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A DYNAMIC INTERACTION OF THE GLOBAL TIMBER MARKET, GLOBAL WARMING, AND CARBON FLUX OF FOREST

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Dug Man Lee and Kenneth S. Lyon

ABSTRACT

Forest management around the globe has been discussed and emphasized as one of the practical environmental protection policies. The Kyoto protocol proposed that promotion of sustainable forest management through afforestation and reforestation will increase the potential carbon sink of forest and thus ameliorate the accumulation of carbon dioxide into the atmosphere. In this sense, in order not only to improve the predictive power of forest management but also to measure the precise carbon flux of forest in the global scale, we want to identify the feedback effect of the global timber market on global warming. For this purpose, we already identified the effect of global warming on the global timber market as a primary step (Lee and Lyon, 2001). Based on the simulation results of primary research, we extended our modeling framework by incorporating the Terrestrial Carbon Model designed to investigate the net carbon release into the atmosphere. Simulating both the base TCM and the modified TCM which reflects climate change, we identified the global timber market has a dampening (negative feedback) effect on global warming. For sensitivity analyses, we performed these simulation procedures under three different timber demand growth scenarios.

JEL Classification: Q23

Key words: global warming, global timber market, terrestrial carbon model, carbon flux of forest.
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INTRODUCTION

Environmental protection agencies around the world are examining alternative techniques to mitigate global warming through the reduction of anthropogenic emission of green house gases, especially carbon dioxide, into the atmosphere. In addition, international conferences have been convened to discuss environmental issues related global warming. The Earth Summit in Rio, 1992 and the UN Conference in Kyoto, 1997, adopted several environmental protection policies that have yet to be adopted and enforced by governments around the world. Forest management was proposed as one of the practical environmental policies to curb anthropogenic emission of carbon dioxide into the atmosphere. The Kyoto protocol proposed the promotion of sustainable forest management practices through afforestation and reforestation to increase the size of the forest carbon sink. Following the Kyoto protocol, Schulze et al. (2000) also suggested that the conservation of old growth forests have a larger effect on carbon sink potential through net carbon sequestering rather than planting young trees at a global scale.

In the same vein, several recent papers in the biospheric literature [Bonan et al. (1992), King and Neilson (1992), and Kirschbaum et al. (1996)] estimated the feedback effect of forest on global warming when climate change occurs. Bonan et al. (1992) and Kirschbaum et al. (1996) focused only on boreal forest; King and Neilson (1992) extended their analysis to the world forests. All of these studies identified a net release of carbon from forests producing a positive feedback effect on global warming. They, however, failed to link ecological change caused by global warming to human adaptation in the global timber market.
In order to address the limitation of these studies, Sohngen and Mendelsohn (1997) developed an integrated modeling framework, which linked the timber market, climate change, and carbon flux of forest in the conterminous U.S.. They concluded that when climate change occurs, the carbon storage in conterminous U.S. forests will be increased much more in comparison with that through natural carbon change, resulting in a reduction of carbon dioxide in the atmosphere. As another example of an integrated modeling approach, Yan (1996) estimated the effects of the global timber market on carbon flux when forests are conserved for environmental protection. In his model, Yan found that the withdrawal of forests for environmental protection will cause a dampening of global warming. Sohngen and Mendelsohn (1997) succeeded in integrating human adaptation in the timber market with carbon model in a framework to measure the carbon flux of forest; however, their study included only the forests of the conterminous U.S.. Yan (1996) performed his research objective without considering the ecological change impacted by climate change.

This research estimates not only the carbon flux of commercial forests in the global scale but also the feedback effect of the global timber market on global warming. That is, to assess carbon exchange between forest and the atmosphere that is associated with human being's economic activities in the global timber market when climate change occurs. Another paper reports on the impact of global warming on the global timber market (Lee and Lyon, 2001). In this primary paper, we modeled and simulated the effect of global warming on the global timber market using dynamic integrated models of ecosystem and economic system that arise from the prediction of global warming. As a result, we identified a positive effect of global warming on the global timber market through an increase of timber production causing stumpage prices to be lower than would otherwise have been.
This paper uses those results to estimate the feedback effect of the commercial forests upon carbon sequestering. Based on the simulation results of the primary research, we estimated the net release of carbon into the atmosphere using the Terrestrial Carbon Model (TCM). We do this for both the base TCM and a modified TCM, which reflects climate change. The reference TCM used for the base TCM is the same as that constructed by Yan (1996). Model simulations of the base TCM and the modified TCM allowed us to identify the net release of carbon into the atmosphere for the base scenario and climate change scenario for each timber demand growth scenario.\(^1\) Under each timber demand growth scenario, the difference in net release of carbon between the base scenario and the climate change scenario of TCM provided information to assess the feedback effect of the global timber market on carbon flux.

The paper is consists of following four sections: First, we will briefly discuss the simulation procedures and results of the primary research. Second, we will describe the TCM developed by Yan (1996) to predict the net carbon release into the atmosphere. Third, we will formulate the TCM for the base scenario and the climate change scenario. Fourth, we will provide the simulation results of TCM for both the base scenario and the climate change scenario under three different timber demand growth scenarios.

THE EFFECT OF GLOBAL WARMING ON THE GLOBAL TIMBER MARKET

In this section, we briefly describe our research procedures and simulation results of the primary research that identified the effect of global warming on the global timber market. To achieve this research objective, the Timber Supply Model 2000 (Lee and Lyon, 2001), BIOME 3 (Haxeltine and Prentice, 1996), and Hamburg (Claussen, 1996) were used as suitable economic

\(^1\) For the sensitivity analysis, we estimated the effect of global warming on the global timber market under three different timber demand growth scenarios.
and ecological models. The TSM 2000 was utilized to model dynamic economic behavior in the global timber market. The BIOME 3 was adopted as a steady state ecological model and Hamburg as a general circulation model (GCM). In particular, we developed the TSM 2000 by extending the TSM developed by Sedjo and Lyon (1990, 1996) to consider additional components in the global timber market. These components included the former Soviet Union as a part of responsive regions, increased plantation forests in the emerging regions since 1980s, forest withdrawals for environmental protection, and the transformed ecosystem types after climate change. In doing this we extended the 22 land classes in 7 responsive regions in the TSM to 42 land classes in 10 regions. These 10 regions include; U.S. South, U.S. Pacific North west, Eastern Canada, Western Canada, Nordic Europe, European USSR, West Siberia, East Siberia, Asia Pacific, and the emerging region.

In particular, the TSM 2000 has the following characteristics in analyzing the global timber market; The TSM 2000 is a nonlinear dynamic optimization model designed to examine dynamic characteristics of timber supply such as aging of trees, timber harvesting and regenerating investments using discrete time, optimal control theory. To generate the optimal time path of economic variables, TSM 2000 defines the objective function as the sum of discounted present value of net surplus (consumers' surplus and producers' surplus), subject to initial inventory stock and two laws of motion of state variables. One law of motion is for

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2 BIOME 3 (Haxeltine and Prentice, 1996) reflects an attempt to provide explicit interaction between biogeographical distribution model and biogeochemical cycle model within a single global framework. The output of BIOME 3 consists of a quantitative vegetation state description in terms of the dominant plant functional types, the total leaf index, and the net primary productivity.

3 We adopted the TSM as a referencing dynamic economic model of timber market behavior in that the TSM has significant of comparative advantages in the analysis of diversified forest ecosystem management strategies, compared with other dynamic economic models of timber market. See Lyon and Sedjo (1992) for more details.

4 In the TSM, timber supplying regions are decomposed into two categories; one is the responsive region and the other is non-responsive region. The responsive regions are defined because they are assumed to respond to profit maximization incentives and therefore generally behave in a way that we have termed as economically efficient. On the other hand, the non-responsive regions are viewed as autonomous and are determined independently of the usual economic incentives.
hectares of trees by age and the other is for the regeneration input level. The TSM 2000 provides economically efficient solutions in the sense that it maximizes total benefit to the society as a whole, not the net income stream of individual landowner. Also, TSM 2000 traces out the system-wide time path of harvesting volume in aggregate and by each land class.

In order to estimate dynamic ecological change impacted by global warming, we used BIOME 3 as a steady state ecological model and Hamburg as our GCM to simulate a steady state ecological change before and after climate change. Because dynamic ecological model designed to cover the globe has not yet been developed, we imposed linearity assumptions about the adjustment of climate and ecosystems. These linearity assumptions follow the Intergovernmental Panel on Climate Change (Houghton et al., 1990) convention and the assumptions that Sohngen et al. (1997) imposed. The IPCC predicted that the average temperature would increase in a linear fashion from 1990 to 2060, the time in which carbon dioxide is posited to double. Also, Sohngen et al. (1997) used these assumptions, but assumed that after 2060, climate variables would stabilize. Under these linearity assumptions, we derived dynamic ecological change as measured by dynamic forest land area change and dynamic productivity change.

With these estimates of dynamic ecological changes, we modified the TSM 2000 to reflect these dynamic ecological changes. Modification of TSM 2000 includes both the law of motion of hectares of trees by age and the volume of commercial timber harvested per hectare. Then, we simulated both the non-climate change base scenario and the climate scenario of TSM 2000 over 90 years, starting in 1995 to simulate the effect of global warming on the global timber market. We performed these simulations for three different timber demand growth scenarios to generate some sensitivity results. Three different timber demand growth scenarios
include normal timber demand (ND) growth, high timber demand (HD) growth, and very high timber demand (VHD) growth. The simulation results suggest that global warming will have a positive impact on the global timber market through an increase of timber productions causing stumpage prices to be lower than would otherwise have been. In welfare sense, we also observed that global warming is economically beneficial to society through the global timber market.

DESCRIPTION OF THE TERRESTRIAL CARBON MODEL

The TCM was developed to examine net carbon release into the atmosphere after mature trees are harvested and when new trees are regenerated in the harvest. Harvesting mature trees releases stored carbon into the atmosphere from all parts of the tree (bole, debris, and root), and from the soil. On the other hand, if young trees are replanted in the harvest sites, they will sequester carbon from the atmosphere as they grow vigorously. Simultaneously, the soil builds up carbon storage to a certain level as young trees grow.

In the TCM, $CV(h)$ denotes the level of carbon storage in the tree, where $h$ is for the land class. The tree is divided into three parts including the merchantable bole, non-merchantable part (tops, branches, and barks, etc), and the roots. $CW(h)$ is the level of carbon stored in the bole; $CD(h)$ is the level of carbon stored in the debris left on the harvested site; and $CR(h)$ is the level of carbon stored in the roots. Hence, the level of carbon storage in vegetation is the sum of that of the bole, debris, and the roots:

$$CV(h) = CW(h) + CD(h) + CR(h)$$

\[5\] For normal timber demand growth, we assumed that an annual rate of world timber growth is 1.0% in the first year, and decreases in a linear fashion each successive year until growth rate is zero in the 90th year. And For high timber demand growth and very high timber demand growth, the annual rate of world timber growth is 1.8% and 3.6% in the first year, respectively and also declines linearly to zero in the 90th year.
It is assumed in the TCM that both the merchantable bole and debris follow the exponential functional form in the process of decomposition (or decaying) after the harvest. In addition, following Houghton et al. (1983), the TCM assumes that the decaying rate is primarily dependent upon the final product of harvested timber. Houghton et al. (1983) observed that it takes over 100 years for solidwood to decompose, while it takes about 10 years for paper. For decomposition of debris, it is also observed that almost 40% of the carbon stays in debris at the end of first year after harvesting. Another 20% decomposes from the second year to year 10. Finally, the remaining 20% decays from year 11 to year 100. Carbon in the roots is assigned to the decay pool of the soil and will decay in a few years following the harvest.

To observe the change of carbon storage in the soil, $CS_a(h)$ is defined as the level of carbon storage in the soil on which old growth trees have been standing, and $CS_b(h)$ for the next generation of trees. After harvesting matured trees some of the carbon is added to the soil as dead roots; hence the carbon in the soil increases immediately after the harvest to $CS_a(h) = CS_a(h) + CR(h)$ for the matured trees. However, as more of the soil is exposed to oxidation after harvesting, decomposition of the organic matter in the soil is enhanced. As a result, carbon storage in the soil decreases due to loss of the organic carbon in the soil, and approaches its minimum level as it continuously declines until the harvested site is regenerated with young trees. From the minimum level, the addition of carbon to the soil, in the form of litter, increases as replanted young trees grow. Carbon storage in the soil increases to the level of carbon storage, $CS_b(h)$. It is assumed that $T_a(h)$ is the time of harvesting, and $T_m(h)$ is the time for reaching the minimum carbon storage in the soil after harvesting the matured trees. $T_b(h)$ is the time of next harvest. The time period, $T_b(h) - T_a(h)$, is, hence, the rotation cycle, and determines the level of carbon storage in the soil.
If the harvested trees are regenerated with young trees, carbon in the young trees increases as the young trees grow vigorously. In this context, the TCM assumes that the increase of carbon storage in the three parts of young trees follows the yield function pattern of the standing volume of young trees. To estimate the carbon of trees, the dry weight of timber per hectare is calculated, and then converted into carbon in the trees per hectare. The dry weight of the merchantable bole is calculated by multiplying \( q(h, i, j) \) by \( cf1(h) \), where \( q(h, i, j) \) is the volume of merchantable bole of trees per hectare in year \( j \) \(^{6} \) and \( cf1(h) \) is the specific gravity of forest type. This dry weight is then multiplied by portion of carbon in the dry weight of the merchantable bole, \( cf2(h) \), to generate the carbon content of merchantable bole per hectare.

We further define \( XH(h, j) \) as hectares of timber harvested in land class \( h \) and year \( j \) and \( CSI(h) \) is the initial level of carbon storage in the soil of land class \( h \) at the timber harvesting time. \( CSI(h) \) will be \( CS_a(h) \) if mature trees are harvested, and \( CS_b(h) \) if the next generation of trees are cut; \( CW(h, j) \) is carbon in the harvested wood at the time of harvest. The decaying rate of harvested wood is \( rw(h) \), which is a weighted average of solidwood and pulpwood decaying rates. \( CD(h, j) \) is carbon in debris left on the harvested site, and \( rd(h) \) is the decaying rate of debris. \( CR(h, j) \) is the carbon in the roots which is transferred to the decaying pool of the soil. \( CY(h, j, j) \) is carbon storage of young trees per hectare in year \( j \), which is regenerated in year \( j \) \((j > j)\).

\(^{6}\) In the equation, \( q(h, i, j) \), which defines the volume of merchantable bole of trees per hectare in land class \( h \), \( i \) and \( j \) denote the age of trees and the year of harvesting, respectively. We used the yield function, \( q(h, i, j) \), which was formulated by Sedjo and Lyon (1990). For more details, see p. 208 in "The Long-Term Adequacy of World Timber Supply" published by Sedjo and Lyon (1990).
FORMULATION OF TERRESTRIAL CARBON MODEL

We want to formulate both the base TCM and the climate change TCM on the basis of characteristics that we discussed in the last section. The formula of the base TCM is the same as that presented in the Yan (1996)'s original work. For the formulation of climate change TCM, we modified the base TCM to include ecological change impacted by global warming.

Formulation of Net Carbon Release in the Base Scenario

For the base scenario, the net carbon release from trees in year $j$, which are harvested from land class $h$ in year $\hat{j}$, is estimated using the following formula;

$$NC(h, \hat{j}, j) = CW(h, \hat{j})(e^{-rw(h)(\hat{j}-j-1)} - e^{-rw(h)(\hat{j}-\hat{j})}) + CD(h, \hat{j})(e^{-rd(h)(\hat{j}-j-1)} - e^{-rd(h)(\hat{j}-\hat{j})}) + [XH(h, \hat{j})(CSI(h) - CS_m(h)) + CR(h, \hat{j})]/(T_m - \hat{j}) - XH(h, \hat{j})(CY(h, \hat{j}, j) - CY(h, \hat{j}, j-1))$$

when $\hat{j} < j \leq T_m(h)$

and

$$NC(h, \hat{j}, j) = CW(h, \hat{j})(e^{-rw(h)(\hat{j}-j-1)} - e^{-rw(h)(\hat{j}-j)}) + CD(h, \hat{j})(e^{-rd(h)(\hat{j}-j-1)} - e^{-rd(h)(\hat{j}-j)}) - XH(h, \hat{j})(CS_b(h) - CS_m(h)) /(T_b(h) - T_m(h)) - XH(h, \hat{j})(CY(h, \hat{j}, j) - CY(h, \hat{j}, j-1))$$

when $T_m(h) < \hat{j} \leq T_b(h)$

In year $j$ for land class $h$, the net carbon release due to timber harvests is the sum of the net carbon release from all harvesting activity occurring before year $j$. This holds as follows;
\[ SNC(h, j) = \sum_{j=0}^{\hat{j}} NC(h, \hat{j}, j) \]

According to previous statements, \( CW(h, \hat{j}) \), \( CD(h, \hat{j}) \), and \( CR(h, \hat{j}) \) come from

\[ CW(h, \hat{j}) = cf_1(h) \cdot cf_2(h) \cdot qlc(h, \hat{j}) \]
\[ CD(h, \hat{j}) = cf_3(h) \cdot CW(h, \hat{j}) - CW(h, \hat{j}) \]
\[ CR(h, \hat{j}) = cf_3(h) \cdot CW(h, \hat{j}) \cdot (cf_4(h) - 1) \]

where \( qlc(h, \hat{j}) \) is the total volume harvested for land class \( h \) and year \( j \); \( cf_3(h) \) is the ratio of carbon in the tree above the ground over that in the bole, and \( cf_4(h) \) is the ratio of carbon in the whole tree over that in the tree above the ground. \( CY(h, \hat{j}, j) \) is calculated as

\[ CY(h, \hat{j}, j) = cf_1(h) \cdot cf_2(h) \cdot cf_3(h) \cdot cf_4(h) \cdot q(h, i, j) \]

where \( q(h, i, j) \) is the merchantable volume of tree per hectare in year \( j \) of land class \( h \), which is regenerated in year \( \hat{j} \) (age \( i = j - \hat{j} \)).

*Formulation of Net Carbon Release in the Climate Change Scenario*

For the climate scenario, the net carbon release from trees in year \( j \), harvested from land class \( h \) in year \( \hat{j} \), is estimated using the following formula;

\[ NC(h, \hat{j}, j) = CWcl(h, \hat{j})(e^{-rw(h)(\hat{j}-j-1)} - e^{-rw(h)(\hat{j}-j)}) \]
\[ + CDcl(h, j)(e^{-rd(h)(\hat{j}-j-1)} - e^{-rd(h)(\hat{j}-j)}) \]
\[ + [(XHcl(h, \hat{j}) + XHslvg(h, \hat{j}))(CSI(h) - CS_m(h)) + CR(h, i)]/(T_m(h) - \hat{j}) \]
\[ - (XHcl(h, \hat{j}) + RR_h)(CYcl(h, \hat{j}, j) - CYcl(h, \hat{j}, j-1)) \]

when \( \hat{j} \leq j \leq T_m(h) \)

and
\[ NC(h, j, j) = CWcl(h, j)(e^{-rw(h)(j-\hat{j}-1)} - e^{-rw(h)(j-j)}) + CDcl(h, j)(e^{-rd(h)(j-\hat{j}-1)} - e^{-rd(h)(j-j)}) - (XHcl(h, j) + XHslvg(h, j))(CS_b(h) - CS_m(h))/(T_b(h) - T_m(h)) - (XHcl(h, j) + RR_h)(CYcl(h, j, j) - CYcl(h, j, j-1)) \] 

when \( T_m(h) < j \leq T_b(h) \)

where \( XHcl(h, j) \) is the hectares of trees harvested in land class \( h \) and year \( j \) after climate change; \( XHslvg(h, j) \) is the hectares of trees salvaged in the land class \( h \) and year \( j \)\(^7\); \( RR_h \) is the forest regenerated hectares per year for land class \( h \). \( CWcl(h, j), CDcl(h, j) \), and \( CRcl(h, j) \) come from

\[ CWcl(h, j) = cf1(h) \cdot cf2(h) \cdot qlc(h, j) \]
\[ CDcl(h, j) = cf3(h) \cdot CW(h, j) - CW(h, \hat{j}) \]
\[ CRcl(h, j) = cf3(h) \cdot CW(h, j) \cdot (cf4(h) - 1) \]

where \( qlc(h, j) \) is the total volume harvested for land class \( h \) and year \( j \) including trees salvaged after climate change\(^8\). \( CYcl(h, j, j) \) is calculated as

\[ CYcl(h, j, j) = cf1(h) \cdot cf2(h) \cdot cf3(h) \cdot cf4(h) \cdot \bar{q}(h, i, j) \]

where \( \bar{q}(h, i, j) \) is the modified merchantable volume of tree per hectare in year \( j \) of land class \( h \), regenerated in year \( j \) (age \( i = j - \hat{j} \))\(^9\). In year \( j \) for land class \( h \), the net carbon release due to

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\(^7\) In the primary research, we accounted for the possibility that some portion of dieback trees were salvaged from dieback areas. For the salvage of dieback trees, the salvage rate was assumed to be 60% of normal merchantable volume on average for both accessible and inaccessible land areas, and 70% of merchantability ratio for all salvage operations. The merchantability ratio is defined as the minimum age of salvage trees divided by the optimal harvest age.

\(^8\) We discussed the total volume harvested after climate change in Lee and Lyon (2001). For more details, see p. 27-28 in Lee and Lyon (2001)

\(^9\) Also, the modified merchantable volume of tree per hectare when climate change occurs, \( \bar{q}(h, i, j) \), is described in Lee and Lyon (2001). For more details, see p. 18-19 in Lee and Lyon (2001)
timber harvest activity is the sum of the net carbon release from all harvesting activity occurring before year $j$. This holds as follows;

$$SNC(h, j) = \sum_{j=0}^{\infty} NC(h, j, j)$$

**Decaying Rates**

The decaying rate of the bole of tree is divided into two different rates that depend on the final products manufactured from harvested timber. If the final product of timber harvested is paper, then the decaying rate is

$$rw^P(h) = \frac{-\ln(0.01)}{10}$$

If the final product usage is solidwood, then the decaying rate is

$$rw^S(h) = \frac{-\ln(0.01)}{100}$$

The decaying rate of the bole of tree is a weighted average of that of solidwood and pulpwood decaying rates. This is expressed as follows;

$$rw(h) = rw^S(h) \cdot \phi_h + rw^P \cdot (1 - \phi_h)^{10}$$

The decaying rates of debris left on the harvested site are calculated as follows;

$$rd_1 = \frac{-\ln(0.40)}{} \quad \text{when } t = 1$$

$$rd_2 = \frac{-\ln(0.20/0.40)}{9} \quad \text{when } 1 < t \leq 10$$

$$rd_3 = \frac{-\ln(0.01/0.20)}{90} \quad \text{when } 10 < t \leq 100$$

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10 In the TSM 2000, we divided the total timber production between solidwood and pulpwood using variable proportions that vary by land class, with $\phi_h$ referring to the portion going to solidwood and $(1 - \phi_h)$ the portion going to pulpwood.
SIMULATION RESULTS OF TERRESTRIAL CARBON MODEL

Net Carbon Release Under Normal Demand Scenario

On the basis of formulations of TCM, we simulated the projections of net carbon release for both the base scenario and the climate change scenario under three timber demand scenarios. Figure 1 shows net carbon release for both the base scenario and the climate change scenario under the normal demand scenario. In the base scenario, the net carbon release is positive during the first 48 years, with the peak in year 11 releasing $1.014.39 \times 10^{12}$ g amount of carbon into the atmosphere. After year 48, the net carbon release becomes negative with decreasing rate until year 2085. In 2085 the net carbon release will be $-641.7 \times 10^{12}$ g (negative value implies net carbon sequestering).

The structure of net carbon release over the entire simulation period suggests that in the early years most carbon released into the atmosphere comes from the harvested volume of wood, debris, roots and the soil. At the same time, the regenerated young trees in the harvested land sites sequester carbon from the atmosphere as regenerated young trees grow. Carbon release is larger than carbon sequestering in the early years because absolute volume of regenerated young trees are smaller. However, as the regenerated young trees grow vigorously, resulting in the increase of volume of regenerated young trees, they sequester more carbon from the atmosphere. Consequently, carbon sequestering dominates carbon release. From year 48, carbon sequestering of regenerated young trees is larger than carbon release from timber harvests.

In the climate change scenario, the net carbon release is positive during the first 37 years. After year 37, it becomes negative with a decreasing rate until 2085. Thus, in the climate
scenario, the year when net carbon release changes from positive to negative is achieved 11 years earlier than in the base scenario. Furthermore, the amount of net carbon release is $-1527.1 \times 10^{12}$ g in 2085. This shows that net carbon sequestering (negative value of net carbon release) in this scenario is about $885 \times 10^{12}$ g larger than in the base scenario in 2085.

(Figure 1 about here)

The accumulated differences in net carbon release between the base scenario and the climate scenario measures how the global timber market has a long-run feedback impact on global warming when climate change occurs. Table 1 shows the accumulated differences in net carbon release by every 1.5 decades between the base scenario and the climate change scenario under normal timber demand scenario. According to Table 1, the accumulated difference in net carbon sequestering between the base scenario and the climate change scenario increases over the simulation period. This structure suggests that the global timber market will have a negative long-run feedback impact on global warming through net carbon sequestering. This structure is also dependent on two important factors presented in the simulation results of BIOME 3. BIOME 3 predicted an increase in net primary productivity for all land classes as well as an increase in hectares of faster growing tree species.

(Table 1 about here)

These two factors predicted by BIOME 3 not only increase total industrial wood production, but also spur the regenerated young trees to grow faster. Consequently, the increase of total industrial wood production releases more carbon into the atmosphere; at the same time, the regenerated young trees sequester more carbon from the atmosphere. Although both carbon release and carbon sequestering increase simultaneously due to the climate change, Table 1 shows that increase of carbon sequestering exceeds that of carbon release as simulation time
passes. This trend implies that the global timber market has a dampening (negative) feedback impact on global warming through the increment of net carbon sequestering.

Net Carbon Release under Both High Timber Demand Scenario and Very High Timber Demand Scenario

Net carbon release under both high timber demand and very high timber demand scenarios shows a similar tendency to that under the normal demand scenario. For the high timber demand scenario, Figure 2 presents net carbon release for both the base scenario and the climate change scenario over the simulation period. In the base scenario, net carbon release is positive during first 66 years, with the peak in year 11 releasing $751.57 \times 10^{12}$ g amount of carbon into the atmosphere. After year 66, the net carbon release is negative with a decreasing rate until 2085. The net carbon release will be -$625.5 \times 10^{12}$ g in 2085. In the climate change scenario, positive net carbon release is during first 54 years, with the peak in year 11 releasing $978.63 \times 10^{12}$ g amount of carbon into the atmosphere. By 2085, net carbon release is -$1145.1 \times 10^{12}$ g. Thus, in the climate change scenario the year when net carbon release changes from positive to negative is achieved about 12 years earlier than in the base scenario. In 2085, net carbon sequestering is about $520 \times 10^{12}$ g larger than in the base scenario.

(Figures 2 and 3 about here)

Also Figure 2 shows that the net carbon release in the climate scenario is lower than in the base scenario from 27 years. For the very high timber demand scenario, Figure 3 shows net carbon release for both the base scenario and the climate change scenarios. In the base scenario, net carbon release is positive during the first 45 years, with peak in year 12 releasing $1147.43 \times 10^{12}$ g amount of carbon into the atmosphere. In year 2085, net carbon release is -$1350.7 \times 10^{12}$ g. In the climate change scenario, net carbon release is positive during the first 45 years,
with the peak in year 16 releasing $986.39 \times 10^{12}$ g amount of carbon. Also, in year 2085 the net carbon release is $-2556.2 \times 10^{12}$ g. Tables 2 and 3 show the accumulated difference in net carbon release between the base scenario and the climate scenario for both high timber demand and very high timber demand scenario.

According to Tables 2 and 3, the accumulated difference in net carbon sequestering between the base scenario and the climate change scenario increases as simulation time passes. As a result, these structures also suggest that the global timber market has a dampening (negative) feedback impact on global warming through the increment of net carbon sequestering.

(Tables 2 and 3 about here)

To estimate dynamic ecological change in the primary research (Lee and Lyon, 2000), we used the simulation results of BIOME 3. In the process of simulation of BIOME 3 the Hamburg was used as a GCM to identify the change of climate variables between current carbon dioxide concentration and a doubling of carbon dioxide concentration in the atmosphere. According to Sohngen et al. (1998), the Hamburg used 340 ppmv for current carbon dioxide concentration and 500 ppmv for a doubling of carbon dioxide concentration in the atmosphere. In Table 1, we found that the accumulated difference in net carbon release between the base scenario and the climate change scenario is $-40,279 \times 10^{12}$ g in 2085 for the normal timber demand scenario. In this context, we identified that climate change reduces about 3.8 % of the amount of carbon dioxide concentration in the atmosphere in 2085. For both high timber demand and very high timber demand scenarios, the accumulated difference in net carbon release shows that the climate change reduces 1.3% and 3.0% of the amount of carbon concentration in the atmosphere over 90 years, respectively.

\[11 \text{ The relationship between ppmv and g is } 1 \text{ ppmv} = 2.123 \times 10^{12} \text{g.}\]
CONCLUSION

In order to estimate the feedback effect of the global timber market on global warming, we extended the integrated modeling framework used in the primary research to incorporate the TCM, and simulated both the base TCM and the climate change TCM, which reflects the climate change. As a result, we identified that the global timber market has a dampening (negative feedback) effect on global warming. We estimated that climate change reduces about 3.8% of the amount of carbon dioxide concentration in the atmosphere over 90 years for normal timber demand growth. For high timber demand growth and very high timber demand growth, climate change also reduced 1.3% and 3.0% of carbon dioxide concentration in the atmosphere over 90 years, respectively through the global timber market. We, hence, acknowledge that these results will contribute to measure the carbon sink potential of forest in more accuracy in combination with the natural carbon storage of forest estimated by the global carbon cycle model. In this sense, our research provides significant insights in establishing practical forest management policies around the world to protect world environment by ameliorating accumulation of anthropogenic carbon dioxide in the atmosphere.

REFERENCES


Sohngen, B.L., Mendelsohn, R and R. Sedjo, 1998, “The Effect of Climate Change on Global Timber Markets.” Mimeo, Department of Agricultural Economics, Ohio State University.
Fig 1 Net Carbon Release
[Normal Demand Scenario]
Fig 3  Net Carbon Release
[Very High Demand Scenario]

Carbon (E12g) vs Time

Base Scenario
Climate Change Scenario
<table>
<thead>
<tr>
<th>Scenario</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base *(A)</td>
<td>10,893</td>
<td>21,268</td>
<td>26,553</td>
<td>26,825</td>
<td>22,433</td>
<td>14,313</td>
</tr>
<tr>
<td>Climate Change *(B)</td>
<td>10,797</td>
<td>18,601</td>
<td>17,766</td>
<td>10,016</td>
<td>-6,203</td>
<td>-25,966</td>
</tr>
<tr>
<td>The Difference in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Carbon Release*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(B-A)</td>
<td>-96</td>
<td>-2,667</td>
<td>-8,787</td>
<td>-16,809</td>
<td>-28,636</td>
<td>-40,279</td>
</tr>
</tbody>
</table>

*denotes accumulated amount of net carbon release.
<table>
<thead>
<tr>
<th>Scenario</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base *(A)</td>
<td>8,076</td>
<td>18,028</td>
<td>25,805</td>
<td>29,571</td>
<td>28,713</td>
<td>21,830</td>
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<td>Climate Change *(B)</td>
<td>10,412</td>
<td>21,359</td>
<td>27,057</td>
<td>27,300</td>
<td>21,598</td>
<td>7,760</td>
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<tr>
<td>The Difference in Net Carbon Release* (B-A)</td>
<td>2,336</td>
<td>3,331</td>
<td>1,252</td>
<td>-2,271</td>
<td>-7,115</td>
<td>-14,070</td>
</tr>
</tbody>
</table>

*denotes accumulated amount of net carbon release.
Table 3
The Accumulated Difference in Net Carbon Release ($10^{12}$g) between the Base Scenario and Climate Change Scenario under Very High Timber Demand Scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Time (yr)</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base *(A)</td>
<td></td>
<td>12,297</td>
<td>26,353</td>
<td>31,081</td>
<td>26,062</td>
<td>14,630</td>
<td>-3,216</td>
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<tr>
<td>Climate Change *(B)</td>
<td></td>
<td>9,386</td>
<td>22,744</td>
<td>27,759</td>
<td>19,289</td>
<td>-1,566</td>
<td>-35,091</td>
</tr>
<tr>
<td>The Difference in Net Carbon Release* (B-A)</td>
<td></td>
<td>-2,911</td>
<td>-3,609</td>
<td>-8,787</td>
<td>-6,773</td>
<td>-16,196</td>
<td>-31875</td>
</tr>
</tbody>
</table>

*denotes accumulated amount of net carbon release.