ADAPTATION AND WORLD MARKET EFFECTS OF CLIMATE CHANGE ON FORESTRY AND FORESTRY PRODUCTS

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Abstract

We use a computable general equilibrium model to study the impacts of climate change on forestry over time. The model is constructed around the GTAP v5 database, with nine regions and eleven production sectors. The model also includes a forestry module, with data of the standing mass and growth rates of the regional forests. The production in the forestry sector is subject to changes in the productivity of "land", which gives rise to a Ricardian rent on forests. The rent depends partly on the natural prerequisites for growth of the bio-mass, which relate to climatic conditions, but also the infrastructure investments required to gain access to the forests. The forestry sector is impacted by different dimensions of climatic change, such as combinations of changes in temperature and precipitation. For a possible future climate change scenario, we assess the consequences on the world market for forestry and derived products.

1 Introduction

Climate change may spur substantial changes to the forestry sectors across the world. Precipitation and temperature patterns are basic to the forest growth, and thereby the potential for harvesting. This may affect the profitability of forestry both in a positive and a negative direction. In addition, the option of carbon sequestration implies that the value of the forest has increased. These impacts will differ across regions, depending on the how the climate develops in each region. But being a traded good, impacts in one region will have an influence on the impacts in other regions as well through the world market. This paper aims at sorting out these different components of impacts on the forestry sector in the different regions of the world.

The motivation is that, to our knowledge, few studies have integrated all three kinds of impacts, namely the physical effects on forests, the consequences for the profitability in the forestry sectors, and the resulting changes in world market prices. The closest we come to this

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is Shongen and Mendelsson (1999), who study the economy of forestry under climate change, but they confine themselves to study the US. The literature is richer when it comes to physical effects and market effects. Common to these are, however, that the economy of the forestry sector is treated in a rather superficial manner, usually by so-called damage cost functions, where the physical impact is 'translated' into an economic figure by means of a fixed price. The harvesting is thereby increased or decreased proportionally irrespective of the marginal rent on the forest.

The reason for this apparent lack is that most general equilibrium models that apply to study world markets have no, or at best poor, linkages between climate and natural resource stocks on the one hand and the economic activities on the other. In this study, we develop such a relationship for forests and forestry and integrate the forestry module in a general equilibrium model in order to capture the way economic agents may adapt to climatic changes. In the end, climate change impacts to forests and forestry in a region can, therefore, be explained by three factors, namely the physical effects on forests from changing weather conditions, how this may affect the economic outcome of forest management, and the world market effects resulting from these changes in other regions. We aim at sorting out the importance of these factors to different regions of the world. Section 2 describes the equilibrium structure of the model. The forestry module is described in section 3. In section 4 we describe the calibration of the forestry module, and the baseline scenario is described in section 5. Section 6 presents the climate change scenario, and the results are discussed in section 7. Section 8 concludes.

2 The equilibrium model structure

In this study, we use the GRACE computable general equilibrium model (CGE). The model, described in Aaheim and Rive (2005), is a global, multi-region, multi-sector, recursively dynamic model based around the GTAP v5.4 database (Dimaranan et al. 2002). It includes 9 regions, 11 production sectors, and 3 final demand sectors. These are listed in Table 1. Our choice of regions reflects a focus towards those with significant importance to the forestry sector. The choice of sectors is focused towards forest and forest-related sectors (i.e. paper and pulp, and lumber), and CO_2-emitting energy sectors.

Regions	Production Sectors	Final Demand Sectors

China (CHN)	Agriculture (AGR)	Private (PRI)
India (IND)	Forestry (FRS)	Public (PUB)
Rest of Asia, Oceania (ROA)	Paper and Pulp Products (PPP)	Investment (INV)
European Union 25 (EU)	Lumber (LUM)	
Norway (NO)	Coal (COL)	
Canada, Mexico, USA (NAFTA)	Electricity (ELC)	
Central and South America (LAM)	Gas (GAS)	
Russian Federation (RUS)	Refined Oil (REF)	
Rest of World (RUS)	Crude Oil (CRU)	
	Services (SER)	
	Other products (PRO)	

Table 1: Regional and sector specification in the GRACE model. Note: GTAP region for Norway includes Liechtenstein and Iceland, who have insignificant forestry sectors

The Production sectors demand intermediate goods from other sectors, and the three factors (capital, labor, and nature). The Final Demand sectors demand goods from the production sectors. The production structure is a nested constant elasticity of supply (CES) demand tree, shown in Figure 1 below.

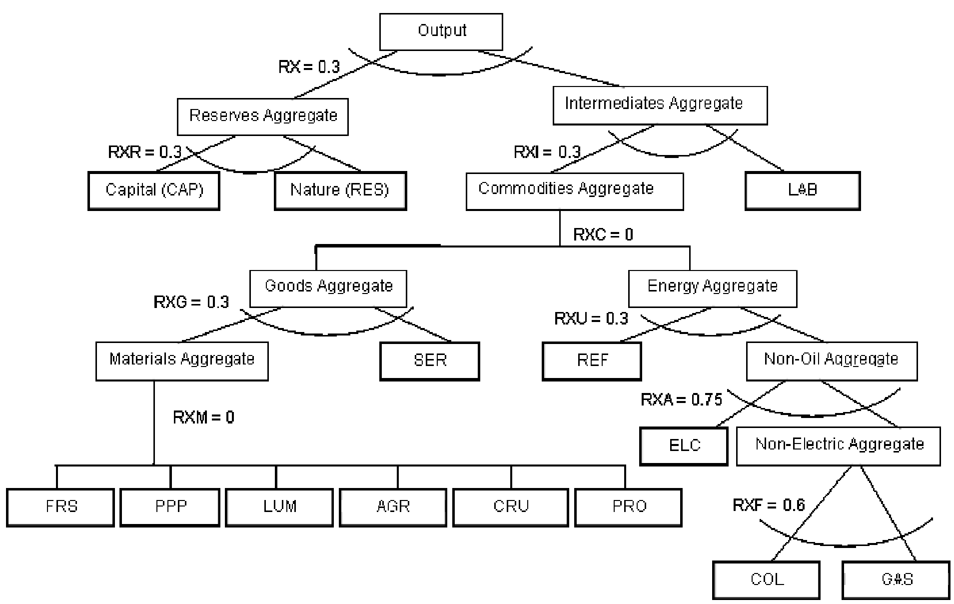

Figure 1: Production sectors demand structure. Elasticities are listed with prefix RX.

Production in each country can either be sold domestically, or exported. Trade occurs bilaterally between the regions. Imported and domestic goods of the same type are differentiable (the Armington assumption), and are combined into an 'Armington aggregate' before being available on the market.

The dynamics and investment in the model are based on the GTAP-Dyn model (Ianchovichina and McDougall, 2000). The model is run for the period 2000 to 2100. With recursive dynamics, the model is solved as a series of static equilibria representing each time period. Each period is tied to the next by growth in the capital, labor and nature stock. Growth in the capital stock is driven by investments. Investors are myopic, and are unable to take into account future prices when making investments. In each period, it is assumed that investors will seek to equalize expected rates of return on capital across all regions. This is subject to an assumed 'normal' rate of growth in the capital stock, at which the expected rate of return does not fall. The expected rate of return in each period becomes the actual rate of return in the next period.

The model includes household and industrial emissions of CO_2 using data from the GTAP/EPA database (Lee 2002). CO_2 emissions are modeled as a fixed factor input (Leontief technology) to the demand of energy goods by production and final demand sectors. Technological improvement (i.e. decarbonization) over time is assumed to take place exogenously, and reduces the emissions intensity of the energy inputs. These emissions are fed into a simple climate model to obtain a temperature scenario for the period 2000-2100.

3 The economics of the forestry sector

The harvesting of forests is, in many respects, comparable with all other activities of the economy. It requires input of the primary production factors, labour and real capital, as well intermediate input, and the sector has to compete on equal terms with other sectors to obtain it. Consequently, the demand for labour, capital and intermediates can be modeled in the same manner as for all other sectors. Harvesting may, however, exhibit diminishing returns to scale, for example because of longer transport distances or increasingly difficult logging terrain. But forestry depends also crucially on the availability of forests. The input of land in the GTAP data-base is meant to reflect this dependency. In GRACE, this item is considered an input similar to real capital. Together, they constitute the 'stock'-aggregate. However, land data are vaguely documented, and it is highly questionable whether a fixed 'input of land' can be used to appropriately represent the biotic constraints to which the forestry sector has to adapt. Therefore, the economic impacts of changes in the biotic constraints resulting from climate change will not be adequately captured.

In order to introduce a more economically reliable relationship between the economic activity in the forestry sector and the biotic constraints, a forestry module has been implemented. The module is based on a rather straightforward text-book representation of biotic constraints for renewable resources in economic models (see e.g. Dasgupta and Heal, 1979). Denote by S the stock of the resource, for example the m^3 mass of wood within a given area. It is assumed that the growth of the stock, $\dot{S}$, can be written as the differential equation

$$\dot{S} = (B - cS)S \tag{3.1}$$

where B and c are positive parameters. (3.1) is sometimes referred to as the Volterra equation. The parameters characterize the biotic conditions under which the forests have to be managed. There is one set of parameters for each region. Thus, differences in the prosperity of the forest resources across regions are characterized by different sets of parameters. In particular, shifts in biotic constraints due to climate change will depend on *how* the climate changes in different regions. For example, in some regions, the growth potential of the standing stock may change without affecting the total forested area much, whereas in other regions, the main impact may be a change of the forested land. This will lead to different combinations of changes in B and c. The parameters that enter the model can be regarded as an aggregate of biotic constraints within each region. The decomposition of each parameter is further discussed in Section 4.

Equation (3.1) gives the total growth of forests in each region, but only a part of this is subject to commercial forestry. How much is an economic question, which depends partly on natural preconditions, such as distance from the market and forest density, and partly on economic circumstances, such as wood prices and investment costs. It is assumed that forest managers can increase the accessible part of the forest if they invest, for example in infrastructure. This means that investments and thereby the capital stock in the forestry sector consists of two categories of real capital. One category is the ‘ordinary’ stock of capital utilized to harvest timber, such as cutting machinery and transport equipment. The other category is capital invested to make the forest accessible for commercial harvesting. For simplicity, this category of capital will be called infrastructure.

Assume that the biotic constraint of the accessible part of the forest, denoted $\dot{v}$, is also subject to a Volterra equation. Investments in infrastructure change the biotic constraint for the accessible forest. To simplify, we introduce a relationship between the increase in biotic growth and the stock of biomass attained by an investment in infrastructure. This relationship refers to the maximum sustainable yield for a given bio-growth curve, which denotes the stock of bio-mass at which the growth is at its maximum. It is assumed that an investment needed to increase the marginal sustainable yield of the accessible forest, $\dot{v}_{msy}$ by 1 m^3 implies an increase of the stock at marginal sustainable yield, v_{msy}, of $v_{msy}^2 / \dot{v}_{msy}$. In that case, investments in infrastructure affect only the parameter corresponding to B in (3.1), leaving parameter c unaffected. With these assumptions, we write the growth of the accessible forest as

$$\dot{v} = \left[(B - bk_2^{-\beta}) - cv \right] v \qquad (3.2)$$

where $b > 0$ and $0 < \beta < 1$ are parameters. I follows from (3.2) that $\dot{v}_{msy} \geq 0$ if $k_2 \geq 0$, $\lim_{k_2 \to \infty} \dot{v} = \dot{S}$, $\partial \dot{v} / \partial k_2 > 0$, and $\partial^2 \dot{v} / \partial k_2^2 < 0$.

The management of forests aims at maximizing the social surplus, which emanates from forestry and services from the standing mass. These services relate, for example, to recreation and biodiversity. Forests also contribute to carbon sinks, which has a value in reducing concentrations of greenhouse gases. The sink is, however, related to the growth of the forests. To simplify the model, we will confine the value of sinks to manageable growth, in line with the intentions of the Kyoto protocol. This means that the value of sink can be included in the price of harvesting.

Denote the production function in the forestry by $f(k_1,x,v)$, where k_1 is the stock of capital in the production process, distinguished from the infrastructure capital. x is the input of other intermediates and v is the standing mass of accessible forests, included to take possible diminishing returns to scale into account. Moreover, let $w(v)$ denote the non-economic social services from the standing mass, while p is the product price and q_i is the factor price of input i. Optimal management of the forests is found by

$$\max_{k_1,k_2,x}\left\{\int_0^\infty \left[pf(k_1,x,v)-w(v)-q_k(k_1+k_2)-q_x x\right]e^{-rt}dt\right\} \qquad (3.3)$$

subject to constraint (3.2). r is the discount rate.

Denote by η the shadow price of the standing mass. Pontryagin's maximum principle then gives the first order static optimum conditions:

$$\eta = p-\frac{q_k}{f_k^{'}} = p-\frac{q_x}{f_x^{'}} = \frac{q_k}{\frac{\partial \dot{v}}{\partial k_2}} \qquad (3.4)$$

From the first two equations, it is clear that the shadow price η equals the marginal net benefit (price minus marginal harvesting cost), or the forest rent. The last equation determines the optimal investment in infrastructure, such that the marginal cost of infrastructure equals the forest rent.

The optimal development of the total and accessible mass over time depends on the initial stocks. It can be shown, however, that if return on alternative investments indicated by the discount rate is lower than the net social return of growth of bio-mass at its minimum stock, it is optimal to approach a positive stationary stock of bio-mass in the long run. Since the forestry model will be implemented in a multi-period stationary model, we apply only the long-run stationary state solution. This means that the optimal stationary state is assumed to be approached immediately when the economy or the bio-growth functions changes.[2] Setting the time derivatives of all variables in the dynamic system equal to zero, we find that the optimal stock of bio-mass in the long run is characterized by the condition

$$\frac{\partial \dot{v}}{\partial v} = r + f_v^{'} - (pf_v^{'} + w_v^{'})\frac{\frac{\partial \dot{v}}{\partial k_2}}{q_k} \qquad (3.5)$$

The easiest way to interpret this condition is to imagine that extraction costs are independent on the scale and that there is no value attached to the standing mass. In optimum, the marginal

[2] This is similar to the way investments in real capital is treated in static, multi-period macro-economic models, sometimes referred to as dynamic recursive models.

physical growth rate of the forest would then equal the discount rate. That is, the forest managers are indifferent as to whether the next tree is cut and the income is invested to gain the monetary return from an alternative activity, or the tree is rather cut next year in order to gain a somewhat higher quantity by then.

4 Calibration of the bio-growth function

Forest growth will vary across the world forests according to climate, species, and forest type, biotic and abiotic conditions. The worlds forests can be divided into four categories by climate; tropical, subtropical, temperate and boreal forests. Each forest category includes a large variation of ecological zones with very different growing conditions. As an example, tropical forest as a broad forest type contains rain forest, moist areas, dry areas, shrub areas, desert areas and mountain areas.

In order to capture some of the differences in growth conditions across forests and to distinguish between different effects of climate change on growth in different types of forests we distinguish between tropical, subtropical, temperate and boreal forests. To keep it simple the growth rate is assumed equal within each forest category within a region.

A bio-growth curve has been calibrated for each forest type in each region based on the relationship

$$\dot{S}_{ij} = B_{ij} - c_{ij} S_{ij}^2 \tag{4.1}$$

where $\dot{S}_{ij}$ is growth in region i and forest type j, S_{ij} is standing mass in region i and forest type j, and B_{ij} and c_{ij} are the parameters in region i and forest type j.

Assume that $\lim_{s \to 0^+} \dot{S} = 0$. Then from (4.1), maximum sustainable yield, S_{msy}, can be expressed by $B/2c$ and $S_{max}=B/c$. Solving this for B gives:

$$B = S_{\max} c \tag{4.2}$$

Inserting the expression for *a* in (1) gives $\dot{S}_{ij} = (S_{\max} c) S_{ij} - c_{ij} S_{ij}^2$. Solved for *c* this gives:

$$c = \frac{\dot{S}_{ij}}{S_{\max} S_{ij} - S_{ij}^2} \qquad (4.3)$$

The expressions above show that an estimate of S_{max} is needed to calibrate the parameters *B* and *c*. We have assumed that the present standing mass accounts to 65% of S_{max}. With this rather arbitrary assumption, it is possible to calibrate the bio-growth function for each forest type in each region.

The model includes only one bio-growth function for each region. The calculated parameters for each forest type have therefore been aggregated into one parameter for each region. The aggregated parameters denoted with the letters *B* and *c,* without the indexes, are found from the expression of the regional aggregate

$$\sum_j (B_{ij} S_{ij} - c_{ij} S_{ij}^2) = B S_i - c S_i^{\,2} \qquad (4.4)$$

Where $S = \sum_j S_{ij}$.

Then

$$B = B_{i1}\left(\frac{S_{i1}}{\sum_j S_{ij}}\right) + B_{i2}\left(\frac{S_{i2}}{\sum_j S_{ij}}\right) + B_{i3}\left(\frac{S_{i3}}{\sum_j S_{ij}}\right) + B_{i4}\left(\frac{S_{i4}}{\sum_j S_{ij}}\right) \qquad (4.5)$$

and

$$c = c_{i1}\left(\frac{S_{i1}}{\sum_j S_{ij}}\right)^2 + c_{i2}\left(\frac{S_{i2}}{\sum_j S_{ij}}\right)^2 + c_{i3}\left(\frac{S_{i3}}{\sum_j S_{ij}}\right)^2 + c_{i4}\left(\frac{S_{i4}}{\sum_j S_{ij}}\right)^2 \qquad (4.6)$$

B and *c* are constants in the model. This means that a change in *S* resulting from changes in the biotic growth parameters is supposed to reflect a proportionate change in the stock of each forest type. The advantage of this aggregate is that changes in the bio-growth curve in each region resulting from climate change can be derived from knowledge about changes both in the growth parameters of each forest type and in the relative size of each type.

	S_{ij} (1000m^3)				S (1000m^3)
Region (i)	**Tropical**	**Subtropical**	**Temperate**	**Boreal**	
CHN	337 480	4 977 830	2 446 730	674 960	8 437 000
IND	2 593 500	136 500	0	0	2 730 000
ROA	21 600 904	5 082 303	3 321 793	0	30 005 000
EU	0	3 800 977	10 269 450	5 934 573	20 005 000
NO	0	0	55 544	732 456	788 000
NAFTA	4 635 803	12 288 904	20 370 394	24 942 286	62 237 387
LAM	110 434 258	2 803 923	1 116 813	0	114 354 994
RUS	0	0	12 479 040	76 656 960	89 136 000
ROW	49 465 782	2 836 808	4 374 033	158 377	56 835 000

Table 2: The standing mass (S_{ij}) by region and forest type, and the standing mass (S) by region.

Table 2 illustrates how standing mass is spread between different forest types and different regions. Latin America and Russia are the two regions with highest standing mass.

The parameters B_{ij} and c_{ij} illustrate that forest growth can be divided into two elements, density-independent and density-dependant growth, where B_{ij} is the former and c_{ij} is the latter. Density independent growth shows that increased standing mass increases growth.
Density dependant growth illustrates that the growth is dependent on the density in the forest. As density increases, competition for light, moisture and nutrients increases, which gives a negative effect on growth. Looking at the graph in figure 2, B_{ij} pulls the graph upwards, while c_{ij} pulls the graph down towards the axis.

The aggregation of the calibrated parameters is presented in table 3. The growth rate in each region has been calculated from the aggregated parameters.

Region	B	c	Growth rate (%)
CHN	0.1114	8.58E-09	5.57
IND	0.1084	2.58E-08	5.42
ROA	0.0967	2.09E-09	4.84
EU	0.0873	2.84E-09	4.36
NO	0.0887	7.32E-08	4.44
NAFTA	0.0773	8.07E-10	3.86
LAM	0.0420	2.39E-10	2.10
RUS	0.0311	2.26E-10	1.55
ROW	0.0815	9.32E-10	4.07

Table 3: The parameters B and c, and growth rate by region

A comparison of table 2 and 3 shows that countries with high standing mass tend to have low growth rates and visa versa. This can illustrate that different countries are at different points on the bio-growth curve. China and India are examples of countries with high growth rates and low standing mass. In these countries most forests are managed as plantations. Latin America and Russia on the other hand, are the two regions with lowest growth rates and highest standing mass. In these regions, large forest areas, the tundra in Russia and the rainforests in the Amazons, are inaccessible for forestry.

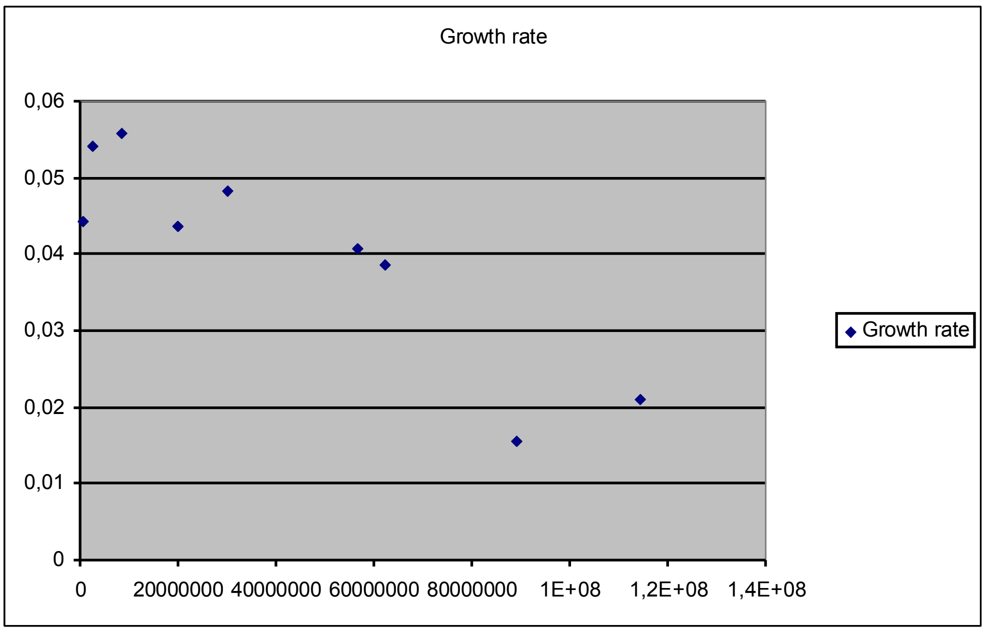

Figure 2. Growth rates and standing mass by region

5 Reference Scenario

We develop a reference scenario in the GRACE model for the period 2000-2100. This reference case establishes the economic growth and sector outputs that would have occurred in the absence of climate change. In addition, the greenhouse gas emissions from this reference scenario are used to determine the physical climate parameters (e.g. temperature change, atmospheric concentration of CO_2) that will be used in the alternative (climate change) scenario in the next section.

In the GRACE model, the baseline economic and greenhouse gas emissions growth pathway are defined exogenously through the assumed (i) 'normal' rate of growth in the capital stock, and (ii) the exogenous emissions intensity improvement in the energy sectors. In this study, we use the growth and technological improvement rates inferred from the SRES B2 scenario (IPCC 2001) to generate our reference case. For simplicity, we assume constant growth and improvement rates for 2000-2100, shown in Table 4 below.

GRACE Region	Annual GDP Growth (%)	Annual Decarbonization (%)
China	3.4	2.1
India	3.4	2.1
Russia	2.7	2.4
Norway	1.0	1.0
Latin America	3.3	1.9
Rest of Asia	1.4	1.2
EU-25	1.0	1.0
NAFTA	1.0	1.0
Rest of World	2.7	1.8

Table 4: Reference GDP growth and decarbonization rates

The current GRACE model only includes CO_2 emissions from industrial and household sources, and thus does not include emissions from other key gases (i.e. CO_2 from land-use and land-use change sources, CH_4 and N_2O). As we are not concerned with abatement in this study, we make simple assumptions for these four gases. We assume land-use and land-use change emissions in our baseline scenario follow the trajectory of that in the SRES B2 scenario. Our baseline CH_4 and N_2O emissions are modeled using ratios (i.e. CH_4 per unit industrial CO_2) taken from the SRES B2. These ratios decrease over time, and thus include an assumed technological improvement over time (such as desulfurization). While we are not able to model mitigation of these respective gases, this treatment allows for consistent changes in emissions when GDP and autonomous decarbonization assumptions are changed.

Figure 3 illustrates the global GDP and industrial CO_2 growth in the baseline for the period 2000-2100.

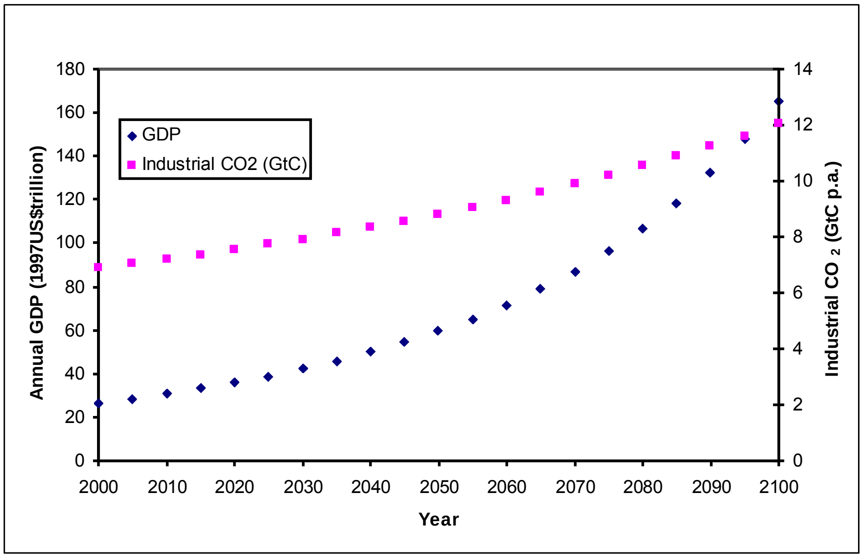

Figure 3: Reference Global GDP and CO_2 emissions growth

6 Climate Change Scenario

Having established the reference case for economic growth and greenhouse gas emissions, the next step is to run a climate change scenario. This climate change scenario uses the same economic growth and technological improvement rates as the reference case. The parameters from the forestry bio-growth equation, however, are shocked to represent the impact of climate change on forestry growth. The shock to these parameters depends on the physical climate parameters associated with our greenhouse gas emissions, and our assumptions of how the changing climate will impact the bio-growth curve in our model.

We determine the physical climate parameters by first using a simple climate model by Fuglestvedt and Berntsen (1999) with an assumed climate sensitivity of ΔT_{2xCO2} = 3.5 °C, using the emissions generated in the reference case. The key parameters we are concerned with are global mean temperature change and atmospheric concentrations of CO_2. These are shown below in Figure 4. These temperature and concentration parameters are then entered into the forestry impact functions. Thus, before GRACE is run to determine the market effects of the impacts on forestry, we already know what the direct impacts on forestry growth will be. We note an inherent weakness in this method. Because we use the reference case emissions to calculate the direct impact on the forestry growth, we are effectively assuming that the greenhouse gas emissions in the climate change scenario will be equal to those in the reference case. This is not the case, as impacts on the forestry sector will create feed-backs on both the greenhouse gas emissions and on concentrations. However, we find the deviation resulting from impacts on forestry is minimal.

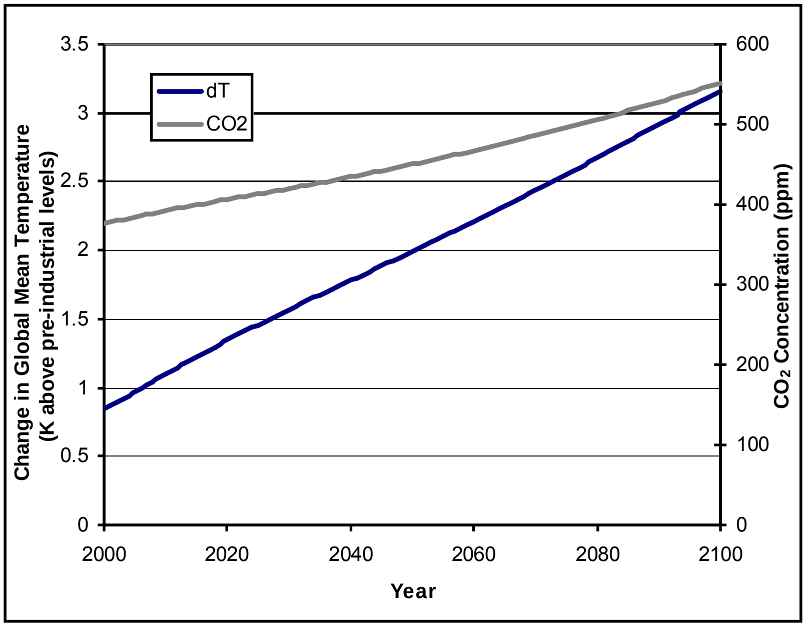

Figure 4: Climate Parameters used in the Climate Change Scenario

The consequences of continued greenhouse gas emissions are highly uncertain, yet include increased atmospheric concentrations of CO_2 and increased in global mean temperature. Region-specific effects, such as changes to local temperature, precipitation patterns, and cloud cover are more uncertain, but are likely to play a significant role in determining the impact of climate change on each region's ecosystems – including forestry. In this paper, however, we do not model region-specific climate effects, and instead employ a treatment of the direct impacts of climate change on forestry that depends solely on changes in global mean temperature (ΔT_{GLOB}) and atmospheric concentrations of CO_2 ($CONC_{CO2}$).

According to the IPCC (2001b) Third Assessment Report, increased temperatures and atmospheric concentrations are likely to increase the net primary production in forests. However, the impact of these effects will differ from region to region, depending on the characteristics of the accessible tree stock, such as share of plantation forests, and tree type.

We use a simple linear impact function that relates ΔT_{GLOB} and $CONC_{CO2}$ to changes in the parameters of the bio growth function – namely B(r) and c(r). These are indexed by region (r) to reflect differences in regional forest with respect to growth, density and vulnerability to climate change. However, the relationship between ΔT_{GLOB} and $CONC_{CO2}$ to B(r) and c(r) in both space and time is unknown. Thus, we must make a number of assumptions to construct these functions for the purposes of this study.

Firstly, we assume that only countries with boreal and temperate forests will see increased productivity. That is, Norway, North America, Russia, and the EU. According to the UN Intergovernmental Panel on Climate Change (IPCC 2001b), sub-tropical forests may see a similar benefit. However, tropical forests are already in near optimal conditions, and may in fact face decreased output with climate change. Thus, we assume neutral impact of climate change on the remaining regions (China, India, Rest of Asia, Latin America, Rest of World).

For these regions, then:

$$B(r) = B_o(r) \tag{6.1}$$

and

$$c(r) = c_o(r) \tag{6.2}$$

where $B_0(r)$ and $c_0(r)$ are the reference bio-growth parameters.

For the four regions that are impacted by climate change, we use results from Matala et al. (2004) to infer a relationship between climate change and the bio-growth parameters. For this study, we assume an increase in global mean temperature above pre-industrial levels of 3°C and an atmospheric concentration of CO_2 of 700ppm is associated with a 30% increase in productivity. Thus, for Norway, NAFTA, Russia, and the EU, we use the equations:

$$B(r) = B_o(r) \times \left(1 + \frac{\Delta T_{GLOB}}{3} \times \frac{CONC_{CO_2}}{700} \times 0.3 \right) \tag{6.3}$$

and

$$c(r) = \frac{B(r)}{SF_{\max}} \tag{6.4}$$

7 Results (Preliminary)

Table 5 shows the change in forest growth at maximum sustainable yield in the climate change case relative to the reference case. These results indicate the direct impact of climate change on the forestry sector, which will have wider market impacts on forestry and forest products. As discussed above, only regions with boreal or temperate forests see increased forest growth as a result of climate change.

GRACE Region	2050	2100
China	0.0	0.0
India	0.0	0.0
Russia	13	25
Norway	13	25
Latin America	0.0	0.0
Rest of Asia	0.0	0.0
EU-25	13	25
NAFTA	13	25
Rest of World	0.0	0.0

Table 5: Forest growth at maximum sustainable yield in climate change scenario relative to reference case (%)

Tables 6, 7, and 8 show the changes in forestry and forest product output in the climate change scenario relative to the base case.

Region	**2050**	**2100**
China	-0.035	-0.030
India	-0.022	-0.015
Russia	0.177	0.183
Norway	0.781	1.094
Latin America	-0.081	-0.055
Rest of Asia	-0.242	-0.288
European Union – 25	0.368	0.635
NAFTA Region	0.275	0.456
Rest of World	-0.185	-0.159

Table 6: Forestry Sector output in the climate change scenario relative to reference case (%)

Region	**2050**	**2100**
China	-0.0027	-0.0025
India	-0.0024	-0.0025
Russia	0.0273	0.0319
Norway	-0.0087	-0.0102
Latin America	-0.0027	-0.0024
Rest of Asia	-0.0009	-0.0013
European Union – 25	0.0095	0.0146
NAFTA Region	0.0041	0.0069
Rest of World	-0.0053	-0.0056

Table 7: Paper and Pulp output in the climate change scenario relative to reference case (%)

Region	**2050**	**2100**
China	-0.0327	-0.0255
India	-0.0120	-0.0090
Russia	0.1201	0.1231
Norway	0.6155	0.7113

Latin America	-0.0184	-0.0149
Rest of Asia	-0.0251	-0.0265
European Union – 25	0.0198	0.0377
NAFTA Region	0.0401	0.0681
Rest of World	-0.0393	-0.0396

Table 8: Lumber output in the climate change scenario relative to reference case (%)

In general, output of these three sectors increases relative to the reference case in Norway, Russia, NAFTA, and the EU. This is a result of the remaining five regions substituting away from their domestic output towards cheaper imports from these four regions. We see in Tables 9, 10, 11 that the four regions benefiting from climate change direct an increasing share of their output towards exports to meet that demand.

We expect the deviation of output and export share to increase with time, as the direct impacts of climate change on forestry increase with higher temperature and concentrations of CO_2. The results in general do show this trend. However, there are some exceptions. The climate change scenario output of lumber (Table 7), for example, in China, India and Latin America diverges from the reference case to a greater extent in 2050 than it does in 2100. This can be explained by the higher economic growth rates in these countries relative to the four regions benefiting from climate change (Table 4). The sectors in these regions grow at a faster rate, and thus over time increasingly dominate over the imports from the four regions. This makes them less susceptible to the productivity improvements associated with climate change. By comparison, we see that the Rest of Asia region, which does not exhibit high growth rates (and does not benefit from climate change), does exhibit the increased divergence in output over time that we expect.

Furthermore, we find that among the secondary forest products, the impact is higher in the lumber sector compared to the paper and pulp industry. This is because a larger share of forestry output goes towards lumber, and the lumber sector requires more forestry goods per unit output compared to the paper and pulp sector. Thus, any changes in forestry output will impact lumber more intensively.

Region	2050	2100
China	-1.2651	-1.3849
India	-1.9062	-2.1106
Russia	0.3923	0.5700
Norway	-0.4046	-0.5103
Latin America	-1.6105	-1.7196
Rest of Asia	-0.4376	-0.3585

European Union – 25	0.9078	1.6082
NAFTA Region	1.9791	3.0496
Rest of World	-0.9385	-0.8764

Table 9: Share of domestic Forestry sector output being exported in the climate change scenario relative to reference case (%)

Region	2050	2100
China	-0.0144	-0.0145
India	-0.0190	-0.0233
Russia	0.0413	0.0468
Norway	-0.0147	-0.0162
Latin America	-0.0156	-0.0148
Rest of Asia	-0.0115	-0.0118
European Union – 25	0.0080	0.0125
NAFTA Region	0.0002	0.0035
Rest of World	-0.0249	-0.0284

Table 10: Share of domestic Paper and Pulp sector output being exported in the climate change scenario relative to reference case (%)

Region	2050	2100
China	-0.1369	-0.1630
India	-0.1734	-0.1974
Russia	0.1795	0.2290
Norway	0.0986	0.1196
Latin America	-0.1500	-0.1562
Rest of Asia	-0.0497	-0.0476
European Union – 25	0.0087	0.0196
NAFTA Region	0.0796	0.1382
Rest of World	-0.1110	-0.1271

Table 11: Share of domestic Lumber sector output being exported in the climate change scenario relative to reference case (%)

8 Conclusions

We have described a forestry module integrated into a standard, recursively dynamic CGE model for the analysis of the world market impacts of climate change on forestry and forest products. Using a simple climate model, and a number of assumptions of the impact of climate change on forest productivity, we have developed a climate change scenario for comparison with a reference no-climate change case.

The direction of changes in price and output are generally as expected. Regions which experience increased growth in the forestry sector experience increased output in forestry and forest product sectors. Exports of these goods then increases, as prices of these goods fall, making them preferable to similar goods from other regions. Output and exports of forestry and forest product in regions that do not experience improved forest growth fall in the climate change scenario relative to the reference case. The magnitude of these changes (on the order of 1% in 2100) is appropriate given the size of the global forestry sector relative to GDP (0.7% in 2100).

It should be stressed that these results are preliminary, and represent only the outcome of the assumptions used. Further work must be conducted to determine the sensitivity of the outcomes to our assumptions. In particular, with respect to the calibration of the bio-growth function in light of quantitative and qualitative aspects of regional forestry sectors, and the relationship between climate change and forest growth.

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