	2.4	0.7	11.7
2085	3.0	1.9	1.3	0.7	0.8	0.2	1.0	2.6	0.7	12.1
2095	3.0	1.9	1.2	0.7	0.7	0.2	1.0	2.8	0.7	12.3
2105	3.0	1.9	1.2	0.7	0.7	0.2	1.1	2.9	0.7	12.6

Table B.35 Subtropical Regions Low Plantation Average Annual Carbon Flux by Decade

Years	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995–2005	–59	13	50	–57	105	6	61	24	8	151
2005–2015	–84	29	73	–37	84	8	62	–7	16	144
2015–2025	–78	43	86	–1	71	10	62	38	24	255
2025–2035	–22	35	82	–98	57	12	47	18	23	154
2035–2045	34	28	37	–110	56	12	35	37	17	147
2045–2055	114	18	–21	–96	–10	–5	18	5	13	37
2055–2065	103	17	–31	68	–113	–8	16	59	10	120
2065–2075	65	9	–38	79	–84	–9	8	4	8	42
2075–2085	–73	11	–13	69	13	6	10	26	6	56
2085–2095	–128	5	–16	46	47	8	4	–3	5	–34
2095–2105	–105	8	–18	–5	67	10	7	51	4	19

(6) Low-elasticity Base Case

Table B.36 Price and Harvest

Year	Price Real 1995 $/cub mt	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
		Million m^3 per year									
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	116	615	180	267	290	118	29	54	166	70	1788
2010	126	614	212	259	264	140	31	75	175	93	1863
2020	133	596	269	254	238	162	35	118	215	131	2019
2030	140	530	320	283	229	166	39	164	229	169	2129
2040	147	522	357	301	191	177	43	195	241	207	2234
2050	153	460	383	316	175	212	55	237	249	234	2323
2060	157	484	404	335	169	193	61	250	257	245	2399
2070	162	544	420	305	149	206	65	258	261	264	2473
2080	164	565	432	296	151	205	66	283	265	276	2538
2090	166	621	441	298	174	172	58	284	267	277	2593
2100	168	614	449	303	213	162	56	283	268	289	2636
2110	170	582	456	319	204	171	56	303	269	296	2656

Table B.37 Low-elasticity Base Case Total Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	165.4	229.3	38.8	213.2	31.8	1.3	22.2	88.8	122.9	913.7
2005	164.3	229.3	39.3	212.0	32.7	1.3	22.8	89.1	122.8	913.6
2015	163.1	229.4	40.0	210.9	33.6	1.4	23.5	89.1	123.0	914.0
2025	162.3	229.9	41.0	210.2	34.5	1.6	24.2	89.5	123.3	916.4
2035	162.2	230.3	41.7	209.8	34.9	1.8	24.8	89.7	123.7	918.7
2045	162.6	230.7	41.8	209.3	35.5	2.1	25.3	90.1	123.9	921.3
2055	164.1	231.0	41.7	209.2	34.9	2.1	25.6	90.2	124.2	922.9
2065	165.1	231.2	41.3	210.0	34.4	2.1	25.8	90.8	124.3	925.1
2075	165.7	231.4	41.3	211.0	33.6	2.1	25.9	90.8	124.5	926.1
2085	164.8	231.5	41.1	211.6	33.9	2.1	26.1	91.1	124.6	926.8
2095	163.7	231.6	41.2	211.6	34.1	2.2	26.1	91.1	124.6	926.1
2105	162.9	231.6	40.9	210.5	35.1	2.3	26.2	91.6	124.7	926.0

Table B.38 Low-elasticity Base Case Tree Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	30.0	74.4	9.7	30.1	7.6	0.1	7.0	46.4	36.8	242.2
2005	29.2	74.6	10.0	29.1	8.1	0.1	7.5	46.3	37.0	242.0
2015	28.3	74.8	10.5	28.3	8.6	0.2	8.0	46.3	37.2	242.0
2025	27.6	74.9	11.1	27.8	9.2	0.3	8.4	46.3	37.3	243.0
2035	27.5	75.0	11.6	27.5	9.5	0.4	8.7	46.3	37.4	243.9
2045	27.8	75.0	11.7	27.3	10.0	0.5	8.8	46.3	37.5	245.0
2055	29.0	75.1	11.6	27.2	9.6	0.5	8.9	46.3	37.5	245.6
2065	29.9	75.1	11.4	27.8	9.1	0.5	8.9	46.5	37.6	246.8
2075	30.4	75.2	11.4	28.6	8.4	0.4	8.9	46.4	37.6	247.3
2085	29.9	75.2	11.3	29.1	8.7	0.3	9.0	46.4	37.6	247.6
2095	29.1	75.2	11.4	29.1	8.9	0.4	9.0	46.3	37.7	247.0
2105	28.5	75.2	11.1	28.4	9.7	0.5	9.0	46.5	37.7	246.5

Table B.39 Low-elasticity Base Case Floor and Understory Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.2	46.3	4.0	26.9	3.2	0.1	0.6	3.9	22.0	126.2
2015	18.9	46.1	4.1	26.7	3.3	0.1	0.7	3.8	21.9	125.6
2025	18.6	46.1	4.1	26.6	3.3	0.1	0.7	3.8	21.9	125.4
2035	18.6	46.1	4.2	26.5	3.3	0.1	0.7	3.8	21.9	125.3
2045	18.6	46.1	4.2	26.4	3.4	0.1	0.8	3.8	21.9	125.2
2055	18.7	46.1	4.1	26.3	3.3	0.1	0.8	3.8	21.9	125.1
2065	18.8	46.1	4.1	26.4	3.2	0.1	0.8	3.9	21.9	125.2
2075	18.7	46.1	4.0	26.5	3.1	0.1	0.8	3.8	21.9	125.1
2085	18.5	46.1	4.0	26.6	3.2	0.1	0.8	3.8	21.9	125.0
2095	18.4	46.1	4.0	26.6	3.2	0.1	0.8	3.8	21.9	124.9
2105	18.3	46.0	4.0	26.5	3.3	0.1	0.8	3.9	21.9	124.8

Table B.40 Low-elasticity Base Case Soil Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	114.2	108.0	24.4	155.4	20.7	1.1	14.5	38.1	63.8	540.1
2005	113.6	107.7	24.4	155.1	21.0	1.0	14.4	38.0	63.6	538.8
2015	113.2	107.6	24.5	154.9	21.1	1.0	14.5	37.9	63.5	538.2
2025	113.0	107.7	24.6	154.8	21.2	1.1	14.6	37.9	63.6	538.5
2035	113.0	107.8	24.6	154.8	21.2	1.2	14.7	37.9	63.7	539.0
2045	113.2	107.9	24.6	154.7	21.3	1.3	14.8	38.0	63.8	539.6
2055	113.4	108.0	24.6	154.8	21.2	1.3	14.9	38.0	63.9	540.0
2065	113.4	108.1	24.5	155.0	21.2	1.3	14.9	38.2	63.9	540.5
2075	113.3	108.1	24.5	155.2	21.1	1.3	14.9	38.1	64.0	540.5
2085	113.0	108.1	24.5	155.2	21.2	1.4	15.0	38.1	64.0	540.5
2095	112.8	108.1	24.5	155.0	21.2	1.4	15.0	38.1	64.0	540.2
2105	112.8	108.1	24.5	154.8	21.4	1.4	15.0	38.2	64.0	540.3

Table B.41 Low-elasticity Base Case Market Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	1.6	0.4	0.7	0.6	0.3	0.1	0.1	0.4	0.2	4.3
2005	2.2	0.6	0.9	0.9	0.4	0.1	0.2	0.9	0.3	6.5
2015	2.7	0.9	1.0	1.0	0.6	0.1	0.3	1.1	0.4	8.1
2025	3.0	1.2	1.1	1.0	0.7	0.1	0.5	1.4	0.5	9.5
2035	3.1	1.4	1.2	1.0	0.8	0.2	0.7	1.6	0.6	10.6
2045	3.0	1.6	1.3	1.0	0.8	0.2	0.9	1.9	0.7	11.5
2055	3.0	1.8	1.4	0.9	0.9	0.2	1.0	2.1	0.8	12.1
2065	3.0	1.9	1.4	0.8	0.9	0.3	1.2	2.3	0.9	12.7
2075	3.2	2.0	1.4	0.7	0.9	0.3	1.3	2.5	1.0	13.2
2085	3.3	2.1	1.3	0.8	0.9	0.3	1.4	2.7	1.0	13.7
2095	3.3	2.2	1.4	0.8	0.8	0.3	1.4	2.9	1.0	14.1
2105	3.3	2.2	1.4	0.8	0.8	0.3	1.5	3.0	1.1	14.4

Table B.42 Low-elasticity Base Case Average Annual Carbon Flux by Decade

Years	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995–2005	–115	–8	52	–120	99	1	57	29	–4	–9
2005–2015	–118	18	75	–106	85	8	69	–6	16	42
2015–2025	–82	45	95	–70	85	18	74	42	34	241
2025–2035	–9	43	68	–46	40	24	57	20	34	232
2035–2045	43	37	16	–43	65	25	49	41	29	263
2045–2055	154	28	–15	–17	–60	7	27	8	22	155
2055–2065	98	21	–35	84	–47	–1	24	62	17	224
2065–2075	56	16	–5	97	–89	–7	12	5	13	98
2075–2085	–90	13	–14	65	40	5	15	29	9	71
2085–2095	–109	9	7	–9	12	10	5	–3	7	–71
2095–2105	–75	8	–28	–104	101	14	11	53	6	–15

(7) Low-elasticity Subtropical Plantations

Table B.43 Price and Harvest

Year	Price Real 1995 $/cub mt	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
		Million m^3 per year									
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	112	630	198	298	285	128	28	52	159	74	1852
2010	117	603	282	267	253	151	30	78	189	106	1960
2020	119	559	412	252	238	135	34	135	248	173	2185
2030	120	471	561	229	197	134	37	199	304	240	2370
2040	122	418	650	207	171	179	40	243	337	300	2545
2050	124	392	713	233	161	149	51	293	365	341	2698
2060	126	431	726	266	142	186	53	301	371	346	2821
2070	129	518	735	290	143	155	54	304	373	361	2932
2080	128	544	743	293	145	177	53	322	375	366	3019
2090	131	582	750	291	180	167	44	323	377	367	3080
2100	134	583	757	277	211	166	44	323	379	378	3119
2110	138	526	765	288	200	192	48	340	381	385	3125

Table B.44 Low-elasticity Subtropical Plantations Total Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	165.2	229.4	38.6	213.1	31.7	1.4	22.3	88.8	122.9	913.4
2005	163.4	230.0	38.7	211.3	32.4	1.5	23.0	89.5	123.1	912.9
2015	161.8	230.9	39.0	210.3	32.7	1.6	23.8	89.6	123.6	913.2
2025	161.0	232.2	39.2	209.6	33.6	1.7	24.8	90.1	124.2	916.3
2035	161.2	233.0	40.2	209.4	34.6	1.8	25.4	90.8	124.7	921.1
2045	162.4	233.7	40.9	209.0	34.9	2.0	26.0	91.2	125.0	925.1
2055	164.3	234.0	41.5	209.4	34.4	2.0	26.2	91.5	125.2	928.5
2065	165.7	234.4	41.3	210.3	33.3	1.9	26.5	92.0	125.4	930.8
2075	165.5	234.4	41.1	211.4	34.2	1.8	26.6	92.4	125.5	932.8
2085	164.6	234.7	40.7	212.1	33.8	1.9	26.7	92.6	125.6	932.7
2095	163.4	234.7	40.8	211.6	34.4	2.0	26.7	92.7	125.6	931.9
2105	163.1	234.9	40.7	210.4	34.2	2.1	26.9	93.1	125.7	931.0

Table B.45 Low-elasticity Subtropical Plantations Tree Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	29.8	74.4	9.6	29.9	7.5	0.1	7.0	46.4	36.8	241.5
2005	28.5	75.0	9.4	28.6	7.8	0.1	7.6	46.6	37.1	240.8
2015	27.3	75.5	9.5	27.8	7.9	0.2	8.1	46.6	37.5	240.5
2025	26.6	76.1	9.6	27.3	8.6	0.2	8.7	46.7	37.7	241.6
2035	26.7	76.2	10.4	27.1	9.4	0.3	9.0	46.9	37.9	244.0
2045	27.7	76.4	11.0	26.9	9.7	0.4	9.2	46.9	38.0	246.2
2055	29.1	76.3	11.6	27.2	9.3	0.4	9.2	46.9	38.0	248.0
2065	30.2	76.5	11.4	28.0	8.5	0.3	9.3	47.0	38.1	249.1
2075	30.2	76.4	11.3	28.8	9.0	0.2	9.2	47.0	38.1	250.2
2085	29.6	76.5	11.0	29.4	8.7	0.3	9.3	47.0	38.1	249.8
2095	28.7	76.4	11.0	29.1	9.2	0.3	9.3	46.9	38.1	249.1
2105	28.3	76.5	10.9	28.2	9.1	0.4	9.3	47.0	38.1	248.0

Table B.46 Low-elasticity Subtropical Plantations Floor and Understory Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.1	46.4	4.0	26.8	3.2	0.1	0.7	3.9	22.1	126.2
2015	18.8	46.3	4.0	26.7	3.2	0.1	0.7	3.9	22.1	125.7
2025	18.6	46.4	4.0	26.6	3.3	0.1	0.8	3.9	22.1	125.7
2035	18.6	46.4	4.1	26.5	3.3	0.1	0.8	3.9	22.1	125.9
2045	18.7	46.4	4.2	26.4	3.3	0.1	0.8	3.9	22.1	126.0
2055	18.9	46.4	4.2	26.5	3.3	0.1	0.8	3.9	22.1	126.2
2065	19.0	46.4	4.1	26.6	3.2	0.1	0.8	3.9	22.1	126.2
2075	18.9	46.4	4.1	26.7	3.2	0.1	0.8	4.0	22.1	126.3
2085	18.8	46.4	4.0	26.8	3.2	0.1	0.8	3.9	22.1	126.1
2095	18.6	46.4	4.0	26.7	3.3	0.1	0.8	3.9	22.1	125.9
2105	18.6	46.4	4.0	26.5	3.3	0.1	0.8	3.9	22.1	125.7

Table B.47 Low-elasticity Subtropical Plantations Soil Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	114.2	108.1	24.4	155.4	20.7	1.2	14.5	38.1	63.8	540.4
2005	113.5	107.9	24.4	155.0	20.9	1.2	14.5	38.0	63.7	539.1
2015	113.1	107.8	24.5	154.9	21.0	1.2	14.6	37.9	63.7	538.6
2025	113.0	107.9	24.5	154.8	21.1	1.2	14.7	37.9	63.8	539.0
2035	113.1	108.0	24.6	154.8	21.2	1.3	14.8	38.0	63.9	539.8
2045	113.4	108.2	24.7	154.8	21.1	1.3	14.9	38.0	64.0	540.4
2055	113.6	108.2	24.7	154.9	21.0	1.3	15.0	38.0	64.1	540.8
2065	113.7	108.3	24.6	155.1	21.0	1.3	15.0	38.1	64.1	541.1
2075	113.4	108.3	24.5	155.2	21.2	1.3	15.0	38.1	64.1	541.2
2085	113.2	108.3	24.5	155.2	21.1	1.4	15.0	38.1	64.1	540.9
2095	113.0	108.3	24.5	155.0	21.2	1.4	15.0	38.0	64.1	540.6
2105	113.1	108.3	24.5	154.8	21.2	1.4	15.0	38.1	64.1	540.5

Table B.48 Low-elasticity Subtropical Plantations Market Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	1.6	0.4	0.7	0.7	0.3	0.1	0.1	0.4	0.2	4.4
2005	2.2	0.8	0.9	0.8	0.5	0.1	0.2	1.0	0.3	6.7
2015	2.6	1.2	1.0	0.9	0.6	0.1	0.4	1.2	0.4	8.5
2025	2.8	1.8	1.1	1.0	0.6	0.1	0.6	1.6	0.6	10.1
2035	2.7	2.3	1.1	0.9	0.7	0.1	0.9	2.0	0.8	11.4
2045	2.7	2.7	1.1	0.9	0.7	0.2	1.1	2.3	0.9	12.6
2055	2.6	3.0	1.1	0.8	0.8	0.2	1.3	2.7	1.0	13.5
2065	2.8	3.3	1.2	0.7	0.7	0.2	1.4	3.0	1.1	14.4
2075	2.9	3.4	1.2	0.7	0.7	0.2	1.5	3.3	1.2	15.1
2085	3.0	3.5	1.2	0.7	0.7	0.2	1.6	3.6	1.2	15.8
2095	3.1	3.6	1.2	0.8	0.8	0.2	1.6	3.8	1.3	16.4
2105	3.1	3.7	1.2	0.8	0.7	0.2	1.7	4.0	1.3	16.8

Table B.49 Low-elasticity Subtropical Plantations Average Annual Carbon Flux by Decade

Years	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995–2005	–180	59	14	–174	69	6	70	60	22	–55
2005–2015	–161	92	27	–101	24	9	87	13	48	38
2015–2025	–82	128	21	–69	93	13	93	50	59	306
2025–2035	24	81	95	–25	100	15	68	69	52	480
2035–2045	124	73	71	–36	28	15	53	43	30	401
2045–2055	186	25	66	40	–42	–2	25	26	22	344
2055–2065	138	44	–27	91	–111	–6	25	52	15	222
2065–2075	–18	3	–20	103	82	–6	8	41	11	204
2075–2085	–89	29	–35	70	–39	9	16	18	8	–13
2085–2095	–120	–7	8	–48	61	11	3	12	6	–73
2095–2105	–35	23	–9	–121	–19	11	13	41	5	–91

Case 2: No Timber Harvesting allowed

Table B.50 **Descriptions:** Planting scenarios 2, 3, 4, 5 are presented

Planting Scenario 2 (50 million hectares in temperate forests)

Year	Carbon Storage with Soil Carbon	Carbon Storage without Soil Carbon
2005	0.22	0.00
2015	0.70	0.14
2025	1.60	0.63
2035	2.64	1.42
2045	3.72	2.35
2055	4.67	3.20
2065	5.55	4.03
2075	6.41	4.86
2085	7.27	5.69
2095	8.11	6.52
2105	8.92	7.33

Table B.51 Planting Scenario 3 (50 million hectares in subtropical plantation forests)

Year	Carbon Storage with Soil Carbon	Carbon Storage without Soil Carbon
2005	0.19	0.01
2015	1.00	0.52
2025	2.89	2.04
2035	5.49	4.42
2045	8.14	6.94
2055	10.22	8.94
2065	11.46	10.14
2075	12.03	10.70
2085	12.06	10.73
2095	12.06	10.73
2105	12.06	10.73

Table B.52 Planting Scenario 3 (10 million hectares in temperate forests)

Year	Carbon Storage with Soil Carbon	Carbon Storage without Soil Carbon
2005	0.04	0.00
2015	0.14	0.03
2025	0.32	0.13
2035	0.53	0.28
2045	0.74	0.47
2055	0.93	0.64
2065	1.11	0.81
2075	1.28	0.97
2085	1.45	1.14
2095	1.62	1.30
2105	1.78	1.47

Table B.53 Planting Scenario 4 (10 million hectares in subtropical plantation forests)

Year	Carbon Storage with Soil Carbon	Carbon Storage without Soil Carbon
2005	0.04	0.00
2015	0.20	0.10
2025	0.57	0.40
2035	1.09	0.88
2045	1.62	1.38
2055	2.04	1.78
2065	2.28	2.02
2075	2.40	2.13
2085	2.41	2.14
2095	2.41	2.14
2105	2.41	2.14

Table B.54 High plantation subtropical case—long rotation maximum sustainable yield (MSY) harvests
Price and Harvest

Year	Price Real 1995 $/cub mt	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
		Million m^3 per year									
1980		456	84	280	277	76	21	26	114	52	1386
1992		582	117	279	256	93	25	32	133	59	1575
2000	73	557	159	284	280	103	27	47	159	58	1674
2010	79	562	207	256	247	122	28	68	163	88	1742
2020	82	535	271	242	231	151	30	101	197	118	1875
2030	84	462	402	223	204	133	32	153	245	182	2033
2040	83	432	524	183	164	126	34	197	291	249	2200
2050	84	369	610	179	156	129	45	234	335	286	2342
2060	87	373	618	241	137	169	45	240	340	290	2452
2070	91	478	550	312	139	195	46	225	301	273	2519
2080	94	509	556	312	142	205	45	235	303	272	2578
2090	93	539	561	336	160	178	35	237	305	274	2624
2100	94	556	641	248	146	124	35	258	335	317	2659
2110	97	465	646	256	218	111	38	266	353	315	2666

Table B.55 High Plantation/Subtropical /MSY Total Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	164.7	229.9	38.4	212.8	31.7	1.5	22.4	88.9	123.2	913.5
2005	163.9	231.0	38.6	211.6	32.6	1.6	23.2	89.7	123.6	915.9
2015	163.0	232.4	39.0	210.8	33.4	1.6	24.1	89.9	124.1	918.2
2025	162.1	233.9	39.1	209.7	33.7	1.8	25.0	90.6	124.8	920.7
2035	161.6	234.9	39.7	209.5	34.1	1.9	25.6	91.0	125.2	923.3
2045	162.1	235.2	40.4	209.1	34.9	2.0	25.9	91.4	125.4	926.5
2055	163.8	235.0	41.7	209.4	36.0	1.9	26.0	91.5	125.3	930.6
2065	165.4	235.1	42.2	210.2	35.1	1.9	26.1	92.2	125.3	933.6
2075	165.5	235.6	41.4	211.1	33.7	1.8	26.3	92.2	125.6	933.2
2085	164.6	236.0	40.4	211.7	32.6	1.8	26.5	92.5	125.8	931.9
2095	163.4	236.1	39.7	211.6	33.3	1.9	26.5	92.7	125.8	931.1
2105	162.8	235.6	40.6	212.5	34.4	2.0	26.4	93.1	125.6	933.0

Table B.56 High Plantation/Subtropical /MSY Tree Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	29.4	74.7	9.3	29.7	7.5	0.1	7.1	46.4	36.9	241.1
2005	28.7	75.6	9.3	28.7	8.0	0.1	7.7	46.9	37.3	242.4
2015	27.9	76.6	9.4	28.0	8.5	0.2	8.3	47.0	37.7	243.7
2025	27.2	77.6	9.4	27.2	8.8	0.2	8.9	47.3	38.2	244.9
2035	26.8	78.0	9.9	27.1	9.1	0.3	9.2	47.4	38.4	246.2
2045	27.2	77.9	10.6	26.8	9.8	0.4	9.3	47.4	38.4	247.8
2055	28.5	77.3	11.7	27.1	10.7	0.3	9.2	47.3	38.2	250.3
2065	29.7	77.3	12.1	27.7	10.0	0.2	9.2	47.5	38.1	252.0
2075	29.9	77.8	11.5	28.5	8.8	0.1	9.3	47.4	38.3	251.6
2085	29.3	78.1	10.6	28.9	7.8	0.2	9.4	47.5	38.5	250.3
2095	28.4	78.0	10.1	29.0	8.4	0.2	9.4	47.5	38.5	249.3
2105	27.9	77.4	10.7	29.6	9.3	0.3	9.3	47.5	38.2	250.3

Table B.57 High Plantation/Subtropical /MSY Floor and Understory Carbon

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	19.6	46.5	4.0	27.1	3.2	0.1	0.6	3.9	22.1	127.1
2005	19.3	46.4	4.0	27.0	3.2	0.1	0.6	3.9	22.1	126.6
2015	19.1	46.4	4.0	26.9	3.3	0.1	0.7	3.9	22.0	126.4
2025	18.9	46.5	4.0	26.7	3.3	0.1	0.7	3.9	22.0	126.2
2035	18.9	46.5	4.1	26.7	3.4	0.1	0.7	3.8	22.0	126.1
2045	18.9	46.5	4.2	26.6	3.4	0.1	0.7	3.8	22.0	126.2
2055	19.1	46.4	4.3	26.6	3.5	0.1	0.7	3.8	22.0	126.5
2065	19.2	46.4	4.3	26.7	3.4	0.1	0.7	3.9	22.0	126.7
2075	19.2	46.4	4.2	26.8	3.2	0.1	0.7	3.8	22.0	126.5
2085	19.0	46.4	4.0	26.8	3.2	0.1	0.7	3.8	22.0	126.2
2095	18.9	46.4	4.0	26.9	3.2	0.1	0.7	3.9	22.0	126.1
2105	18.8	46.4	4.1	26.9	3.3	0.1	0.7	3.9	22.0	126.3

Table B.58 High Plantation/Subtropical /MSY Soil Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
					Petagrams carbon					
1995	114.2	108.3	24.4	155.4	20.7	1.3	14.7	38.1	64.0	541.2
2005	113.8	108.4	24.5	155.1	20.9	1.3	14.7	38.0	64.0	540.8
2015	113.5	108.4	24.6	155.0	21.0	1.3	14.8	38.0	64.0	540.6
2025	113.3	108.6	24.6	154.8	21.0	1.3	14.9	38.0	64.1	540.7
2035	113.3	108.7	24.6	154.8	21.0	1.4	15.0	38.0	64.2	541.0
2045	113.5	108.7	24.7	154.8	21.1	1.4	15.0	38.1	64.2	541.5
2055	113.8	108.7	24.8	155.0	21.2	1.4	15.1	38.0	64.2	542.1
2065	113.9	108.7	24.7	155.1	21.0	1.4	15.1	38.1	64.3	542.4
2075	113.7	108.8	24.6	155.3	20.9	1.4	15.1	38.1	64.3	542.0
2085	113.4	108.8	24.5	155.2	20.9	1.4	15.1	38.1	64.3	541.7
2095	113.3	108.8	24.5	155.1	21.0	1.4	15.1	38.1	64.3	541.6
2105	113.3	108.7	24.6	155.2	21.1	1.4	15.1	38.2	64.3	541.9

Table B.59 High Plantation/Subtropical /MSY Market Storage

Year	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995	1.5	0.3	0.7	0.6	0.3	0.1	0.1	0.4	0.2	4.1
2005	2.0	0.6	0.9	0.8	0.4	0.1	0.2	0.9	0.2	6.1
2015	2.5	0.9	1.0	0.9	0.5	0.1	0.3	1.0	0.3	7.5
2025	2.7	1.3	1.0	0.9	0.6	0.1	0.5	1.4	0.5	8.9
2035	2.7	1.7	1.0	0.9	0.6	0.1	0.7	1.7	0.6	10.0
2045	2.5	2.2	0.9	0.8	0.6	0.2	0.9	2.1	0.8	11.0
2055	2.4	2.5	1.0	0.8	0.6	0.2	1.0	2.3	0.9	11.8
2065	2.5	2.6	1.1	0.7	0.7	0.2	1.1	2.6	0.9	12.5
2075	2.7	2.6	1.2	0.7	0.8	0.2	1.1	2.9	0.9	13.1
2085	2.9	2.7	1.3	0.7	0.8	0.2	1.2	3.1	1.0	13.7
2095	2.9	2.9	1.2	0.7	0.7	0.2	1.3	3.3	1.0	14.1
2105	2.8	3.0	1.2	0.7	0.6	0.2	1.3	3.5	1.1	14.4

Table B.60 High Plantation/Subtropical /MSY Average Annual Carbon Flux by Decade

Years	North America	South America	Europe	FSU	China	India	Oceania	Asia-Pacific	Africa	TOTAL
	Petagrams carbon									
1995–2005	–83	114	23	–112	93	6	82	84	42	248
2005–2015	–94	134	34	–88	78	8	85	16	52	224
2015–2025	–83	155	14	–107	33	11	86	69	68	247
2025–2035	–52	94	59	–24	36	12	60	37	44	266
2035–2045	51	39	71	–39	82	12	39	44	20	319
2045–2055	164	–25	127	33	107	–6	9	10	–11	408
2055–2065	165	7	57	82	–83	–9	11	65	3	299
2065–2075	10	50	–80	91	–142	–10	14	7	22	–38
2075–2085	–90	46	–103	56	–114	6	17	29	24	–130
2085–2095	–122	5	–71	–6	76	7	4	20	4	–83
2095–2105	–56	–53	88	89	105	9	–6	37	–21	193

Appendix C: Model of Global Timber Markets

The demand for timber logs is derived from a well-behaved utility function over industrial wood end products and all other goods. Any increase in demand for timber logs reflects an increase in demand for end products, net of the effect of technological change in the timber-processing sector. In this model, the global demand function is assumed to be the additive sum of many different regional demand functions. While trade could be addressed with a more detailed demand system and bilateral trade flows, such a model would distract from the long-term, dynamic focus of this paper. The model accounts for trade by assuming that each region has a distinct constant marginal cost of transporting timber to its major demand region. Regional price differences, therefore, exist, but are assumed to follow the law of one price.

The inverse demand function is:

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

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 benefit of industrial wood harvests is Marshallian consumer surplus or the area underneath the demand curve.

This model explores how supply adjusts to the anticipated increase in demand for timber products over time. Globally, the forest resource is composed of i different stocks of trees, $X_i(t)$. The ecological characteristics of these stocks vary dramatically, depending on locational factors such as climate and soils. The use of these stocks for industrial wood also varies depending on the quality of the wood and access. For example, large stocks of mature natural forests in northern Canada, the Former Soviet Union, and the tropics have yet to be exploited. In contrast, landowners in accessible fertile areas in South America, Africa, Iberia, Australia, and New Zealand are spending substantial resources every year establishing approximately 3.2 million hectares of new fast-growing plantations each year (U.N. Food and Agriculture Organization 1995). This model seeks to explain these choices, and predict how they will change over time.

Forests in different regions are assumed to grow according to $V_i(a_i(t);m_i(t_0))$, where $a_i(t)$ is the age of the stand of tree type i at time t, and $m(t_0)$ represents management intensity for a stand planted at time t_0. A single yield function exists for the species in each ecosystem type. Ecosystem types are aggregations of many timber species, which have been classified as one for modeling purposes (see, for example, Kuchler 1975). This yield function is assumed to be typical for the species in each ecosystem type, where $V_{a_i}>0$ and $V_{a_i a_i}<0$. Over all species harvested in a given year, the quantity of timber harvested at time t is the sum of the area harvested, $H_i(t)$, times the yield per hectare,

(2) $$Q(t) = \sum_i H_i(t) V_i\left(a_i(t); m_i(t_0)\right).$$

There are many costs of timber management, including the costs associated with accessing, harvesting, and transporting timber. These costs are expressed as

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

$c_i^A(q_i(t))$ is the cost of accessing timber stocks and $c_i^H(q_i(t))$ is the cost of harvesting and transporting timber to markets. 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, because of the absence of roads and infrastructure. Marginal 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 and transportation costs are assumed to be constant in terms of the quantity of timber harvested, although they vary by region.

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

where $m_i(t)$ is a unit of management intensity purchased at price $p_{i,m}$ (Sedjo and Lyon [1991). 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, $\frac{dV_i(t_{a_i}-t_0;m_i(t_0))}{dm_i(t_0)} \geq 0$, and $\frac{d^2V_i(t_{a_i}-t_0;m_i(t_0))}{dm_i(t_0)^2} \leq 0$, where t_{a_i} is the time of harvest for species i, 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 them for timber. If new lands in timber plantations are $N_i(t)$, the costs of new land are given as

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

where $f_{N,i}(N_i(t))$ represents 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 market benefits:

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

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

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

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. The model solution determines how much to harvest, $H_i(t)$, how many 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) $\dot{X}_i = -H_i(t) + G_i(t) + N_i(t)$, $\forall$ i

which expresses the change in the size of the total population of each type of organism in each period. Equation (8) is the difference between area harvested and regenerated. In addition, initial stocks must be given (equation 9), and all choice variables are constrained to be greater than or equal to 0 (equation 10):

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

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

Equation (9) defines not only the total quantity harvested, but also the age distribution through a yield function associated with each hectare of land.

The model can be solved using the maximum theorem (Pontryagin et al. 1962). One set of conditions resulting from this model involves harvesting accessible forests. These forests will be harvested according to

(11) $\dot{P}V_i\left(a_i(t);m_i(t_0)\right) + \left(P(t) - c_i^{H}{}'\right)\dot{V}_i = r\left(P(t) - c_i^{H}{}'\right)V_i\left(a_i(t);m_i(t_0)\right) + R_i(t)$.

P(t) is the global market clearing price of industrial timber logs, and $c_i^{H\prime}$ 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

$$(12) \qquad \dot{P} = r\left(P(t) - c_i^{H}{}' - c_i^{A}{}'\right),$$

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 can 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. This close choice between harvesting or not, however, makes harvests of marginal forests sensitive to world prices. Any public decision that 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,

$$(13) \qquad \left(P(t_{a_i}) - c_i^{H}{}'\right)V_i(t_{a_i} - t_0; m_i(t_0))e^{-r(t_{ai}-t_0)} = p_{m,i}m_i(t_0) + \int_{t_0}^{t_{ai}}\left[R_i(z_i)e^{-rz_i}\right]dz_i \ .$$

According to (13), land will be replanted in forests as long as the discounted marginal benefits of the last hectare offset 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) $$\left(P(t_{a_i}) - c_i^{H}{'}\right)\left(\frac{dV_i(t_{a_i} - t_0; m_i(t_0))}{dm_i(t_0)}\right)e^{-r(t_{ai}-t_0)} = p_{m,i}\,.$$

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

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 and Baseline Case

The model is programmed and solved using the GAMS programming language and the MINOS solver. 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 starting in 150 years. It is difficult to know what terminal conditions to choose, but the above are at least reasonable. Further, by choosing a moment sufficiently far in the future, the terminal conditions should have little impact on current decisions.

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) $P(t) = 140*\exp(bt) - 0.04*Q(t)$,

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 (with GNP), the demand curve will shift out. Under current global prices and consumption, the initial elasticity of demand in the baseline case is approximately 1.0. This is consistent with the empirical results of Sohngen (1996) and the price elasticity used by Sedjo and Lyon (1990).

References

FAO (Food and Agriculture Organization). 1995. *Fort Resource Assessment 1990.* FAO Forestry Paper 124. The Food and Agricultural Organization of the United States.

Hotelling, H. 1931. The Economics of Exhaustible Resources of the Industrial Countries: An ECE/FAO Assessment. *Unasylva* 44:20–30.

Kuchler, August W. 1975. *Potential Natural Vegetation of the United States.* 2nd ed. New York: American Geographical Society.

Pontryagin, Lev S., V.S. Boltyanskii, R.V. Gamkrelidze, and E.F. Mischenko. 1962. *The Mathematical Theory of Optimal Processes*. New York: John Wiley.

Sedjo, Roger A., and Kenneth S. Lyon. 1990. *The Long-Term Adequacy of the World Timber Supply*. Washington, D.C.: Resources for the Future.

Sohngen, Brent L. 1996. Integrating Ecology and Economics: The Economic Impacts of Climate Change on Timber Markets in the United States. Ph.D. dissertation, Yale School of Forestry and Environmental Studies, New Haven, CT.