Forest Ecology and Management 162 (2002) 105–115

Forest Ecology and Management

www.elsevier.com/locate/foreco

Temporal uncertainties of integrated ecological/economic assessments at the global and regional scales

John Perez-Garcia[a,*], Linda A. Joyce[b], A. David McGuire[c]

[a]Center for International Trade in Forest Products, University of Washington, Seattle, WA, USA
[b]Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO, USA
[c]Department of Biology and Wildlife, University of Alaska, Fairbanks, AK, USA

Abstract

Over the past several years, research using the Center for International Trade in Forest Products (CINTRAFOR) Global Trade Model (CGTM) and the Terrestrial Ecosystem Model (TEM) has estimated the potential effects of climate change on the global forest sector. The process of linking these two models—many model runs with alternative economic, ecological and climate scenarios—provides useful information on (i) the behavior of the economic model under alternative assumptions, (ii) integrated economic/ecological results and (iii) their implication for decision makers. Previous works indicate that assumptions on economic behavior and ecology interactions are important when estimating the economic effects of climate change on the forest sector. This paper estimates the economic effects associated with alternative transient paths of change in climate and CO_2 on the forest sector. The results indicate economic welfare measures change significantly under two alternative assumptions of the path that changes in climate and CO_2 may take. An assumption of a pseudo-transient constant rate of change to reach an equilibrium endpoint produces larger global welfare changes over the time period than a ''true'' transient change in climate by an average US$ 2 billion over the period 1994–2040. In addition, regional and market segment impacts are not uniformly distributed and should also be considered when programmatic needs are identified.

Keywords: Climate change; Economic model; Economic welfare; Ecosystem model; Transient change

1. Introduction

Average surface temperatures are projected to increase by 1.4–4.4 °C during the 21st century (IPCC, 1995). The likely changes in climate have the potential to impact social, political and economic systems through direct climatic effects on ecological and economic systems and through programs designed to curb greenhouse gas emissions and reduce unwanted climatic effects. The process of evaluating the long-term effects of climate change on the ecological and economic systems of nations necessarily involves uncertainties. This paper examines one aspect of uncertainty: the effect that two alternative paths of change have on economic welfare of the global forest sector.

The time path or transient effects of climate change on ecosystem productivity produce uncertainty in the economic effects of climate change. Over a period of time when climate is changing, the forest sector may see greater available inventory in response to higher ecological productivity associated with climate change (Binkley, 1988; Perez-Garcia et al., 1997; Sohngen et al., 1998; Sohngen and Mendelsohn, 1998; Perez-Garcia et al., in review). During the period, the forest sector's response to the increase

* Corresponding author.

0378-1127/02/$ – see front matter
PII: S0378-1127(02)00053-1

in inventory will depend on the amount of vegetative carbon that accumulates in timber stands and the rate and pattern of this accumulation over time. As a result, economic welfare measures used to evaluate benefits and losses to society will also depend on this rate and pattern of accumulation over time. Understanding the effects of these assumptions on economic welfare measures becomes important because economic welfare measures are used to assess programmatic needs to reduce risks to social, economic and political systems.

A number of modeling studies have applied equilibrium ecological responses from the doubled carbon dioxide (CO_2) equilibrium climate scenarios to transient forest sector models (Callaway et al., 1994; Joyce et al., 1995; Perez-Garcia et al., 1997; Sohngen et al., 1998; Sohngen and Mendelsohn, 1998; McCarl et al., 2000; Perez-Garcia et al., in review). These studies have shown that changes in atmospheric CO_2 and climate influence the economic welfare of the forest sector through effects on prices, production, consumption and international trade in timber products. In these studies the climate was assumed to be in equilibrium with the doubled atmospheric concentration of CO_2 and the ecological response was assumed to be in equilibrium with the altered climate. In all studies except Perez-Garcia et al. (in review), the equilibrium ecological response was converted to a transient response by assuming a constant rate of increase over the time period needed to reach the doubled atmospheric concentration of carbon dioxide.

The transient effects of climate change on economic welfare measures have not been analyzed using the recent advances in the transient simulation of climate and carbon dynamics (Mitchell et al., 1995; Xiao et al., 1998; Prinn et al., 1999). Sohngen and Mendelsohn (1998) explore the effects of large-scale ecological changes in a timber market in a transient analysis and a steady-state analysis. They constructed their transient ecological changes from equilibrium ecological analyses and their steady-state analysis focuses on the equilibrium condition. They concluded that the steady-state response dramatically overstates the welfare effect because the steady-state analysis does not capture the gradual changes in ecosystems over time or the dynamic changes in the adjustment and adaptations within the market. However, this analysis assumes a constant rate of change over the time period in the ecological systems.

The study builds on the Sohngen and Mendelsohn (1998) results by incorporating the recent advances in the atmospheric and ecological that provide the opportunity to simultaneously assess how both climate and terrestrial carbon dynamics may respond to different scenarios of emissions controls (Xiao et al., 1998). We expand economic welfare measures to include both timber and product markets with regional market details. In the present paper, we analyze these transient changes in the ecological systems to measure the effect of the time path of climate change on economic welfare in the global forest sector and their regional implication.

2. Methods

2.1. Approach

Our approach integrates global ecological and economic models to simulate 12 alternative futures of the response of the forest sector behavior to projected climatic change. We construct two alternative time paths for each of three climate scenarios and each of two economic scenarios. A "true" ecological transient path utilizes the transient changes in climate and CO_2 to drive the carbon dynamics in forest and their subsequent effects on the economic behavior of the forest sector.[1] A pseudo-transient path is constructed by assuming a constant rate of ecological change, sufficient to reach the climate and CO_2 endpoint of the transient analysis. This constant rate of change is a common assumption that has been used to convert equilibrium scenarios to a transient scenario for analysis in forest models. We control for ecological variation in the transient analysis by projecting the physiological responses of forest inventory to three different climate scenarios using the Terrestrial Ecosystem Model (TEM: see Xiao et al., 1998). The potential response of forest inventory simulated by TEM are then used as inputs to the CINTRAFOR

[1] Our use of the term "true" is by no means an assertion that we know the true path of climate change. We use it to distinguish it from the pseudo transient path that assumes a constant rate of change between two points when we lack information on what happens in between. From our perspective, the pseudo transient path of change is less likely to reflect the true path since it assumes a constant rate of ecological change.

Global Trade Model (CGTM; see Cardellichio et al., 1989) for forest products to simulate changes in timber supply and the subsequent economic behavior of the forest sector. We control for economic behavioral variation by specifying two economic supply scenarios with the CGTM.

Our initial step is to create an economic baseline and then impose one of two economic supply scenarios with one of three transient climate scenarios. To each of these six scenarios we measure economic welfare using a "true" ecological transient path and a pseudo-transient path. We report changes as economic welfare measured from an economic baseline. The three transient climate scenarios provide a range of responses integrating CO_2 emissions, atmosphere–ocean thermal interactions and aerosol effects as described below. The economic scenarios place boundaries on behavioral assumptions of non-market mechanisms employed in the forest sectors of centrally planned or otherwise non-market economies.

Global economic welfare in the forest sector is measured as the sum of regional and product consumer and producer welfare using the CGTM (Cardellichio et al., 1989). The maximum welfare measure is the global competitive equilibrium point.

$$\max\left[\sum_{\mathrm{rk}}\int_0^{q_{\mathrm{rk}}}\pi_{\mathrm{rk}}(q)\,\mathrm{d}q-\sum_{\mathrm{rm}}\int_0^{y_{\mathrm{rm}}}C_{\mathrm{rm}}(z)\mathrm{d}z-\sum_{\mathrm{rsk}}D_{\mathrm{rsk}}e_{\mathrm{rsk}}\right]$$

subject to

$$q_{\mathrm{r}}-A_{\mathrm{r}}y_{\mathrm{r}}+\sum_{\mathrm{s}}(e_{\mathrm{rs}}-e_{\mathrm{sr}})=0$$

(materials balance constraint)

$q_{\mathrm{r}} \in C_{\mathrm{r}}$ (consumption possibilities)

$z_{\mathrm{r}} \in Z_{\mathrm{r}}$ (production possibilities)

$(e_{\mathrm{rS}}, e_{\mathrm{Sr}}) \in T_{\mathrm{r}}$ (trade possibilities)

where the demand from wood products consuming sectors is given by the demand function $\pi_{\mathrm{rk}}(q)$ for region r and product k; the supply from wood product producing sectors is given by the supply function $C_{\mathrm{rm}}(z)$ for region r and products m. A timber supply function is explicitly derived and incorporated in the product supply function through changes in wood costs and harvested quantities. The welfare measure is the sum of the area under each region/product demand curve minus the sum of the area under each region/product supply curve minus transportation costs $D_{\mathrm{rsk}}e_{\mathrm{rsk}}$, summed over all regions, products and trade flows. Products considered in the model are softwood and hardwood lumber and plywood. Softwood and hardwood logs are used to produce these products.

Three transient climate change scenarios are used to describe possible future climates for the period of 1977–2100 and are from a global integrated analysis described by Prinn et al. (1999). Emissions in the RRR scenario are similar to the IS92a scenarios of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 1995). The HHL scenario is based on higher CO_2 emissions, slower diffusion of heat into the ocean, smaller effects of cooling associated with atmospheric aerosols, and smaller heating effects associated with the radiative forcing of doubling CO_2 than the RRR scenario. The LLH scenario is based on lower CO_2 emissions, faster diffusion of heat into the ocean, larger effects of cooling associated with atmospheric aerosol, and largest heating effects associated with the radiative forcing of increasing CO_2. In comparison with the RRR scenario, the LLH scenario leads to a smaller change in temperature and the HHL scenario leads to a larger change in temperature. Atmospheric CO_2 concentration is 354 ppmv in 1990 and is projected to reach about 745 ppmv in the RRR, 936 ppmv in the HHL, and 592 ppmv in the LLH scenario in 2100. Compared to its value in 1990, global annual mean temperature in 2100 increases by about 2.6 °C for the RRR, 3.1 °C for the HHL, and 1.6 °C for the LLH prediction. Global daily precipitation increases slightly over time for all three predictions. Global mean annual cloudiness decreases in the RRR and the LLH predictions but increases in the HHL prediction.

Xiao et al. (1998) used these three scenarios as input to the TEM model to examine the impact of climate change on the productivity of ecosystems globally. Because the application of TEM in this study simulates the dynamics of potential mature natural vegetation, the effects of land use and land cover changes are not considered in outputs generated by TEM for this analysis. To use the changes in vegetation carbon simulated by TEM for the three scenarios, we cross-walked the TEM results to the timber types considered by the CGTM. The forest ecosystem types in TEM were converted to the three timber types of the CGTM (softwood, hardwood, and mixed vegetation) in a manner similar to Perez-Garcia et al. (1997). For several regions plantations that have been introduced and comprise the majority of industrial wood supply do not confirm to natural timber types. In these situations, we used the simulated changes in the appropriate ecosystem types available for the region as the most plausible response for the region. For example, in the southeastern US we used the mixed vegetation type to estimate changes for softwood plantations.

2.2. "True" and pseudo-transient time paths

Fig. 1 illustrates the potential proportional change in timber inventory for the "true" transient and the pseudo-transient time paths for the RRR climate. Regional changes have been averaged for the globe to illustrate the difference in the two time paths. For the "true" transient climate change scenario we calculate the potential proportional annual change in timber inventory (dI_{Pt}) associated with changes in CO_2 and climate for each grid cell as:

$$dI_{Pt} = \frac{(C_{Vt} - C_{Vt-1})}{C_{Vt-1}}$$

where t is the year and C_V is vegetation carbon calculated at the end of December of the year. We average dI_{Pt} across all grid cells of a timber type within a timber region to determine the mean potential proportional change in timber inventory for the region. This index was used to adjust the regional timber supply functions in CGTM from 1985 to 2040, which is the timeframe considered in this analysis.

A similar approach is employed to construct the alternative pseudo-transient constant rate of change in climate scenario. The 55-year change in timber inventory is computed as:

$$dI_{P55} = \frac{(C_{V2040} - C_{V1985})}{C_{V1985}}$$

where t has been substituted for the start and ending points of 1985 and 2040. The annual rate of change from 1985 to 2040 is assumed constant and the periodic change in timber inventory follows an exponential

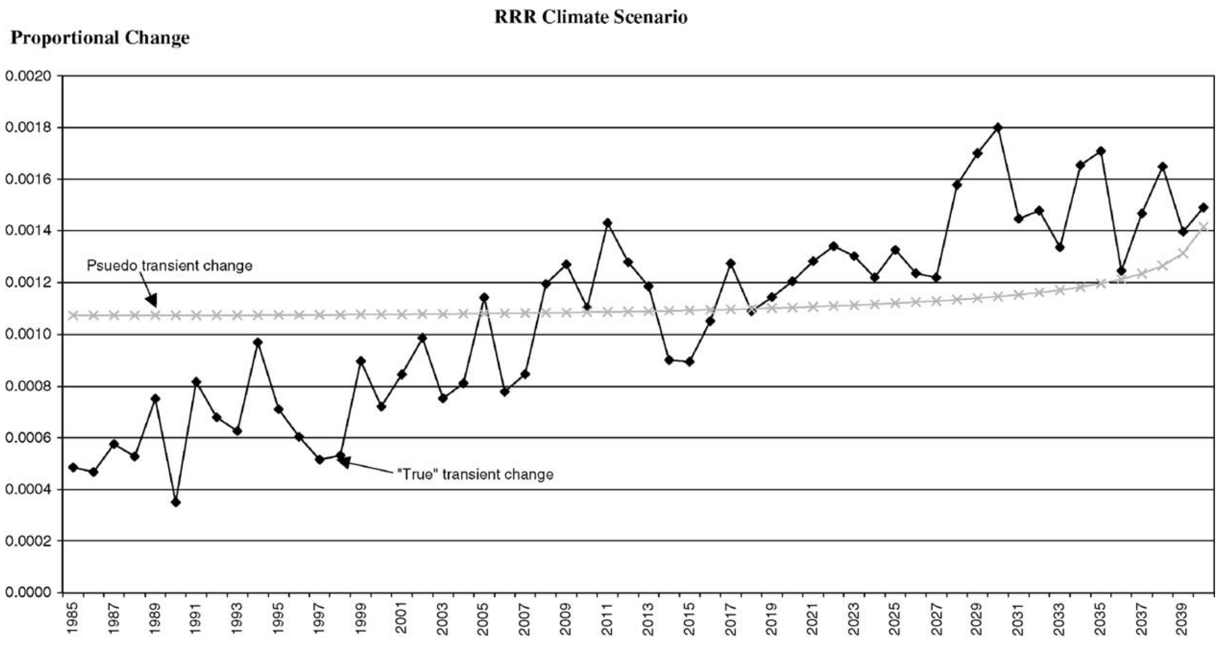

Fig. 1. The global average potential proportional change in timber inventory for two time paths for the RRR climate scenario.

curve. This index is used to adjust the regional timber supply functions in CGTM from 1985 to 2040 for the pseudo-transient change scenario.

Regional timber supply functions in the CGTM are adjusted annually using the indices above. The log supply function in CGTM is of the form:

$$\pi = \alpha \left(\frac{Q}{I}\right)^{\beta}$$

where π is the log price (real value per m^3 of wood), Q the log quantity (million m^3 of wood), I the growing stock volume (million m^3 of wood), and α, β are the estimated parameters.

The change indices above are entered annually into CGTM affected I, the growing stock volume for each region. The changes in inventory in turn affect log prices and harvest quantities, which in turn affect product markets and trade flows.

2.3. Economic scenarios

In this study, we explore the economic variability by using behavioral assumptions similar to previous work (Perez-Garcia et al., 1997). Two sets of assumptions are made with respect to harvest behavior. The first assumption relates to timber harvesting behavior in regions at the extensive economic margin. Forests in these regions are characterized by non price-responsive harvest behavior. Under this intensive margin economic scenario, we constrain harvests to the economic baseline in all regions where harvesting behavior is not responsive to prices. Regions where harvests are constrained under the intensive economic scenario include the former Soviet Union and Eastern Europe, where large extensive areas of forests exist but political and infrastructure constraints prevent them from expanding harvests even in the presence of higher prices. The second economic scenario relaxes these constraints on extensive margin regions. This extensive economic scenario assumes that changes in forest productivity lead to changes in harvests in regions that are not sensitive to price. It includes all supply responses from the intensive economic margin scenario as well as shifts in timber supply associated with changes in forest growth in all other regions.

The analysis first focuses on the global response and then analyzes regional responses of economic welfare. Total welfare is defined as the sum of economic welfare to timber producers, log processors and product consumers. Total welfare is reported in 1980 US dollar for the cumulative annual welfare measured from 1994 to 2040 in present value terms. Discount rates of 5 and 8% are used to compare the effects of alternative discount rates on total welfare.

3. Results

The global welfare effects are presented in Fig. 2 for the 12 scenarios. The figure illustrates the discounted global welfare using a 5% discount rate over the period from 1994 to 2040. The bars represent the change in global welfare associated with each scenario as measured from the baseline reference. Total discounted values are consistently lower by 42–46% of the values presented in Fig. 1 when an 8% discount rate is used. The effect of climate change under all scenarios is to increase global forest sector welfare. The average effect of using the pseudo-transient assumption is to further increase the global welfare measure by US$ 2 billion. Percentage-wise, the increase associated with the pseudo-transient change assumption is largest for the LLH climate scenarios, where under the extensive economic scenario it more than doubles the welfare impact of climate change. The increase is smallest for the HHL climate scenarios, where the global welfare impact ranges from nearly US$ 12 to 18 billion.

Change in welfare measures are presented by selected countries for each of the six climate and economic scenarios in Tables 1 and 2. Table 1 presents the change in welfare induced by the potential annual change in timber inventory associated with the "true" transient change assumption in climate and CO_2. Table 2 presents the change in welfare induced by the potential annual change in timber inventory associated with the pseudo-transient change in climate and CO_2.

Total welfare measures are divided into three groups representing each producing and consuming sector in a region. Log producer welfare (PS log) represents economic producer surplus for log producers. Log processor welfare (PS processor) represents the producer surplus for lumber and plywood mill operators. Product consumer welfare (CS product) for lumber and plywood products is measured by

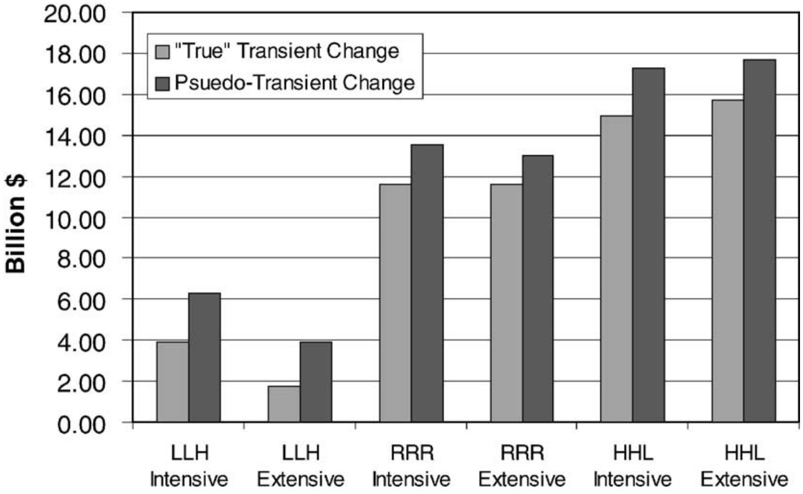

Fig. 2. Global economic welfare changes from baseline reference for 12 scenarios. (See text for explanation of scenarios).

consumer surplus. Total welfare is the sum of the producer surplus measures in the log and product sectors plus consumer surplus in the product sectors.

The change in welfare is measured from the reference baseline in 1980 million dollars using a 5% discount rate. Again, the use of an 8% discount rate lowers the present value but does not significantly change the patterns of welfare redistribution illustrated in Tables 1 and 2.

In Table 1, economic welfare for Canadian log producers is US$ 141 million less under the LLH climate and intensive economic scenario than under the baseline reference by the end of the study time period. Mill owners lose US$ 17.4 billion under the HHL climate and intensive margin scenario than under the baseline reference. In all scenarios climatic change negatively affects the welfare of Canadian log and mill owners. Consumer welfare rises, but not to an extent that can offset the losses to producers. As a consequence, total welfare in Canada is lowered from US$ 1.5 to 14.3 billion depending on the climate and economic scenario.

The transient annual fluctuations in vegetative carbon productivity and its corresponding effect of available timber lead to significant distributional changes in regional welfare, even though globally, gains by consumers offset losses incurred by timber producers and mill owners. Within each region, the various players—log producers, log processors and product consumers—are affected differently. Log owners generally lose welfare. Table 1 illustrates two exceptions: Chile and New Zealand. In their cases, higher inventory associated with climate change leads to expanded harvests, which lowers prices. The welfare gained from an increase in harvest however, offsets the effect of lower prices. Other timber suppliers in the region cannot expand harvests sufficiently to offset the lower price effect. As a result, the forest plantations of Chile and New Zealand expand their international markets.

In general, processors gain welfare through lower log costs. There are several notable exceptions under the ‘‘true’’ transient change scenario. Processors in Canada, the US north and south regions realize lower welfare under climate change. In Western Europe, processors experience losses under the RRR and HHL extensive margin scenarios. These processor losses are associated with lower product prices and the inability to expand their own market share to offset lower revenues.

In Canada, log producers respond to lower log prices by reducing harvests. This affects the ability of log processors to offset welfare losses from lower product prices since they cannot expand production. In the US North, its consuming sector is much larger than the producing sector. As a result, lower product prices realized by producers more than offset any gains through lower wood costs. The US south region has large producer and consumer sectors. Lower product

Table 1
Changes in economic welfare from baseline reference: "true" transient climate change

	Climate and economic scenario					
	LLH		RRR		HHL	
	Intensive	Extensive	Intensive	Extensive	Intensive	Extensive
Canada						
PS log	(141.31)	(150.05)	(408.32)	(403.20)	(501.90)	(469.64)
PS product	(2079.94)	(1826.15)	(13,015.07)	(12,153.60)	(17,417.06)	(15,905.72)
CS product	420.71	472.49	2674.10	3064.06	3607.84	4079.74
Total	(1800.54)	(1503.71)	(10,749.30)	(9492.74)	(14,311.12)	(12,295.61)
Chile						
PS log	4651.67	2607.28	3878.78	1704.07	3461.73	1310.97
PS product	301.07	184.99	394.22	193.35	357.94	198.51
CS product	52.48	285.68	350.86	633.65	473.40	740.39
Total	5005.23	3077.94	4623.86	2531.08	4293.07	2249.87
West Europe						
PS log	(514.66)	(550.80)	(643.81)	(1135.18)	(713.30)	(1464.20)
PS product	54.94	144.22	119.89	(308.87)	151.06	(526.80)
CS product	1097.11	1927.21	1701.45	5141.96	1996.60	6796.51
Total	637.39	1520.64	1177.52	3697.91	1434.36	4805.51
Finland						
PS log	(244.59)	(70.28)	(353.33)	(222.99)	(407.77)	(297.16)
PS product	99.29	69.64	113.91	(14.37)	120.89	(78.05)
CS product	52.97	163.92	75.76	289.36	87.21	358.37
Total	(92.34)	163.28	(163.65)	52.00	(199.67)	(16.84)
Japan						
PS log	(267.87)	(237.55)	(1426.67)	(1354.87)	(2004.41)	(1815.15)
PS product	93.07	47.52	324.83	366.57	409.87	545.08
CS product	415.24	188.76	2524.34	2303.96	3591.51	3102.81
Total	240.43	(1.26)	1422.50	1315.66	1996.97	1832.75
New Zealand						
PS log	2334.25	1197.51	1850.93	724.93	1511.43	419.14
PS product	174.24	151.02	333.70	175.41	317.35	167.13
CS product	30.96	6.05	293.56	251.97	394.18	334.01
Total	2539.46	1354.58	2478.19	1152.30	2222.96	920.27
Sweden						
PS log	(146.12)	(186.46)	(240.03)	(488.95)	(288.72)	(654.34)
PS product	201.79	264.58	294.23	247.63	342.08	224.43
CS product	72.39	160.00	103.07	307.71	118.78	386.69
Total	128.06	238.11	157.27	66.39	172.14	(43.21)
US North						
PS log	(171.87)	(278.92)	(757.65)	(725.63)	(979.64)	(864.49)
PS product	(126.42)	(161.83)	(83.99)	(166.55)	(52.91)	(156.24)
CS product	843.87	769.84	6474.41	6084.48	8826.22	8108.75
Total	545.58	329.09	5632.76	5192.30	7793.67	7088.01
US South						
PS log	(4264.76)	(4204.01)	(5148.63)	(4744.64)	(5443.83)	(4681.10)

Table 1 (*Continued*)

	Climate and economic scenario					
	LLH		RRR		HHL	
	Intensive	Extensive	Intensive	Extensive	Intensive	Extensive
PS product	(977.12)	(1593.15)	(68.98)	(953.29)	347.10	(620.82)
CS product	929.18	1546.86	6937.38	7500.80	9449.16	9762.38
Total	(4312.70)	(4250.30)	1719.77	1802.87	4352.43	4460.46
US West						
PS log	(141.65)	(392.31)	(1069.55)	(990.57)	(1451.44)	(1597.59)
PS product	902.79	756.45	6354.85	5927.72	8623.98	7898.11
CS product	211.26	470.02	6.84	302.72	26.87	456.77
Total	972.41	834.16	5292.14	5239.87	7199.41	6757.29

Table 2
Changes in economic welfare from baseline reference: pseudo-transient climate change

	Climate and economic scenario					
	LLH		RRR		HHL	
	Intensive	Extensive	Intensive	Extensive	Intensive	Extensive
Canada						
PS log	(260.87)	(242.20)	(494.76)	(456.61)	(603.80)	(560.42)
PS product	(6166.32)	(5153.74)	(15,887.22)	(14,276.61)	(20,486.86)	(18,685.88)
CS product	1301.28	1155.45	3330.60	3495.31	4326.12	4689.98
Total	(5125.91)	(4240.49)	(13,051.38)	(11,237.92)	(16,764.53)	(14,556.32)
Chile						
PS log	4282.57	2261.26	3899.09	1663.14	3619.22	1290.47
PS product	307.46	204.24	421.80	243.61	429.48	251.22
CS product	165.26	356.40	434.22	693.62	563.97	848.11
Total	4755.28	2821.91	4755.11	2600.37	4612.67	2389.79
West Europe						
PS log	(309.42)	(338.52)	(472.38)	(987.26)	(622.10)	(1377.27)
PS product	13.45	(9.95)	82.34	(415.33)	121.85	(629.51)
CS product	590.15	1120.53	1255.91	4368.75	1709.28	6193.82
Total	294.17	772.06	865.87	2966.16	1209.02	4187.03
Finland						
PS log	(103.49)	87.13	(252.06)	(62.51)	(336.29)	(158.04)
PS product	93.16	31.79	111.86	(58.62)	139.38	(98.55)
CS product	27.64	118.84	53.76	277.07	72.44	356.63
Total	17.31	237.77	(86.44)	155.93	(124.47)	100.05
Japan						
PS log	(906.12)	(778.33)	(1881.40)	(1727.97)	(2409.07)	(2176.71)
PS product	140.77	66.95	195.30	311.11	201.55	335.19
CS product	1250.40	945.51	3263.48	2876.86	4426.04	3921.57
Total	485.06	234.13	1577.38	1460.00	2218.52	2080.05

Table 2 (*Continued*)

	Climate and economic scenario					
	LLH		RRR		HHL	
	Intensive	Extensive	Intensive	Extensive	Intensive	Extensive
New Zealand						
PS log	2025.10	996.19	1604.60	565.27	1482.30	340.98
PS product	209.56	147.52	347.72	172.21	358.15	189.16
CS product	119.49	75.28	359.45	299.72	466.06	398.33
Total	2354.15	1219.00	2311.77	1037.20	2306.51	928.46
Sweden						
PS log	(96.57)	(103.71)	(166.88)	(400.18)	(223.90)	(569.87)
PS product	89.06	99.92	189.85	107.05	261.01	125.94
CS product	35.77	84.55	70.85	254.94	95.89	359.44
Total	28.26	80.77	93.82	(38.20)	133.00	(84.49)
US North						
PS log	(451.44)	(509.01)	(936.84)	(870.46)	(1170.01)	(1047.00)
PS product	(167.59)	(207.27)	(94.38)	(182.19)	(56.90)	(167.34)
CS product	2908.92	2479.77	7980.55	7239.03	10445.14	9587.09
Total	2289.89	1763.50	6949.33	6186.37	9218.23	8372.75
US South						
PS log	(3896.10)	(3469.55)	(4853.49)	(4077.81)	(5311.60)	(4387.23)
PS product	(421.52)	(1043.69)	382.37	(566.90)	797.84	(285.25)
CS product	3130.22	3383.57	8540.89	8811.59	11,171.04	11,464.69
Total	(1187.40)	(1129.68)	4069.76	4166.89	6657.27	6792.21
US West						
PS log	(639.67)	(651.36)	(1692.68)	(1724.26)	(2306.74)	(2077.12)
PS product	2873.81	2410.94	7798.92	7038.06	10,175.45	9325.91
CS product	120.25	370.51	(70.56)	371.19	(37.95)	222.64
Total	2354.39	2130.09	6035.67	5684.99	7830.75	7471.42

prices are large enough that they offset gains to producers from lower wood costs. In West Europe, mill processors lose market share to East European producers under the extensive margin economic scenarios. With exception of Canadian producers, processor losses are small under climate change.

Without exception, consumers gain welfare from climate change. They benefit from lower product prices and higher consumption levels. The overall addition to timber inventory worldwide from changes in climate creates surplus conditions that benefit consumers everywhere.

In order to gauge the effects of the alternative assumption of a pseudo-transient change, we again measure economic welfare and compare it to the measures found under the ‘‘true’’ transient changes. Table 2 presents the change in welfare measured as the difference between welfare under an assumed pseudo-transient change in climate and the reference baseline. The assumption of a pseudo-transient change produces larger percentage differences in the estimated economic welfare at the global level and for selected regions. The differences in economic welfare vary by region and the economic and climate scenarios, however.

In Canada, the estimated welfare impacts from climate change are larger under the pseudo-transient assumption for the three climate scenarios. Under the LLH climate, total welfare loses nearly double. The percentage increase under the RRR and HHL climate scenarios is smaller but still significant; close to 20% of the losses under the ‘‘true’’ transient change scenario. On average over the three climate scenarios

LLH, RRR and HHL, the pseudo-transient change in climate results in nearly US$ 2.5 billion in larger losses, the majority of the loss affecting the processing sector. The loss is similar in size to the average global gain in total welfare between transient assumptions.

The US south region also has significantly different economic welfare changes. Total forest sector welfare is significantly larger under the pseudo-transient change in climate. Under the LLH climate scenario, where total welfare changes are negative, the South's welfare loss is substantially smaller, from US$ 4.3 to 1.1 billion, primarily due to an increase in consumer welfare. Substantial differences also are evident in the RRR and HHL climate scenarios between the two transient assumptions.

The increase in total welfare measures is also evident in the US West region under the pseudo-transient climate change scenario. Total welfare under the LLH climate scenario nearly triples. Smaller but significant gains are also evident in the other two climate scenarios, RRR and HHL. Similar gains are observed for the US North as well.

Differences in other regions are not as large and in some instances lower than the "true" transient change as was the case for Canada. Chile and New Zealand, where the timberland bases are expanding, show smaller total welfare change under the LLH climate scenario. In West Europe, the assumption of a pseudo-transient change in climate also lowers total welfare changes.

4. Discussion

The study analyzes the effect of climate change on economic welfare in the forest sector under two different but plausible time paths. The economic welfare results of a "true" transient path produced by annual climate changes are compared to the welfare results for an assumed pseudo-transient constant rate of climate change. Changes to economic welfare are the result of potential inventory responses taken from TEM and converted to economic responses through adjustments in timber supply in the hardwood and softwood forest sectors in the CGTM. The changes in inventory produce harvest and price changes that are summarized by economic welfare changes in timber and product markets.

We consider various assumptions of economic and ecological behavior to isolate the effect of alternative time path assumptions of transient change. The time path assumption leads to a smaller impact on welfare estimates than the effects observed under varying climate scenarios. The two time paths produce a larger effect in economic welfare than alternative economic assumptions, however.

Globally, total economic welfare increases for all 12 scenarios. The result is consistent with previously reported effects by others (Perez-Garcia et al., 1997; Sohngen and Mendelsohn, 1998). In addition, the welfare effects of climate change on forest product markets and trade patterns of a region are influenced by the time-path of climate change chosen. Global total economic welfare is higher under the pseudo-transient constant rate of change assumption. In addition, regional product markets produce differences in the estimates of regional welfare changes. These effects have not been reported in the literature previously. Finally, market segments—log producers, mill owners and product consumers—are all impacted differently. In North America, a pseudo-transient constant rate of climate change leads to a larger total welfare change for the US while leading to larger losses in Canada. Low cost log producers of Chile and New Zealand have only relatively small changes in their total welfare measures under alternative assumptions of transient change.

The two time paths differ on when changes in climate will produce changes in timber inventory. Under the pseudo-transient change, inventory expands early during the transition phase to equilibrium compared to the "true" transient change. As a result, economic welfare expands early on in the transition phase of climate change under the constant rate of change assumption. Summed over the period 1994–2040, this leads to the larger estimate of global total welfare under the pseudo-transient assumption. Alternative assumptions on the discount rate do not significantly alter the results.

5. Conclusion

The study indicates that assumptions on the time path of change in climate and CO_2 are important. When time path is evaluated under alternative assumptions about emission controls, ocean–atmosphere thermal interactions, and the effects of atmospheric aerosols, as well as alternative economic behavioral assumptions, a pseudo-transient, constant rate of change leads to larger global economic welfare effects than a ''true'' transient change assumption. This generalization does not carry over to regional effects, however. In several regions, differences in ecological and economic assumptions lead to situations where the total economic welfare is lower under the pseudo-transient change. Also, welfare measures for regional timber and product markets produce differences that suggest alternative programmatic needs for each region and market segment. Care must be taken to include transient change assumptions that reflect expected climate changes when programmatic needs of regions and sectors within regions are assessed. These considerations to time path assumptions when evaluating programmatic needs are in addition to variation in economic assumptions regarding timber harvesting behavior and alternative assumptions regarding ecological interactions that also influence economic welfare measures.

References

Binkley, Clark S., 1988. The impact of CO_2-induced climate change on the world's forest sector. In: M. Parry, T. Carter and N. Konijn, (Eds.), The Impact of Climate Variations on Agriculture, Kluwer Academic Publishers, Dordrecht.

Callaway, J, Smith, J., Keefe, S., 1994. The effect effects of climate change for U.S. forests. U.S. Environmental Protection Agency, Adaptation Branch, Climate Change Division, Office of Policy, Planing and Evaluation, Washington, DC.

Cardellichio, P., Youn, Y., Adams, D., Joo, R., Chmelik, J., 1989. A preliminary analysis of timber and timber products production, consumption, trade and prices in the Pacific Rim until 2000. CINTRAFOR Working Paper 22. College of Forest Resources, University of Washington, Seattle.

Intergovernmental Panel on Climate Change (IPCC). 1995. Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios, Cambridge University Press, New York.

Joyce, L.A., Mills, J., Heath, L., McGuire, A.D., Haynes, R., Birdsey, R., 1995. Forest sector impacts from changes in forest productivity under climate change. J. Biogeogr. 22, 703–714.

McCarl, B.A., Burton, D.M., Adams, D.M., Alig, R.J., Chen, C.C., 2000. Effects of global climate change on the US forest sector: response function from a dynamic resource and market simulator. Climate Res. 15 (3), 195–205.

Mitchell, J.F.B., Johns, T.C., Gregory, J.M., Tett, S.F.B., 1995. Climate response to increasing levels of greenhouse gases and sulphate aerosols. Nature 376, 501–504.

Perez-Garcia, J., Joyce, L.A., McGuire, A.D., Xiao, X. Impacts of emission controls on the global forest sector (in review).

Perez-Garcia, J., Joyce, L.A., Binkley, C.S., McGuire, A.D., 1997. Economic impacts of climate change on the global forest sector. Crit. Rev. Environ. Technol. 27, S123–S138.

Prinn, R.G., Jacoby, H., Sokolov, A., Wang, C., Xiao, X., Yang, Z., Echaus, R., Stone, P., Ellerman, D., Melillo, J., Fitzmaurice, J., Kicklighter, D., Liu, Y., Holian, G., 1999. Integrated global system model for climate policy assessment: Feedbacks and sensitivity analysis. Climatic Change 41, 469–546.

Sohngen, B., Mendelsohn, R., Neilson, R., 1998. Predicting CO_2 emissions from forests during climatic change: a comparison of natural and human response models. Ambio 27 (7), 509–513.

Sohngen, B., Mendelsohn, R., 1998. Valuing the impact of large-scale ecological change in a market the effect of climate change on US timber. Am. Econ. Rev. 88, 686–710.

Xiao, X., Melillo, J.M., Kicklighter, D.W., McGuire, A.D., Prinn, R.G., Wang, C., Stone, P.H., Sokolov, A., 1998. Transient climate change and net ecosystem production of the terrestrial biosphere. Global Biogeochem. Cycles 12, 345–360.