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INTERNATIONAL AND INTERGENERATIONAL DIMENSIONS OF CLIMATE CHANGE: NORTH-SOUTH COOPERATION IN AN OVERLAPPING GENERATIONS FRAMEWORK

by

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International and Intergenerational Dimensions of Climate Change: North-South Cooperation in an Overlapping Generations Framework.

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Abstract

Global environmental problems such as climate change have both an international and an intertemporal dimension. Recently, some papers have used an overlapping generations framework to analyze the climate change problem taking into account jointly the issues of intergenerational equity and intertemporal efficiency but without considering the international aspect of the problem. In this paper, we extend such approach by considering an overlapping generations model of climate-economy interactions where the world is split into two regions: North and South. We resort to numerical simulations of the calibrated model to analyze the effect of cooperation over economic and climate variables under two different scenarios: long-lived and short-lived governments. The main aim of our analysis is to test numerically whether John and Pecchenino's (1997) theoretical result, which states that international agreements with transfers that lack an intergenerational perspective could actually harm the environment, applies to the problem of climate change or not. Numerical results obtained allow us to conclude that when we consider short lived governments: (1) the lack of cooperation always leads to higher environmental degradation, (2) the higher the welfare weight attached to the North under cooperation, the lower the environmental degradation in the long run, and (3) some cooperative scenarios may lead in the short run to higher environmental degradation than what it would arise in the non cooperative scenario.

JEL classification: C70, D62, Q2
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1 Introduction

In the last decade the international community has become increasingly concerned with the fact that the increased concentration of greenhouse gases (GHG hereafter) in the atmosphere will cause a global climate change which might have serious effects on society in the future. In fact, the question is not whether the Earth's climate will change, but rather how much climatic conditions will change, how fast it will occur and how the effects of this change will be distributed across different regions in the world. Most scientists, whilst recognizing that uncertainties exist, believe that human-induced climate change is already occurring and that future change is inevitable[1].

It has been widely recognized that cooperation among countries to reduce GHG emissions is necessary to avoid or to mitigate global climate change. Nevertheless, and in spite of the potential welfare gains that countries can obtain from cooperation, a binding international agreement on climate change has not been reached yet. The 1997 Kyoto Protocol represents the only agreement reached on climate change so far and it has not entered into force because it is still awaiting ratification by many of the 159 countries that adopted it[2]. In Kyoto, countries agreed to emissions reductions targets and methods, but it was left to subsequent meetings to decide on most of the rules and operational details that will determine how these cuts will be achieved and how countries' efforts will be measured and assessed. Although many countries signed the Protocol, the majority were waiting for these operational details to be negotiated before deciding whether or not to ratify the Protocol. Currently, the Protocol only needs ratification by the Russian Federation to enter into force.

Each Conference of the Parties (COP), where decisions are taken about the implementation of the Protocol, has faced a lot of difficulties[3]. It is

[1] As it is stated in the IPCC reports to the UNFCCC, it is undisputed that the two last decades have been the warmest for the last 1000 years, sea level is rising, precipitations patterns are changing, Arctic sea ice is thinning and the frequency and intensity of El-Niño events appear to be increasing. Moreover, in its Third Assesment Report (2001), the IPCC estimated that globally average surface temperature would increase in the range of 1.4 to 5.8^{o}C between 1990 and 2100. Only eight years ago, the IPCC predicted that average temperatures would, at worst, rise by 3^{o}C.

[2] The Kyoto Protocol commits 39 advanced industrialized states to cut emissions of fossil fuel gases by an average of 5.2% of 1990 levels by the period 2008-2012. To enter into force, this Protocol must be ratified by 55 Parties to the UN climate change treaty, including Annex I Parties representing at least 55% of the total carbon dioxide emissions for 1990. The latest information concerning negotiations and the status of ratification of the Kyoto Protocol can be found in http://unfccc.int.

[3] At the World Summit for Sustainable Development held in Johannesburg in 2002 the Executive Secretary of the UNFCCC noted that: *"In the Convention's first decade, the centrepiece of global negotiations was to agree on rules for implementation. Our challenge now is to apply those rules and move climate change to the centre of national policy-making and action by business and civil society."*

evident that some of the difficulties are due to both the international and the intergenerational dimension of the problem. Climate change is an international problem because it will affect all countries of the world, with developing countries (specially the poor in developing countries) being most vulnerable. But it is also an intergenerational problem because damage due to climate change will occur over time affecting not only to present generations but also to future generations.

The economic literature on climate change has typically adopted the infinitely-lived agent (ILA) framework to analyze the international and intertemporal dimension of the problem. However, these models do not always allow to take into account in a proper way the intergenerational dimension of the problem. As Schelling (1995) points it out, ILA models rest on strong assumptions regarding the aggregation of welfare between generations and world regions[4]. Some recent studies of climate change have made use of overlapping generations (OLG) models to study jointly intertemporal efficiency and intergenerational distribution issues. Examples include Ansuategi and Escapa (2002), Gerlagh and Zwaan (2001b), Gerlagh (2000), Howarth (1996 and 1998) and Marini and Scaramozzino (1995). There are also several papers that compare the results derived from ILA and OLG models used to analyze climate change. On the one hand, Howarth (2000) and Stephan et al. (1997) show that, under certain assumptions and parameter values, both types of models do not differ in their implication for greenhouse policy. On the other hand, Gerlagh and Zwaan (2001a) show that policy recommendations derived from OLG models can prove rather different from those resulting from conventional ILA models depending on various assumptions on demographic change and public institutions designed for the protection of the environment. To be exact, their model includes demographic change that represents increasing life expectancy[5], specifies environmental damages as a loss of an environmental amenity associated to an environmental resource and considers a transfer mechanism that distributes the value of this resource to consumers.

In the studies mentioned above, the world is described as a single region. However, in real life, the world is divided into a set of heterogenous countries each of whom can decide about its own environmental policy. As we have just mentioned, international cooperation to coordinate those environmental policies is crucial to tackle the global warming problem. To our knowledge, there is only one paper (John and Pecchenino 1997) where an international externality is analyzed taking into account explicitly the intergenerational dimension of such external effect. In John and Pecchenino's paper a successive generation model[6] is considered and it is assumed that each region's government can be either a long-lived or a short-lived government, depending on the time horizon the government

[4] An important issue of discussion in these models refers to the discount rate to be used. A description of the two major approaches used to determine the discount rate for climate change analysis can be found in IPCC (1995).

[5] It is modeled as a transition from a lifecycle of two periods to one of three periods.

[6] It is assumed that a new generation is born at each date t in each country and lives for one period.

uses to select its optimal policy. They conclude that, although transfers may be necessary to compensate the developing world, international agreements with transfers that lack an intergenerational perspective could actually harm the environment.

In this paper, we use the OLG model with climate-economy interactions described in Howarth (1998). Since we are interested in the international dimension of the problem, we have divided the world into two regions, which will be referred to as North and South. As in John and Pecchenino (1997), we consider that each region's government can be either a long-lived or a short-lived government. Distinguishing long–lived governments from short–lived governments makes it possible to study the effect of taking into account the intergenerational dimension of climate change in international agreements.

We assume that taxes are used to internalize all types of externalities and that both, short-lived and long-lived governments, are able to implement intergenerational transfers, which are chosen simultaneously with optimal taxes when the social welfare function is maximized. Besides, we consider the possibility that each region is willing to make unilateral monetary transfers[7] to the other region. The scenario where long-lived governments act cooperatively allows us to obtain the intertemporally and internationally efficient taxes on GHG emissions which are such that marginal cost of GHG emissions abatement is set equal to the discounted sum of every future benefit.

The main aim of the paper is to check whether international agreements with transfers that lack an intergenerational perspective could actually increase global GHG emissions with respect to the non–cooperative solution, as John and Pecchenino (1997) predicted in a theoretical setting. A priori, this result may occur in our model because when short-lived governments decide the transfers from North to South, they do not take into account the effects of these transfers on future generations. Given that the emission-output ratio is higher in the South and that transfers imply an increase in the production growth rate of the South in relation to the non–cooperative solution, cooperation with transfers could imply a level of GHG emissions higher than that of the non–cooperative solution.

Simulation exercises are used to compare numerically the evolution of economic and climate variables on the different scenarios considered. The calibration of the model is based on the scientific and technological assumptions of RICE (Nordhaus and Yang 1996) and the specific parameters for North and South regions have been taken from Yang (1999).

The paper is organized as follows. After this introduction, section 2 presents

[7] Germain, Toint and Tulkens (1997), Germain, Toint, Tulkens and Zeeuw (2003) and Eyckmans and Tulkens (2003) show how international transfers may be used to facilitate cooperation as they allow to compensate those countries which are worse off with the agreement. However, these studies do not consider an overlapping generations framework. Yang (1999) also analyzes the effects of unilateral transfers from North to South but in an environmental-economic optimal growth model. In contrast to Yang's paper, where government receiving the transfer must use it to purchase technology to reduce GHG emissions, we assume that the government receiving the monetary transfers uses them to make transfers to consumers.

the model. Section 3 describes the command optimum. Section 4 obtains the market equilibrium. Section 5 combines the results obtain in the previous two sections to show the required policy intervention in different institutional settings. The model is calibrated in section 6 and numerical results are contained in section 7.

2 The model

In our model of global climate-economy interactions the world is divided into two regions: North and South. Each region is assumed to produce a single commodity which can be used for either consumption or investment. Population growth and technological change are exogenous, whereas capital accumulation is determined through optimization of life-cycle saving by individuals. The model does not consider inter-regional trade in goods or capital nor inter-regional mobility of labor, but unilateral transfers of output between the North and the South (θ_t) are allowed.

The approach taken in the model views the economy in the simplest overlapping generations framework that assumes that each generation lives only for two periods. At each date $t = 0, 1, ..., T$ and in each region $i = North$, $South$ a new generation of n_t^i identical individuals is born who lives at dates t and $t+1$. Individuals of generation t will be young in t and old in $t+1$. A typical person born at date t in region i enjoys the consumption levels c_{yt}^i in youth and c_{ot+1}^iin old age. It is assumed that individuals do not get utility from leisure and so supply their unit of labor inelastically to the production sector at each stage of life, earning a real wage of w_t^i in youth and w_{t+1}^iin old age. Besides, each individual receives net income transfers π_{yt}^i and π_{ot+1}^i from the regional government at dates t and $t+1$[8].

Individual preferences are represented by an additive separable utility function defined over per capita consumption in youth and in old age:

$$u_t^i = u(c_{yt}^i) + \frac{1}{1+\rho^i} u(c_{ot+1}^i) \qquad \rho^i \geqq 0, u'(.) > 0, u''(.) < 0 \quad (1)$$

where ρ^i represents individuals' pure time preference in region i[9].

Agents are born with no assets and choose to end up with zero assets when they die. The aggregated saving of the young in region i at time t ($S_t^i \equiv n_t^i s_t^i$) generates the aggregated capital stock ($K_{t+1}^i \equiv n_t^i k_{t+1}^i$) that is used in region i at time $t+1$ to produce output in combination with the aggregated labor supply ($N_{t+1}^i \equiv n_{t+1}^i + n_t^i$) and the residual emissions of GHGs (E_{t+1}^i) in region i at time $t+1$. The investment in capital of the young in region i at time

[8] Regional governments use these intergenerational income transfers to release the revenues raised by a pigovian tax on greenhouse gas emissions and to achieve a desired distribution of welfare between generations.

[9] The higher is ρ^i the higher is the weight attached to increments of consumption in youth relative to increments of consumption in old age.

t (k^i_{t+1}) is rented out at an interest rate $r^i_{t+1}$to the production sector to help financing consumption in old age. Thus, the following equations represent a typical person's budget restrictions in region i:

$$c^i_{yt} + s^i_t = w^i_t + \pi^i_{yt} \tag{2}$$

$$c^i_{ot+1} = w^i_{t+1} + (1 + r^i_{t+1})k^i_{t+1} + \pi^i_{ot+1} \tag{3}$$

Production at time t in region i is organized by competitive firms that use constant returns technology:

$$Y^i_t = f^i_t(K^i_t, N^i_t, E^i_t, T_t) \tag{4}$$

We assume that $f^i_t(.)$ is increasing in capital (K^i_t), labor (N^i_t) and GHG emissions (E^i_t) and decreasing in the change of mean global temperature relative to the preindustrial norm (T_t). The time subscript on the production function allows for exogenous technological change.

The change of mean global temperature relative to the preindustrial norm (T_t) is a global public bad that will be determined by the time path of GHG emissions in the past:

$$T_t = T_t\left(\sum_i E^i_0, ..., \sum_i E^i_{t-1}\right) \tag{5}$$

Thus, current emissions will imply increased future environmental degradation and hence reduced future output. We will therefore assume that each regional government taxes GHG emissions at a rate v^i_t to account for their negative impact on production.

Before proceeding with the analysis we require explicit assumptions regarding governments' scope and distributional justice criteria. These are discussed in the next section.

3 The command optimum

3.1 Non–cooperative short–lived governments

We will first consider the case of short–lived regional governments (NCSL governments hereafter) that do not behave cooperatively. We will consider that the non cooperative situation is represented by the open loop Nash solution which implies that governments commit themselves to an optimal policy and cannot react to any deviations from that optimal policy. Therefore, NCSL government at time t in region i optimizes resource allocation and consumption decisions at time t in region i in order to maximize utility of those agents living at time t in region i and assuming that the government at time t in region j as well as governments at time $l > t$ in both regions will also follow the same strategy.

The non–cooperative nature of the government implies that pigovian taxes will be designed in order to yield a *within–regional* efficient allocation of resources. In other words, GHG emissions will be locally priced according to their marginal impact on the local economy and ignoring their marginal impact on the rest of the world economy. Note also that, as non–cooperative governments will *think regional* instead of *global*, no inter–regional transfers of output will take place ($\theta_t = 0$).

The short–lived nature of the government implies that pigovian taxes will be designed in such a way that they will only pursue an efficient allocation of resources from an intergenerationally limited perspective. This means that, when determining the optimal price of GHG emissions, all those effects that outlive the two generations represented by the government will be ignored.

As it has been mentioned in the previous section, the government uses net income transfers to release the revenues raised by the tax on GHG emissions and to achieve a desired distribution of welfare between generations. We assume that taxes and transfers are chosen to obey the balanced budget condition:

$$n_t^i \pi_{yt}^i + n_{t-1}^i \pi_{ot}^i = v_t^i E_t^i \tag{6}$$

The desired distribution of welfare between young people and old people will depend on social preferences, which are captured by the following social welfare function:

$$W_t^i = \frac{1}{1+\rho^i} u(c_{ot}^i) + \frac{1}{1+R^i} \left[u(c_{yt}^i) + \frac{1}{1+\rho^i} u(c_{ot+1}^i) \right] \tag{7}$$

where $\left[1+R^i\right]^{-1}$ represents the weight the government in region i attaches to the life–cycle utility of a typical young person relative to the life–cycle utility of a typical old person. The NCSL regional government's decisions are subject to individuals' budget constraints (equations (2) and (3)) and the following three constraints:

$$f_t(K_t^i, N_t^i, E_t^i, T_t) = n_t^i c_{yt}^i + n_{t-1}^i c_{ot}^i + K_{t+1}^i - K_t^i \tag{8}$$

$$f_{t+1}(K_{t+1}^i, N_{t+1}^i, E_{t+1}^i, T_{t+1}) = n_{t+1}^i c_{yt+1}^i + n_t^i c_{ot+1}^i + K_{t+2}^i - K_{t+1}^i \tag{9}$$

$$T_{t+1} = T_{t+1} \left(\sum_i E_0^i, ..., \sum_i E_t^i \right) \tag{10}$$

Equations (8) and (9) characterize consumption possibilities of the economy in region i at times t and $t+1$ respectively. Equation (10) establishes the impact of current emissions on future environmental quality.

At each point in time, t, the NCSL government maximizes (7) subject to different budget constraints. This maximization problem yields the conditions:

$$\frac{\left(1+R^i\right) n_t^i}{\left(1+\rho^i\right) n_{t-1}^i} = \frac{u^{'}(c_{yt}^i)}{u^{'}(c_{ot}^i)} \tag{11}$$

$$\frac{(1+\rho^i)u^{'}(c_{yt}^i)}{u^{'}(c_{ot+1}^i)} = \left(1 + \frac{\partial f_{t+1}^i}{\partial K_{t+1}^i}\right) \tag{12}$$

$$\frac{\partial f_t^i}{\partial E_t^i} = -\left(1 + \frac{\partial f_{t+1}^i}{\partial K_{t+1}^i}\right)^{-1} \frac{\partial f_{t+1}^i}{\partial T_{t+1}} \frac{\partial T_{t+1}}{\partial E_t^i} \tag{13}$$

Equation (11) establishes that aggregated consumption at each date must be distributed between individuals as to equate the marginal contribution of each generation's consumption to perceived social welfare. Equation (12) establishes that each individual's marginal rate of intertemporal substitution must be set equal to the gross return on capital investment. Equation (13) establishes that the marginal cost of GHG emission abatement must be set equal to the marginal present–value damage that current emissions impose locally in the next period.

3.2 Cooperative short–lived governments

Next we will consider the case of short–lived regional governments that do behave cooperatively (CSL governments hereafter). The CSL government at time t optimizes resource allocation and consumption decisions at time t in order to maximize aggregated utility of those agents living at time t in both regions and assuming that governments at time $l > t$ will also follow the same strategy.

The cooperative nature of the government implies that pigovian taxes will be designed in order to yield a *cross–regional* efficient allocation of resources. In other words, GHG emissions will be locally priced according to their marginal impact on the global economy. Note also that, as cooperative governments will *think global* we will relax the assumption that no inter–regional transfers of output will take place.

The short–lived nature of the government still implies that pigovian taxes will be designed in such a way that they will only pursue an efficient allocation of resources from an intergenerationally limited perspective. Thus, as in the previous scenario, when determining the optimal price of GHG emissions, all those effects that outlive the two generations represented by the short–lived governments will be ignored.

Having specified two types of transfers, intergenerational transfers and inter–regional transfers, we need to re–specify regional governments' balanced budget conditions. In what follows we will represent variables referring to the South with an asterisk to distinguish them from variables referring to the North. The balanced budget conditions of CSL governments are thus the following:

$$n_t \pi_{yt} + n_{t-1} \pi_{ot} = v_t E_t - \theta_t \tag{14}$$

$$n_t^* \pi_{yt}^* + n_{t-1}^* \pi_{ot}^* = v_t^* E_t^* + \theta_t \tag{15}$$

We assume that when θ_t is positive (negative), the South (North) uses net income transfers to release the revenues raised by both the tax on GHG emissions and the transfers received from the North (South) and the North (South) uses the revenues raised by the tax on GHG emissions to make transfers to individuals in its region and to make transfers to the South (North).

The desired distribution of welfare between young people and old people in both the North and the South will depend on social preferences agreed by the two cooperative governments. These social preferences will be captured by the following social welfare function:

$$\begin{aligned} W_t \quad = \quad & \alpha \left[\frac{1}{1+\rho} u(c_{ot}) + \frac{1}{1+R} \left[u(c_{yt}) + \frac{1}{1+\rho} u(c_{ot+1}) \right] \right] + \\ & + (1-\alpha) \left[\frac{1}{1+\rho^*} u(c_{ot}^*) + \frac{1}{1+R^*} \left[u(c_{yt}^*) + \frac{1}{1+\rho^*} u(c_{ot+1}^*) \right] \right] \end{aligned} \tag{16}$$

where α and $(1-\alpha)$ represent the weight attached to the local welfare of the North and the South, respectively.

At each point in time, t, CSL governments maximize (16) subject to different budget constraints. This maximization problem yields the conditions:

$$\frac{(1+R)\, n_t}{(1+\rho)\, n_{t-1}} = \frac{u^{'}(c_{yt})}{u^{'}(c_{ot})} \tag{17}$$

$$\frac{(1+R^*)\, n_t^*}{(1+\rho^*)\, n_{t-1}^*} = \frac{u^{'}(c_{yt}^*)}{u^{'}(c_{ot}^*)} \tag{18}$$

$$\frac{(1+\rho) u^{'}(c_{yt})}{u^{'}(c_{ot+1})} = \left(1 + \frac{\partial f_{t+1}}{\partial K_{t+1}} \right) \tag{19}$$

$$\frac{(1+\rho^*) u^{'}(c_{yt}^*)}{u^{'}(c_{ot+1}^*)} = \left(1 + \frac{\partial f_{t+1}^*}{\partial K_{t+1}^*} \right) \tag{20}$$

$$\frac{u'(c_{ot})}{u'(c^*_{ot})} = \frac{n_{t-1}(1-\alpha)(1+\rho)}{n^*_{t-1}\alpha(1+\rho^*)} \tag{21}$$

$$\frac{\partial f_{t+1}}{\partial K_{t+1}} = \frac{\partial f^*_{t+1}}{\partial K^*_{t+1}} \tag{22}$$

$$\frac{\partial f_t}{\partial E_t} = \frac{\partial f^*_t}{\partial E^*_t} = -\left(1 + \frac{\partial f_{t+1}}{\partial K_{t+1}}\right)^{-1} \left[\frac{\partial f_{t+1}}{\partial T_{t+1}} + \frac{\partial f^*_{t+1}}{\partial T_{t+1}}\right] \frac{\partial T_{t+1}}{\partial E_t} \tag{23}$$

Equations (17) and (18) establish that aggregated consumption in each region at each date must be distributed between individuals as to equate the marginal contribution of each generation's consumption to perceived social welfare. Equations (19) and (20) establish that in each region each individual's marginal rate of intertemporal substitution must be set equal to the gross return on capital investment. Equation (21) establishes that aggregate consumption in the world economy at each date must be distributed between individuals in different regions as to equate the marginal contribution of individuals of different regions to perceived social welfare. Equation (22) establishes that productive capital must be redistributed internationally as to equate the marginal productivity of capital across regions. Equation (23) establishes that the marginal cost of GHG emission abatement in each region must be set equal to the marginal present–value damages that current emissions impose globally in the next period.

3.3 Cooperative long–lived governments

Finally we will consider the case of long–lived regional governments that do behave cooperatively (CLL governments hereafter). The CLL government at time 0 in region i optimizes resource allocation and consumption decisions at time $t \in [0, T]$ in region i in order to maximize aggregated utility of those agents living at time $t \in [0, T]$ in both regions and assuming that the government in region $j \neq i$ will also follow the same strategy.

The cooperative nature of the government implies that pigovian taxes will be designed in order to yield a *cross–regional* efficient allocation of resources and that inter–regional transfer of output may take place.

The long–lived nature of the government still implies that pigovian taxes will be designed in such a way that they will pursue a fully efficient allocation of resources from an intergenerational perspective. When determining the optimal price of GHG emissions every future impact of emissions will be taken into account.

We assume that at each point in time the CLL governments face the same balanced budget conditions that were assumed for CSL governments. With regard to social preferences, these preferences will be captured by the following social welfare function:

$$W_0 = \alpha \left[\sum_{t=0}^{T} (1+R)^{-t-1} u(c_{yt}) + (1+\rho)^{-1} \sum_{t=0}^{T} (1+R)^{-t} u(c_{ot}) \right] + \quad (24)$$
$$(1-\alpha) \left[\sum_{t=0}^{T} (1+R^*)^{-t-1} u(c^*_{yt}) + (1+\rho^*)^{-1} \sum_{t=0}^{T} (1+R^*)^{-t} u(c^*_{ot}) \right]$$

At time 0, CLL governments maximize (24) subject to different budget constraints. This maximization problem yields the same first order conditions as those of the short–lived governments except for equation (23), that now it has to be re–written as:

$$\frac{\partial f_t}{\partial E_t} = \frac{\partial f^*_t}{\partial E^*_t} = -\sum_{h=t+1}^{T} \left(\prod_{l=t+1}^{s} \left(1 + \frac{\partial f_l}{\partial K_l}\right)^{-1} \right) \left[\frac{\partial f_h}{\partial T_h} + \frac{\partial f^*_h}{\partial T_h} \right] \frac{\partial T_h}{\partial E_t} \quad (25)$$

Equation (25) establishes that the marginal cost of GHG emission abatement in each region must be set equal to the present–value of future marginal damage that current emissions impose globally.

4 The market equilibrium

The previous section provided the social governments' solution to the optimal resource allocation problem. In this section we consider the decisions of consumers and firms.

The consumers' problem:

The representative consumer's optimization problem can be written as follows:

$$\max_{c^i_{yt}, c^i_{ot+1}} \quad u(c^i_{yt}) + \frac{1}{1+\rho^i} u(c^i_{ot+1}) \quad (26)$$

subject to the following budget constraints:

$$c^i_{yt} + s^i_t = w^i_t + \pi^i_{yt} \quad (27)$$

$$c^i_{ot+1} = w^i_{t+1} + (1 + r^i_{t+1}) s^i_t + \pi^i_{ot+1} \quad (28)$$

Solving the first order conditions gives us

$$\frac{1+r^i_{t+1}}{(1+\rho^i)} = \frac{u^{'}(c^i_{yt})}{u^{'}(c^i_{ot+1})} \tag{29}$$

The firms' problem:

The firms' optimization problem can be written as follows:

$$\max_{K^i_t, E^i_t} \quad f^i_t(K^i_t, N^i_t, E^i_t, T_t) - w^i_t N^i_t - r^i_t K^i_t - v^i_t E^i_t \tag{30}$$

The first order conditions will be:

$$\frac{\partial f^i_t}{\partial K^i_t} = r^i_t \tag{31}$$

$$\frac{\partial f^i_t}{\partial E^i_t} = v^i_t \tag{32}$$

>From the zero profit condition, we note that

$$\frac{f^i_t(K^i_t, N^i_t, E^i_{t,}, T_t) - r^i_t K^i_t - v^i_t E^i_t}{N^i_t} = w^i_t \tag{33}$$

The competitive equilibrium for this economy is completed with the goods market clearing condition that establishes that the capital stock at time $t+1$ is fully determined by saving decisions made at time t:

$$K^i_{t+1} = n^i_t s^i_t \tag{34}$$

5 GHG emission taxes and intergenerational transfers

In this section we combine the results obtained in sections 3 and 4 to show the required policy interventions in different institutional settings. After comparing the conditions obtained in the previous two sections, it is clear that the competitive equilibrium does not in general support an optimal distribution of welfare. Two types of interventions are required in order to achieve an optimal distribution of welfare. First, emissions must be properly priced (emission taxes). Second, income transfers (π^i_{yt} and π^i_{ot}) have to be selected with the intention of maximizing social welfare.

Emission taxes will vary depending on the international and intertemporal scope of the regulatory body. NCSL governments will choose emission taxes to equate the marginal present–value damage that current emissions impose locally in the next period:

$$v_t^i = -\left(1 + \frac{\partial f_{t+1}^i}{\partial K_{t+1}^i}\right)^{-1} \frac{\partial f_{t+1}^i}{\partial T_{t+1}} \frac{\partial T_{t+1}}{\partial E_t^i} \tag{35}$$

This will ensure the equivalence between equations (13) and (32). CSL governments will choose emission taxes to equate marginal cost of GHG emissions abatement and the marginal present value damage that current emissions impose globally on generation t when old:

$$v_t = v_t^* = -\left(1 + \frac{\partial f_{t+1}}{\partial K_{t+1}}\right)^{-1} \left[\frac{\partial f_{t+1}}{\partial T_{t+1}} + \frac{\partial f_{t+1}^*}{\partial T_{t+1}}\right] \frac{\partial T_{t+1}}{\partial E_t} \tag{36}$$

This will ensure the equivalence between equations (23) and (32). CLL governments will choose emission taxes to equate marginal cost of GHG emissions abatement and the marginal present–value future damage that current emissions impose in every region at any point in time:

$$v_t = v_t^* = -\sum_{h=t+1}^{T} \left(\prod_{l=t+1}^{s} \left(1 + \frac{\partial f_l}{\partial K_l}\right)^{-1}\right) \left[\frac{\partial f_h}{\partial T_h} + \frac{\partial f_h^*}{\partial T_h}\right] \frac{\partial T_h}{\partial E_t} \tag{37}$$

This will ensure the equivalence between equations (25) and (32).

6 Model calibration

To proceed with the analysis we must impose specific assumptions regarding the model's functional forms and parameter values. We calibrate the model based on the technical constraints of Yang's (1999) two region version of the RICE model developed by Nordhaus and Yang (1996). Both models simulate economy–environment interactions using an ILA framework. The main difference is that in Nordhaus and Yang's RICE model the global economy is divided into six regions, whereas in Yang's modified RICE model these six regions are merged into two regions: the North and the South. More precisely, in the modified RICE model the North represents the USA, Japan and the European Union, while the South includes the Former Soviet Union, China and the rest of the world in the original RICE model.

We take the year 2000 as the starting point for our analysis with an initial global population of 5.88921 billion people, with 0.77521 billion people living in the North and 5.114 living in the South. According to data taken from the U.S. Bureau of the Census (http://www.census.gov) people under the age of thirty–five account for some 50% in the North and 65% in the South. Based on these observations, the number of young people living at each date in each region can be parameterized in the following manner[10]:

$$n_{yt} = 0.42944 - 0.04183(0.21054)^t \tag{38}$$

$$n^*_{yt} = 4.29933 - 0.9752(0.68129)^t \tag{39}$$

Equation (38) implies an initial population growth rate of 0.3%/*year* in the North with convergence over the long run to a population of 0.8589 billion people. Equation (39) implies an initial population growth rate of 1.04%/*year* in the South with convergence over the long run to a population of 8.589 billion people. These patterns closely match the aggregate demographic assumptions contained in Yang's modified RICE model.

Following Yang, utility is logarithmic in consumption and we assume that in each region gross regional output (Y^i_t) is given by a Cobb–Douglas production function defined over capital (K^i_t) and labor (N^i_t):

$$Y^i_t = A^i_t K^{i0.25}_t N^{i0.75}_t$$

where A^i_t is an index of total factor productivity. The input–output elasticities are based on the assumption that wage income accounts for 75% of gross output in the global economy. Based on Yang's baseline model's estimates for the year 2000, the initial capital stock is set equal to 38.99 trillion dollars in the North and 15.32 trillion dollars in the South.

The level of GHG emissions that would arise in the absence of pollution abatement (E^i_{ot}), measured in billion tons of carbon–equivalent per period, are assumed to be linearly proportional to gross output:

$$E_{ot} = \left(0.0746 + 0.0708\,(0.4661)^t\right) Y_t \tag{40}$$

$$E^*_{ot} = \left(0.0893 + 0.4258\,(0.6484)^t\right) Y^*_t \tag{41}$$

Equation (40) implies that the emissions–output coefficient falls at an annual rate of 1.03% in the North in the year 2000, with convergence to a 49% reduction of the emissions–output coefficient in the long run. Equation (41) implies that the emissions–output coefficient falls at an annual rate of 1.14% in the South in the year 2000, with convergence to a 476% reduction of the emissions–output coefficient in the long run. These patterns of energy-saving technological change closely match the numerical content of the modified RICE model.

[10] Having assumed that each generation lives for two periods, each period should represent half of human life–span ($\simeq$ 35 years).

Total factor productivity in each region is determined by the interaction of three terms:

$$A_t = \left(1105.5 - 801.04(0.7748)^t\right)\left(1 - 0.01155\left(\frac{T_t}{2.5}\right)^{1.5}\right)\left(1 - 0.07\left(1 - \frac{E_t}{E_{ot}}\right)^{2.89}\right) \tag{42}$$

$$A_t^* = \left(758.118 - 711.1(0.8139)^t\right)\left(1 - 0.016\left(\frac{T_t}{2.5}\right)^{1.5}\right)\left(1 - 0.12\left(1 - \frac{E_t}{E_{ot}}\right)^{2.89}\right) \tag{43}$$

The first term in equation (42) implies an initial rate of exogenous technological progress of 1.38%$/year$ in the North. This rate falls steadily over time with a long–run productivity increase of 263% relative to the present. The first term in equation (43) implies an initial rate of exogenous technological progress of 3.19%$/year$ in the South. This rate falls steadily over time with a long–run productivity increase of 1507% relative to the present. The patterns of exogenous technological change closely match the numerical content of the modified RICE model.

Following the modified RICE model, our model assumes that climate–change damages increase with the square root of the cubic change in mean global temperature relative to the pre–industrial norm. A temperature increase of 2.5^oC causes a 1.155% reduction in gross output in the North and 1.6% reduction of gross output in the South. This effect is captured in the second term of equations (42) and (43). The third term in these equations measures the cost that GHG emissions abatement imposes on economic activity. It can easily be seen that reducing emissions in the South costs twice as much share of gross output as reducing emissions in the North.

With regard to the relationship between gross and net output, we keep the assumption that capital depreciates at 10%$/year$. This means that, over generational time spans, gross capital investment (I_t^i) will be represented using:

$$I_t^i = K_{t+1}^i - (1 - 0.1)^{35} K_t^i \tag{44}$$

The functional relationship between GHG emissions and environmental quality is the same that it is used by Howarth (1998) in his OLG model of economy–climate interactions:

$$T_t = \left(5.92 \ln\left(\frac{Q_t}{590}\right) + F_t\right)/1.41 \tag{45}$$

In equation (45) Q_t measures the effective stock of carbon dioxide and CFCs in the atmosphere (measured in billion tons of carbon–equivalent) and F_t

captures the radiative forcing caused by trace concentrations of methane, nitrous oxide and water vapor (measured in watts/m^2). This variable is exogenously determined according to a path Howarth approximates using:

$$F_t = 1.42 - 0.764(0.523)^t \tag{46}$$

The atmospheric stock of carbon dioxide and CFCs is governed by the following difference equation:

$$Q_{t+1} - 590 = 0.64 \left(\sum_i E_t^i \right) + (1 - 0.00833)^{35} (Q_t - 590) \tag{47}$$

Equation (47) implies that (1) 64% of GHG emissions remain in the atmosphere at the end of one period and (2) that, over the long run, the stock of GHGs in excess of the pre–industrial norm (590 billion tons of carbon–equivalent) is 'naturally' removed from the atmosphere at a rate of $0.833\%/year$. The initial GHG stock is set at the level reported by Howarth: 784 billion tons of carbon–equivalent.

Before presenting the results, it is necessary to address four final technical considerations concerning (1) the choice of the pure rates of time preference (ρ and ρ^*), (2) the choice of the international welfare weights (α), (3) the choice of the intergenerational discount rates (R and R^*) and (4) the choice of the time horizon T.

With regard to the pure rates of time preference, we have chosen them to equate the rates of capital accumulation in the NCSL scenario and the modified RICE model. This has led us to consider a pure rate of time preference of $0.5\%/year$ both in the North and in the South.

With regard to the international welfare weight attached to the North, we have considered several values (ranging from $\alpha = 0.2$ to $\alpha = 0.8$) in order to analyze how they affect to the cooperative solution. These different welfare weights may reflect different degrees of either bargaining power or interregional altruism of cooperative short lived governments.

With regard to intergenerational discount rates, for the sake of simplicity, we have decided to start assuming that it is institutionally infeasible to implement an intergenerational transfers scheme. This implies that, independently on the rate of intergenerational discount rate chosen by society in each region, governments will lack the necessary instruments to pursue the desired distribution of welfare between generations. Thus, not being able to re-allocate initial endowments, there will be a single "efficient" allocation of resources within each region. Intergenerational transfers will be considered in future development of the analysis.

Finally, with regard to the time horizon, computational difficulties have forced us to consider year 2490 ($T = 15$) as the final year in the analysis.

7 Preliminary results and conclusions

In this session we present the numerical results obtained using both GAMS and the solver routine of Excel. Figures 1a and 1b show how climate change and total emissions evolve under the CSL and NCSL scenarios[11]. The number in brackets represents the value of α.

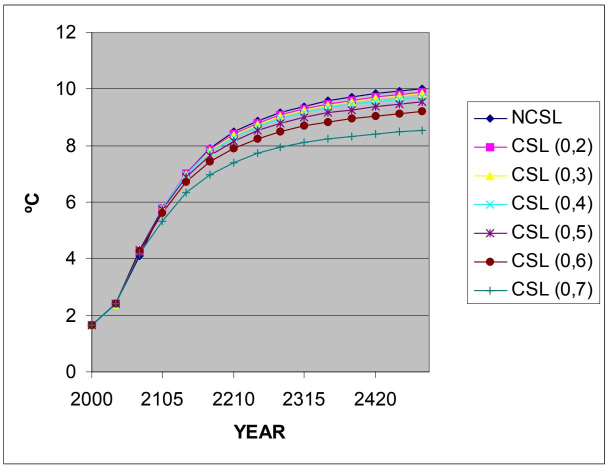

Figure 1a: Temperature Change

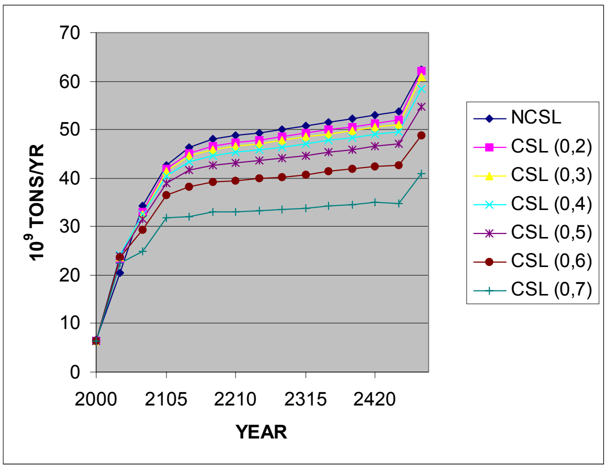

Figure 1b: GHG Emissions

[11] So far our analysis focuses on decisions by short-lived governments, since it is in the case of short-lived governments where we can expect cooperation to harm the environment.

Several preliminary results follow:

1. The NCSL scenario leads to higher environmental degradation in the long run than any CSL scenario.

2. The higher the welfare weight attached to the North under cooperation, the lower environmental degradation in the long run.

3. It may happen that some CSL scenarios lead to higher environmental degradation in the short-run than the NCSL scenario. In fact, this seems to be happening when the welfare weight attached to the North is 20%.

Result no 3 is in line with the cautionary note of John and Pecchenino (1997): "international agreements with transfers that lack an intergenerational perspective could actually harm the environment". This result is more clearly ilustrated in Figures 2a and 2b. The intuition behind our result is the following: When $\alpha = 0.2$, given that (1) international agreements capture that the South's social welfare has to be weighted four times as much as the social welfare of the North and (2) the North is initially richer than the South, there are important transfers of income from North to South. This implies that some growing potential is transferred from North to South. These transfers imply an increase in total emissions of GHGs, due to the fact that the South produces using a technology that it is less environmentally friendly.

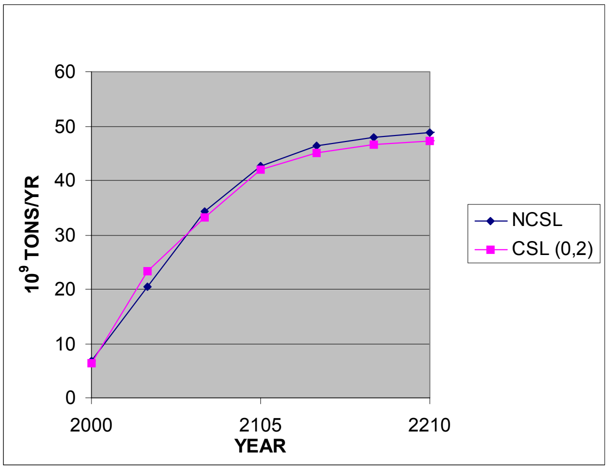

Figure 2a: GHG Emissions in the Short Run

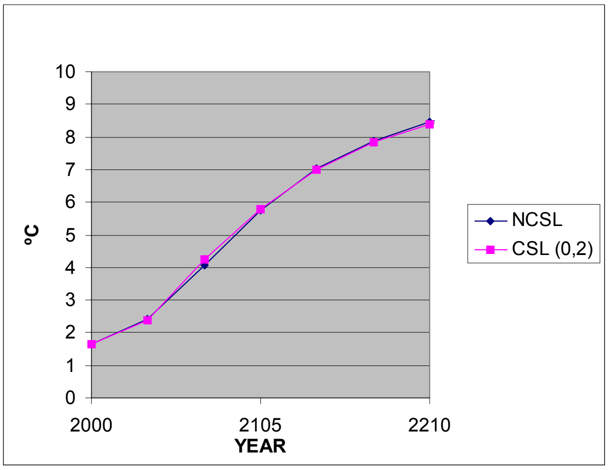

Figure 2b: Temperature Change in the Short Run

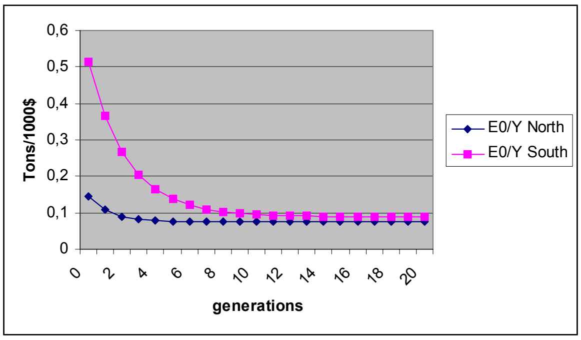

Figure 3: Energy-saving technological change

Thus, the exogenous nature of energy-saving technological change is an important driving force behind our result (see Figure 3). Energy-saving technological change cannot be estimulated with growth. Consequently, accelerating the growth in the South may result in greater environmental degradation unless it is accompanied with higher abatement effort. The incentives to implement higher abatement effort are clearly weakened by the short-lived nature of the government.

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