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Stéphane Lambrecht

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The effects of a demographic shock in an OLG economy with pay-as-you-go pensions and property rights on the environment: the case of selfish households*

Stéphane Lambrecht†

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Abstract

We first analyze an economy in which there are no institutions to carry out environmental policy. We refer to this economy as the business-as-usual (BAU) economy. In the long run, a negative demographic shock increases the households' welfare through higher environmental quality, while lifetime consumptions are unchanged. On the transition, a negative demographic shock permanently and monotonically increases the environmental quality. It sets the individual lifetime income, and thus consumptions, on an inverted-U path. This process is only temporary since long run consumptions remain unchanged. In a second step we introduce property rights on the environment. We assume the existence of a fund which is responsible of selling to the firms the property rights of the households each period. We study the effects of a demographic shock in this economy with property rights. In the long run, a negative demographic shock increases the households' welfare through higher lifetime consumptions while environmental quality is unchanged. On the transition, environmental quality remains unchanged while capital intensity first falls below the pre-shock level and then increase untill it reaches the higher post-shock level.

Keywords: OLG models, environmental quality

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†Center for Operations Reasearch and Econometrics (CORE), Université Catholique de Louvain, Belgium; e-mail: lambrecht@core.ucl.ac.be

1 Introduction

The use of permits in the design of environmental policies has recently received a great deal of attention in economic research. Most of the time economists are interested in disentangling the interplay between growth and policies aiming at reducing pollution and in designing policies to re-establish economic optimality (se e.g. Jouvet,Michel and Rotillon (2005), Lambrecht (2005) and Ono (2002)). To enhance the knowledge of the ins and outs of permits-based or property rights-based environmental policies, investigations should also be oriented towards the re-assessment of the effects of non-environmental shocks or policies.

The motivation of this paper is the following: What are the effects on the agents' welfare of a change in the population size, when a fixed volume of property rigths on the environment is issued each period to stabilize emissions. More precisely, how do these effects compare with those observed in an economy without environmental policy, a business-as-usual (BAU) economy? It is shown that a negative demographic shock positively affects the individuals' welfare in both the BAU economy and the one with property rights, but in distinctive fashions: through the rise of environmental quality in the BAU economy, through the rise of income and consumptions in the economy with property rights.

In the literature, Gerlagh and van der Zwaan (2001) and Ono and Maeda (2001) are two papers dealig with the question of population size variations in economies with environmental policies. In an overlapping generations (OLG) model, Gerlagh and van der Zwaan (2001) stress the importance of demographic changes and environmental policies for the evolution of interest rates in the long run. The design of public institutions, namely grandfathering versus a trust fund, has significant effects on the interest rate and thus on the efficient greenhouse gas emissions reduction. Ono and Maeda (2001) use an OLG model with uncertain lifetimes and show that if the relative risk aversion with respect to consumption in old age is low enough ageing has a positive effect on environmental quality.

In this paper, we also look at the implications for capital accumulation and environmental quality of a demographic change. We model an OLG economy with an environmental externality and a constant population. We study the effects of a unique and once-and-for-all decrease in the population size in two alternative cases: (i) the BAU economy and (ii) the economy with property rights.

The paper is organized as follows. Section 2 describes the evolution of environmental quality across time. Section 3 studies the BAU economy , starting with the analysis of the equilibrium and then the assessment of the short and long run effects of a negative demographic shock. Section 4 introduces environmental policy through the issue, each period, of property rights on the environment and compares the effects of the demographic shock under this hypothesis with the conclusions in the BAU economy. Section 5 concludes.

2 Greenhouse gas concentrations and environmental quality

We consider a competitive economy with overlapping generations. Time is discrete : $t = 0, 1, 2, ... + \infty$ and agents have perfect foresight. The population size is constant at the level N. We rule out the study of the behavior of labor supply by assuming that individuals inelastically supply one unit of labor on the labor market.

The activity of firms results in emissions of greenhouse gas (GHG) which accumulate in the atmosphere and are responsible of global climate change. Although carbon dioxyde is the most often considered GHG, there are many other types of GHG with different temporal behaviour. The concentrations of these GHG in the atmosphere is modelled here as a single stock $M_t > 0$. The equation which governs the evolution of the GHG concentrations M_t is the following:

$$M_{t+1} = (1 - \delta_M) M_t + \varepsilon E_t \tag{1}$$

The first term of the right-hand side of this equation tells that the current concentrations stock M_t survives in the next period but only up to a fraction $1 - \delta_M$. Thus the parameter δ_M is a factor of natural decay. Alternatively, δ_M may be interpreted as the rate at which the climate system renews itself across time. The parameter ε in the second term is the rate at which firms' emissions E_t increase the concentrations of the next period M_{t+1}.

According to this equation, if GHG emissions are equal to zero each period, the GHG concentrations tend to zero. This particular steady state corresponds to the case in which the atmosphere is perfectly pure. On the other hand, the stock of GHG concentrations may be arbitrarily large, even if temporarily. We are interested only in the range of GHG concentrations which are compatible with human life. This restricts the set of values which M_t can take. We shall assume that there exists a threshold level of GHG concentrations $\bar{Q}$ beyond which human life and, hence, the economy disappear.

In this paper, we shall use the notion of environmental quality Q_t which is linked to GHG concentrations M_t in the following way. The environmental quality Q_t is defined as the difference between the threshold concentration $\bar{Q}$ and the pollutant stock at time t, M_t :

$$Q_t = \bar{Q} - M_t \tag{2}$$

Therefore the threshold $\bar{Q}$ can also be interpreted as the highest attainable environmental quality.

From the equation of the stock of GHG concentrations, one derives the equation which governs the evolution of the environmental quality (multiplying both sides by -1, then adding $(1-\delta_M)\,\bar{Q}$ to both sides of the M_t stock equation):

$$Q_{t+1} = (1-\delta_M)\,Q_t + \delta_M \bar{Q} - \varepsilon E_t \tag{3}$$

In the absence of emissions, the environmental quality equation is simply: $Q_{t+1} = (1-\delta_M)\,Q_t + \delta_M \bar{Q}$ and the steady state without emissions is simply: $Q = \bar{Q}$. When emissions are positive and stationary (E), the steady state is given by: $Q = \bar{Q} - (\varepsilon/\delta_M)\,E$.

3 The business-as-usual economy

We now turn to the description of the economy. We first analyze an economy in which there are no institutions to carry out environmental policy. We refer to this economy as the business-as-usual (BAU) economy. In a second step we shall introduce policy instruments like property rights on the environment.

3.1 The BAU equilibrium

In the BAU economy, there is a representative firm which produces one consumption/investment good according to the following constant returns to scale technology:

$$Y_t = \widetilde{A} K_t^{\alpha} L_t^{1-\alpha} z_t \tag{4}$$

where $\widetilde{A} > 0$ is an index of productivity, $K_t \geq 0$ and $L_t \geq 0$ are capital and labour at time t and $z_t \in (0,1)$ is the intensity of pollution. We assume $0 < \alpha < 1$. Production generates environmentally harmful emissions

$$E_t = Y_t z_t^{\theta} \tag{5}$$

with $\theta > 0$. Alternatively, the intensity of pollution may be written as a function of the ratio between emissions and output:

$$z_t = \left(\frac{E_t}{\tilde{A} K_t^{\alpha} L_t^{1-\alpha}} \right)^{1/(1+\theta)} \tag{6}$$

Pollution is maximum in the absence of policy. This corresponds to the case for which $z_t = 1$ and implies: $E_t = \tilde{A} K_t^{\alpha} L_t^{1-\alpha}$.

We assume that capital is entirely used in the production process. The representative firm is a price taker and maximizes its real profit, which is defined by

$$\pi_t = \tilde{A} K_t^{\alpha} L_t^{1-\alpha} - w_t L_t - R_t K_t \tag{7}$$

The variables L_t and K_t are respectively labour and capital demands and w_t and R_t the real wage rate and interest factor, i.e. one plus the interest rate r_t. The first-order conditions, which characterize the representative firm's factor demands, are the usual relations equating each factor marginal productivity with its prices: $w_t = (1-\alpha)\tilde{A} k_t^{\alpha}$ and $R_t = \alpha \tilde{A} k_t^{a-1}$, where $k_t = K_t/L_t$ is the capital-labor ratio.

In the BAU economy, households supply inelastically one unit of labour to the firm for a real wage rate w_t, pay a contribution τ_t to a pay-as-you-go pension system; this contribution is a fraction $\overline{\tau}$ of their wage income. Net wage income is allocated to consumption c_t and savings s_t. When old they receive capital income $R_{t+1}s_t$, where R_{t+1} is the interest factor, and a pension θ_{t+1}. Since they are selfish, they entirely consume this old-age income. This is summarized in the youth and old-age budget constraint:

$$(1-\overline{\tau}) w_t = c_t + s_t \tag{8}$$

$$R_{t+1} s_t + \theta_{t+1} = d_{t+1} \tag{9}$$

Households derive utility from youth and old-age consumptions, c_t and d_{t+1} and from environmental quality Q_{t+1}. Let their utility be loglinear:

$$u_t = (1-\beta)\log c_t + \beta \log d_{t+1} + \chi \log Q_{t+1} \tag{10}$$

where $\beta \in (0,1)$ is the weight on old-age consumption, and χ the weight put on environmental quality. Households maximize their utility under their budget constraints (8) – (9), taking prices as given. Their optimal consumption plans are simple fractions of the lifetime income Ω_t: $c_t = (1-\beta)\Omega_t$ and $d_{t+1} = \beta R_{t+1}\Omega_t$, with

$$\Omega_t = (1-\overline{\tau}) w_t + \frac{\theta_{t+1}}{R_{t+1}} \tag{11}$$

These optimal consumptions are achieved through the following optimal savings:

$$s_t = \beta (1-\overline{\tau}) w_t - (1-\beta)\frac{\theta_{t+1}}{R_{t+1}} \tag{12}$$

In equilibrium, the labour market clears: $L_t = N$. Savings of the young at time $t-1$, invested in capital, constitutes the current period capital stock: $Ns_{t-1} = K_t$. Equilibrium wage and interest factor are functions of capital intensity: $w^{bau}(k_t) \equiv (1-\alpha)\tilde{A}k_t^{\alpha}$ and $R^{bau}(k_t) \equiv \alpha \tilde{A} k_t^{\alpha-1}$, where k_t is the capital per head K_t/N. Emissions are equal to output. The pay-as-you-go pension system collects the amount $N\tau_t = N\overline{\tau}(1-\alpha)\tilde{A}k_t^{\alpha}$ of contributions and redistribute them to the contemporaneous old $N\theta_t$. Hence the level of pensions is given by $\theta_t = \overline{\tau}(1-\alpha)\tilde{A}k_t^{\alpha}$. The dynamics of capital intensity and environmental quality are given by:

$$k_{t+1} = \frac{(1-\overline{\tau})\beta(1-\alpha)}{1+(1-\beta)\overline{\tau}\dfrac{1-\alpha}{\alpha}}\tilde{A}k_t^{\alpha} \tag{13}$$

$$Q_{t+1} = (1-\delta_M) Q_t + \delta_M \bar{Q} - \varepsilon N \tilde{A} k_t^{\alpha} \tag{14}$$

where (i) the first equation is obtained by replacing, in $k_{t+1} = s_t$, savings s_t by its expression with equilibirum prices and pension and (ii) the second equation is obtained by replacing emissions by their equilibrium expression in the environmental quality equation (3). A steady state of the BAU economy is a pair (k^{bau}, Q^{bau}) with $k^{bau} > 0$ and $Q^{bau} > 0$, which solves: $k^{bau} = (1-\alpha)\tilde{A}(k^{bau})^{\alpha}$ and $Q^{bau} = (1-\delta_M)Q^{bau} + \delta_M\bar{Q} - \varepsilon N\tilde{A}(k^{bau})^{\alpha}$. Here are the expressions of capital per head, pensions, lifetime income, output per head, aggregate output and environmental quality at the BAU steady state equilibrium:

$$
(15) \quad \left|
\begin{array}{l}
k^{bau} = \left[\dfrac{(1-\overline{\tau})\,\beta\,(1-\alpha)}{1+(1-\beta)\,\overline{\tau}\dfrac{1-\alpha}{\alpha}} \tilde{A} \right]^{1/(1-\alpha)} \\
\theta^{bau} = \overline{\tau}\,(1-\alpha)\,\widetilde{A}\left(k^{bau}\right)^{\alpha} \\
\Omega^{bau} = (1-\overline{\tau})\,(1-\alpha)\,\widetilde{A}\left(k^{bau}\right)^{\alpha} + \overline{\tau}\dfrac{1-\alpha}{\alpha} k^{bau} \\
y^{bau} = \widetilde{A}\left(k^{bau}\right)^{\alpha} \\
Y^{bau} = N\widetilde{A}\left(k^{bau}\right)^{\alpha} \\
Q^{bau} = \bar{Q} - \dfrac{\varepsilon}{\delta_M} N\tilde{A}\left(k^{bau}\right)^{\alpha}
\end{array}
\right.
$$

3.2 A demographic shock in the BAU economy

Suppose that we are initially ($t=0$) at the steady state equilibrium in the BAU economy: $k_0 = k^{bau}$. The ratio of the number of old households (N) over the number of young households (N) is equal to 1. At time $t=1$, the size of the young generation is lower than the size of the old generation. Hence in that period the structure of the population is as follows: N old households and δN young households, with $\delta \in (0,1)$ and the time $t=1$ ratio of the number of old over the number of young is $1/\delta$. In subsequent periods, the population size remains constant at δN young households appearing each period and the old to young ratio is again equal to 1. We first look at the long run impact of the demographic shock and then turn to the analysis of the transition.

3.2.1 The long run impact

It is fairly easy to look at the post-shock steady state equilibrium. The households' utility depends on both wealth, measured by their lifetime income, and environmental quality.

Proposition 1 *In the long run, a negative demographic shock increases the households' welfare through higher environmental quality, while lifetime consumptions are unchanged (Proof in appendix 1).*

After the demographic shock, the steady state equilibrium intensity is the same as before: $\tilde{k} = k^{bau}$. Long run capital per head remains unchanged. Thus all individual variables like pensions or lifetime income and consumptions are unchanged. The combination of an unchanged capital intensity with the fall in the population size implies some variations in aggregate variables, especially a lower aggregate capital stock. Environmental quality is positively affected since emissions are equal aggregate output which is equal to the unchanged intensive output $\widetilde{A}\left(k^{bau}\right)^{\alpha}$ times the reduced number of young households δN. This is summarized as follows:

$$
(16) \quad \left|
\begin{array}{l}
\tilde{k} = k^{bau} \\
\tilde{\theta} = \theta^{bau} \\
\tilde{\Omega} = \Omega^{bau} \\
\tilde{y} = y^{bau} \\
\tilde{Y} = \delta N\tilde{y} < N y^{bau} = Y^{bau} \\
\tilde{Q} = \bar{Q} - \dfrac{\varepsilon}{\delta_M}\delta N\tilde{A}\left(\tilde{k}\right)^{\alpha} > \bar{Q} - \dfrac{\varepsilon}{\delta_M} N\tilde{A}\left(k^{bau}\right)^{\alpha} = Q^{bau}
\end{array}
\right.
$$

As a consequence, even without conducting any environmental policy of pollution abatement, environmental quality increases because of a fall in production. This is simply the consequence of a reduced availability of labor.

3.2.2 The transitional impacts

It is easy to analyze the transitional impacts.

Proposition 2 *On the transition, a negative demographic shock permanently and monotonically increases the environmental quality. It temporarily sets the individual lifetime income, and thus consumptions, on an inverted-U path. This process is only temporary since long run consumptions remain unchanged (Proof in appendix 2).*

Whether or not the time $t = 1$ shock is anticipated by the time $t = 0$ young households, the transition equation at time $t = 0$ has the same solution: $\tilde{K}_1 = K_1$. This is because the present value of pensions is unchanged. Indeed, there are less young households to finance the elderly's pensions (the share of wages taxed to finance pensions is $\delta\overline{\tau}$ instead of $\overline{\tau}$) but the present value of the period 1 wages is higher than before because of the increase in the capital intensity $\tilde{K}_1/\delta N$. These two opposite effects cancel out. So the period 1 aggregate capital stock is unaffected by the future demographic shock: $\tilde{K}_1 = K_0 = K^{bau}$.

In period 1, the unchanged capital stock $\tilde{K}_1$ is nonetheless divided by a lower young population. The time $t = 1$ capital intensity $\tilde{k}_1$ is thus higher then the initial one k^{bau}. This increase in the capital per head implies a higher wage but the saving out of this wage is lower than the time $t = 1$ capital intensity because $\tilde{k}_1$ lies below the 45° line. Thus the economy sets to a decreasing path and goes back to its initial position. The transition is summarized in the following:

$$\left| \begin{array}{l} \tilde{k}_1 = \frac{K_1}{\delta N} > \frac{K_1}{N} = k^{bau}, \text{ with } K_1 = K^{bau}; \\ \tilde{k}_2 < \tilde{k}_1;\ \tilde{k}_3 < \tilde{k}_2 \end{array} \right. \tag{17}$$

$$\left| \begin{array}{l} \tilde{\theta}_1 = \delta\overline{\tau}\left(1-\alpha\right)\tilde{A}\tilde{k}_1^{\alpha} < \theta^{bau} \text{ (because of decreasing returns to scale)} \\ \tilde{\theta}_2 = \overline{\tau}\left(1-\alpha\right)\tilde{A}\tilde{k}_2^{\alpha} \in \left(\theta^{bau}, \tilde{\theta}_1\right) \end{array} \right. \tag{18}$$

$$\left| \begin{array}{l} \tilde{\Omega}_0 = \left(1-\overline{\tau}\right)\left(1-\alpha\right)\tilde{A}\left(k^{bau}\right)^{\alpha} + \frac{\delta\overline{\tau}(1-\alpha)}{\alpha}\frac{K_1}{\delta N} = \Omega^{bau} \\ \tilde{\Omega}_1 = \left(1-\overline{\tau}\right)\left(1-\alpha\right)\tilde{A}\tilde{k}_1^{\alpha} + \frac{\overline{\tau}(1-\alpha)}{\alpha}\tilde{k}_2 > \tilde{\Omega}_0 \\ \tilde{\Omega}_2 = \left(1-\overline{\tau}\right)\left(1-\alpha\right)\tilde{A}\tilde{k}_2^{\alpha} + \frac{\overline{\tau}(1-\alpha)}{\alpha}\tilde{k}_3 \in \left(\tilde{\Omega}_0, \tilde{\Omega}_1\right), \ldots \end{array} \right. \tag{19}$$

$$\left| \begin{array}{l} \tilde{y}_1 = \tilde{A}\tilde{k}_1^{\alpha} > y^{bau} \\ \tilde{y}_2 = \tilde{A}\tilde{k}_2^{\alpha} \in \left(y^{bau}, \tilde{y}_1\right), \ldots \end{array} \right. \tag{20}$$

$$\left| \begin{array}{l} \tilde{Y}_1 = \delta N\tilde{A}\tilde{k}_1^{\alpha} < N\tilde{A}\left(k^{bau}\right)^{\alpha} = Y^{bau} \\ \tilde{Y}_2 = \delta N\tilde{A}\tilde{k}_2^{\alpha} < \delta N\tilde{A}\tilde{k}_1^{\alpha} = \tilde{Y}_1 \end{array} \right. \tag{21}$$

$$\left| \begin{array}{l} \tilde{Q}_1 = \left(1-\delta_M\right)Q_0 + \delta_M\overline{Q} - \varepsilon Y^{bau} = Q_0 = Q^{bau} \\ \tilde{Q}_2 = \left(1-\delta_M\right)\tilde{Q}_1 + \delta_M\overline{Q} - \varepsilon\tilde{Y}_1 > \tilde{Q}_1 \\ \tilde{Q}_3 = \left(1-\delta_M\right)\tilde{Q}_2 + \delta_M\overline{Q} - \varepsilon\tilde{Y}_2 > \tilde{Q}_2, \ldots \end{array} \right. \tag{22}$$

4 The economy with property rights on the environment

We now introduce property rights on the environment. We first study the equilibrium and then turn to the analysis of the impact of a demographic shock.

4.1 The equilibrium with property rights

The property rights are used to implement an emissions ceiling $\bar{E}$ to which the government is committed from an international agreement. This ceiling is lower than the BAU steady state level: $\bar{E} < E^{bau} = N\tilde{A}\left(k^{bau}\right)^{\alpha}$. We introduce a fund which sells the global volume of rights $\bar{E}$ to the firms and recycles its revenues to the households. The setting of the global volume of rights affects the households' budget constraints and thus their behavior and it also affects the firms' behavior. We first describe the activity of the fund, then we describe what changes in households' and firms opportunities and behavior.

4.1.1 The fund's activity

We assume the existence of a fund which is responsible of selling to the firms the property rights of the households each period. It sells the global volume of rights $\bar{E}$ to the firms at the price q_t and recycle the revenue, $q_t\bar{E}$, to the households, young and old, in an egalitarian way. Since in any time period the population is $2N$ each individual receives the following quantities:

$$\bar{\varepsilon}_t = \bar{\varepsilon} = \frac{\bar{E}}{2N}, \forall t \tag{23}$$

The total share owned by the young is $\bar{E}^Y = N\bar{\varepsilon}$. It is equal to the total share owned by the old $\bar{E}^O$. The fund's budget constraint writes:

$$q_t\bar{E} = 2q_t N\bar{\varepsilon} \tag{24}$$

4.1.2 The households' behavior

With respect to the BAU economy, the households' budget constraints are modified. In addition to net wage income, $(1-\overline{\tau})\,w_t$, young households receive the income from the rights supplied to the firms by the fund. The price of one unit of rights is q_t. When old, they also get the income from the supply of their rights by the fund at time $t+1$ in addition to their capital income. This is summarized by the following budget constraint

$$(1-\overline{\tau})\,w_t + q_t\bar{\varepsilon} = c_t + s_t \tag{25}$$

$$R_{t+1}s_t + \theta_{t+1} + q_{t+1}\bar{\varepsilon} = d_{t+1} \tag{26}$$

The lifetime income now reads:

$$\Omega_t = (1-\overline{\tau})\,w_t + q_t\bar{\varepsilon} + \frac{\theta_{t+1} + q_{t+1}\bar{\varepsilon}}{R_{t+1}} \tag{27}$$

The households' savings is given by:

$$s_t = \beta\left[(1-\overline{\tau})\,w_t + q_t\bar{\varepsilon}\right] - (1-\beta)\,\frac{\theta_{t+1} + q_{t+1}\bar{\varepsilon}}{R_{t+1}} \tag{28}$$

4.1.3 The firms' behavior

Firms are obliged to pay for any unit of emissions. Since there is no heterogeneity among firms, all firms will demand the same amount of rights at the price q_t. Let E_t be the demand for rights expressed by the representative firm. We need to re-write the production function in order to let appear the three production factors, capital, labour and emissions. Eliminating z_t from the production function, one gets

$$Y_t = AK_t^{\alpha_K}L_t^{\alpha_L}E_t^{\alpha_E} \tag{29}$$

with $A = \tilde{A}^{\theta/(1+\theta)}$, $\alpha_K = \alpha\theta/\left(1+\theta\right)$, $\alpha_L = (1-\alpha)\,\theta/\left(1+\theta\right)$ and $\alpha_E = 1/\left(1+\theta\right)$. Note that $\alpha_K + \alpha_L + \alpha_E = 1$. The share of capital and labour in production are reduced with respect to the BAU case: $\alpha_K < \alpha$ and $\alpha_L < 1-\alpha$. The firm's profit is then :

$$\pi_t = AK_t^{\alpha_K}L_t^{\alpha_L}E_t^{\alpha_E} - R_tK_t - w_tL_t - q_tE_t \tag{30}$$

The maximization of profit implies : $R_t = \alpha_K A k_t^{\alpha_K-1}e_t^{\alpha_E}$, $w_t = \alpha_L A k_t^{\alpha_K}e_t^{\alpha_E}$ and $q_t = \alpha_E A k_t^{\alpha_K}e_t^{\alpha_E-1}$ with $k_t = K_t/L_t$ and $e_t = E_t/L_t$.

4.1.4 The equilibrium

In equilibrium, as in the BAU economy, labor and capital markets clear, which imply, respectively, $N = L_t$ and $Ns_{t-1} = K_t$. Moreover the market of rights must be balanced:

$$E_t = \bar{E} \tag{31}$$

Thus equilibrium prices can be written as functions of the capital per young person, $k_t = K_t/N$, and of the constant ratio of emissions per young persons $\bar{e} = \bar{E}/N$, which are generally referred to as capital or emissions "per head", but actually are per head of young individual: $R(k_t, \bar{e}) \equiv \alpha_K A k_t^{\alpha_K - 1} \bar{e}^{\alpha_E}, w(k_t, \bar{e}) \equiv \alpha_L A k_t^{\alpha_K} \bar{e}^{\alpha_E}$ and $q(k_t, \bar{e}) \equiv \alpha_E A k_t^{\alpha_K} \bar{e}^{\alpha_E - 1}$, with $k_t = K_t/N$ and $\bar{e} = \bar{E}/N$. At last, the level of pensions is given by: $\theta_t = \overline{\tau} \alpha_L A k_t^{\alpha_K} \bar{e}^{\alpha_E}$. and the fund's budget is balanced:

$$\alpha_E A k_t^{\alpha_K} \bar{e}^{\alpha_E - 1} \bar{E} = \alpha_E A k_t^{\alpha_K} \bar{e}^{\alpha_E - 1} 2N\bar{\varepsilon} \tag{32}$$

Note that the emissions per head are equal to twice the individual endowments in rights

$$\bar{e} = \frac{\bar{E}}{N} = 2\bar{\varepsilon} \equiv 2\left(\frac{\bar{E}}{2N}\right) \tag{33}$$

The transition equation of capital intensity and environmental quality are given by:

$$k_{t+1} = \frac{\beta\left((1-\overline{\tau})\alpha_L + \frac{\alpha_E}{2}\right)}{\left(1 + (1-\beta)\frac{\overline{\tau}\alpha_L + \frac{\alpha_E}{2}}{\alpha_K}\right)} A k_t^{\alpha_K} \bar{e}^{\alpha_E} \tag{34}$$

$$Q_{t+1} = (1-\delta_M) Q_t + \delta_M \bar{Q} - \varepsilon \bar{E} \tag{35}$$

A unique steady state equilibrium clearly exists. It is given by:

$$\left| \begin{array}{l} k = \left[\frac{\beta\left((1-\overline{\tau})\alpha_L + \frac{\alpha_E}{2}\right)}{\left(1+(1-\beta)\frac{\overline{\tau}\alpha_L + \frac{\alpha_E}{2}}{\alpha_K}\right)} A\bar{e}^{\alpha_E} \right]^{\frac{1}{1-\alpha_K}} \\ \theta = \overline{\tau}\alpha_L A k^{\alpha_K} \bar{e}^{\alpha_E} \\ \Omega = (1-\overline{\tau})\alpha_L A k^{\alpha_K} \bar{e}^{\alpha_E} + \frac{\overline{\tau}\alpha_L + \frac{\alpha_E}{2}}{\alpha_K} k \\ y = A k^{\alpha_K} \bar{e}^{\alpha_E} \\ Y = N A k^{\alpha_K} \bar{e}^{\alpha_E} \\ Q = \bar{Q} - \frac{\varepsilon}{\delta_M} \bar{E} \end{array} \right. \tag{36}$$

4.2 A demographic shock in the economy with property rights

We assume that we start at time $t = 0$ at a steady state equilibrium of the economy with property rights. At time $t = 1$, the size of the new generation is δN, with $\delta \in (0, 1)$.

4.2.1 The long run impact

The impact of the demographic shock in the economy with property rights on the environment displays some differences with respect to the BAU economy.

Proposition 3 *In the long run of the economy with property rights on the environement, a negative demographic shock increases the households' welfare through higher lifetime consumptions while environmental quality is unchanged (Proof in appendix 3).*

The contrast with the BAU economy is thus clear. Individual welfare also increase but not out of higher environmental quality. It increases because households are wealthier. In the presence of a fixed emission ceiling, implemented by selling property rights and redistributing the proceeds to the households, the negative demographic shock makes the individual share of the fixed production factor larger. Individual variables like the level of pensions, the lifetime income and output per head increase.

Corollary 4 *In the long run of the economy with property rights on the environement, a negative demographic shock increases output per head but decreases aggregate output. (Proof in appendix 4)*

Let us summarize by the following

$$(37)\qquad \left|\begin{array}{l} \hat{k} > k \\ \hat{\theta} = \overline{\tau}\alpha_L A\hat{k}^{\alpha_K}\left(\dfrac{\bar{e}}{\delta}\right)^{\alpha_E} > \theta = \overline{\tau}\alpha_L A k^{\alpha_K}\bar{e}^{\alpha_E} \\ \hat{\Omega} > \Omega \\ \hat{y} = A\hat{k}^{\alpha_K}\left(\frac{\bar{e}}{\delta}\right)^{\alpha_E} > y = Ak^{\alpha_K}\bar{e}^{\alpha_E} \\ \hat{Y} < Y \\ \hat{Q} = Q \end{array}\right.$$

4.2.2 The transitional impacts

The effects of the demographic shock on the transition are given by the following proposition:

Proposition 5 *On the transition of the economy with property rights on the environement, a negative demographic shock leaves environmental quality unchanged, decreases the immediate capital intensity and then sets the economy on an increasing path towards the new higher steady state equilibrium $\hat{k}$.(Proof in appendix 5)*

The reason why period 0 households immediately react by reducing their capital accumulation is because they expect an increase in their lifetime income, out of a higher present value of pensions and income from property rights when old. This effect is however temporary. In subsequent periods, no shock is expected. But the increased ratio of emissions per head of young households remains and acts as a positive shock on income per head and thus on the willingness to save.

5 Conclusions

We have first analyzed an economy in which there are no institutions to carry out environmental policy (BAU economy). In the long run, a negative demographic shock increases the households' welfare through higher environmental quality, while lifetime consumptions are unchanged. On the transition, the shock permanently and monotonically increases the environmental quality. Individual lifetime income, and thus consumptions, follow an inverted-U path until they are back to their pre-shock level. We then introduced property rights on the environment and assumed the existence of a fund which is responsible of selling to the firms the property rights of the households each period. The effects of a demographic shock in this economy with property rights are the following. In the long run, a reduction in the population size increases the households' welfare through higher lifetime consumptions while environmental quality is unchanged. On the transition, environmental quality remains unchanged while capital intensity first falls below the pre-shock level and then increase untill it reaches the higher post-shock level.

6 Appendices

1. Proof of Proposition 1

The equation which governs the new steady state equilibrium is the following:

$$(38)\qquad \tilde{K} = \delta N \tilde{s}$$

$$(39)\qquad \frac{\tilde{K}}{\delta N} = \beta\left(1-\overline{\tau}\right)\left(1-\alpha\right)\tilde{A}\left(\frac{\tilde{K}}{\delta N}\right)^{\alpha} - \left(1-\beta\right)\frac{\overline{\tau}\left(1-\alpha\right)}{\alpha}\frac{\tilde{K}}{\delta N}$$

It is identical to the pre-shock equation. This implies that the post-shock steady state is $\tilde{k} = \tilde{K}/\delta N$ is the same as the pre-shock steady state $k^{bau} = K^{bau}/N$; so individual lifetime income and thus consumptions are unchanged. Output per capita is unchanged: $\tilde{A}\tilde{k}^{\alpha} = \tilde{A}\left(k^{bau}\right)^{\alpha}$ but aggregate output is lower: $\delta N\tilde{A}\tilde{k}^{\alpha} < N\tilde{A}\left(k^{bau}\right)^{\alpha}$ which implies lower emissions since in the BAU economy $\tilde{E} = \tilde{Y}$. QED.

2. Proof of proposition 2

If the shock had not appeared (or if it were not anticipated), the time $t = 1$ capital stock would have verified:

$$K_1 = Ns_0 \Leftrightarrow \frac{K_1}{N} = \beta(1-\overline{\tau})(1-\alpha)\widetilde{A}\left(\frac{K_0}{N}\right)^{\alpha} - (1-\beta)\overline{\tau}\frac{1-\alpha}{\alpha}\frac{K_1}{N} \tag{40}$$

What changes at time $t = 0$ if the shock is anticipated by the time $t = 0$ young households? The transition equation would read as follows:

$$\tilde{K}_1 = N\tilde{s}_0 \Leftrightarrow \frac{\tilde{K}_1}{\delta N} = \frac{N}{\delta N}\tilde{s}_0 \tag{41}$$

$$\Leftrightarrow \frac{\tilde{K}_1}{\delta N} = \frac{\beta}{\delta}(1-\overline{\tau})(1-\alpha)\widetilde{A}\left(\frac{K_0}{N}\right)^{\alpha} - \frac{1-\beta}{\delta}\delta\overline{\tau}\frac{(1-\alpha)}{\alpha}\frac{\tilde{K}_1}{\delta N} \tag{42}$$

$$\Leftrightarrow \frac{\tilde{K}_1}{N} = \beta(1-\overline{\tau})(1-\alpha)\widetilde{A}\left(\frac{K_0}{N}\right)^{\alpha} - (1-\beta)\overline{\tau}\frac{1-\alpha}{\alpha}\frac{\tilde{K}_1}{N} \tag{43}$$

The aggregate capital stock $\tilde{K}_1$, solution to this equation, is the same as the one above: $\tilde{K}_1 = K_1$. But when divided by the period 1 number of young households, δN, a higher capital intensity appears: $\tilde{k}_1 = K_1/\delta N > K_1/N = k_1$. So the transition equation in period 0 is unchanged but the period 1 capital intensity $\tilde{k}_1$ goes up. Since the starting capital intensity was a steady state and the transition equation is unchanged, the capital intensity $\tilde{k}_1$ lies below the 45° line. When the shock appears in $t = 1$, the transition equation is unchanged and given by:

$$\tilde{K}_2 = \delta N\tilde{s}_1 \Leftrightarrow \frac{\tilde{K}_2}{\delta N} = \beta(1-\overline{\tau})(1-\alpha)\widetilde{A}\left(\frac{\tilde{K}_1}{\delta N}\right)^{\alpha} - (1-\beta)\overline{\tau}\frac{1-\alpha}{\alpha}\frac{\tilde{K}_2}{\delta N} \tag{44}$$

$$\Leftrightarrow \frac{\tilde{K}_2}{\delta N} = \frac{\beta(1-\overline{\tau})(1-\alpha)}{1+(1-\beta)\overline{\tau}\frac{1-\alpha}{\alpha}}\widetilde{A}\left(\frac{\tilde{K}_1}{\delta N}\right)^{\alpha} \tag{45}$$

and the capital intensity goes back to the pre-shock value. QED.

3. Proof of proposition 3

Before the shock, the long run capital stock satisfy:

$$k = \left[\frac{\beta\left((1-\overline{\tau})\alpha_L + \frac{\alpha_E}{2}\right)}{\left(1+(1-\beta)\frac{\overline{\tau}\alpha_L+\frac{\alpha_E}{2}}{\alpha_K}\right)}A\bar{e}^{\alpha_E}\right]^{\frac{1}{1-\alpha_K}} \tag{46}$$

After the shock, the long run capital stock must satisfy:

$$\hat{K} = \delta N\hat{s} \Leftrightarrow \frac{\hat{K}}{\delta N} = \beta\left[(1-\overline{\tau})\alpha_L + \frac{\alpha_E}{2}\right]A\left(\frac{\hat{K}}{\delta N}\right)^{\alpha_K}\left(\frac{\bar{E}}{\delta N}\right)^{\alpha_E} - (1-\beta)\frac{\overline{\tau}\alpha_L + \frac{\alpha_E}{2}}{\alpha_K}\frac{\hat{K}}{\delta N} \tag{47}$$

$$\Leftrightarrow \hat{k} = \beta\left[(1-\overline{\tau})\alpha_L + \frac{\alpha_E}{2}\right]A\hat{k}^{\alpha_K}\left(\frac{\bar{e}}{\delta}\right)^{\alpha_E} - (1-\beta)\frac{\overline{\tau}\alpha_L + \frac{\alpha_E}{2}}{\alpha_K}\hat{k} \tag{48}$$

$$\Leftrightarrow \hat{k} = \left[\frac{\beta\left((1-\overline{\tau})\alpha_L + \frac{\alpha_E}{2}\right)}{\left(1+(1-\beta)\frac{\overline{\tau}\alpha_L+\frac{\alpha_E}{2}}{\alpha_K}\right)}A\left(\frac{\bar{e}}{\delta}\right)^{\alpha_E}\right]^{\frac{1}{1-\alpha_K}} \tag{49}$$

So $\hat{k} > k$ since $\hat{k} > k \Leftrightarrow (1/\delta) > 1$. As a result, the lifetime income $\hat{Q}$ is higher:

$$\hat{\Omega} = \left[(1 - \overline{\tau}) \alpha_L + \frac{\alpha_E}{2} \right] A \hat{k}^{\alpha_K} \left(\frac{\bar{e}}{\delta} \right)^{\alpha_E} + \frac{\overline{\tau} \alpha_L + \frac{\alpha_E}{2}}{\alpha_K} \hat{k} > \Omega \tag{50}$$

and thus lifetime consumptions are also higher. Environmental quality is unchanged because the level of emissions is unchanged

$$\hat{Q} = \bar{Q} - \frac{\varepsilon}{\delta_M} \bar{E} = \overline{Q} \tag{51}$$

QED.

4. Proof of corollary 4

Output per head $A\hat{k}^{\alpha_K}$ is simply higher than before because $\hat{k} > k$. As far as aggregate output is concerned:

$$\hat{Y} = \delta N A \hat{k}^{\alpha_K} \left(\frac{\bar{e}}{\delta} \right)^{\alpha_E} < N A k^{\alpha_K} \bar{e}^{\alpha_E} = Y \tag{52}$$

$$\delta^{1-\alpha_E} < \left(\frac{k}{\hat{k}} \right)^{\alpha_K} \tag{53}$$

$$\delta^{1-\alpha_E} < \frac{1}{\left(\frac{1}{\delta} \right)^{\frac{\alpha_E \alpha_K}{1-\alpha_K}}} \Leftrightarrow \delta^{1-\alpha_E} < \delta^{\frac{\alpha_E \alpha_K}{1-\alpha_K}} \Leftrightarrow \delta^{\frac{(1-\alpha_E)(1-\alpha_K) - \alpha_E \alpha_K}{1-\alpha_K}} < 1 \tag{54}$$

$$\delta^{\frac{1-\alpha_K-\alpha_E+\alpha_E\alpha_K-\alpha_E\alpha_K}{1-\alpha_K}} < 1 \Leftrightarrow \delta^{\frac{1-\alpha_K-\alpha_E}{1-\alpha_K}} < 1 \Leftrightarrow \delta^{\frac{\alpha_L}{1-\alpha_K}} < 1 \Leftrightarrow \delta^{\frac{\alpha_L}{\alpha_L+\alpha_E}} < 1 \tag{55}$$

Always true, so we have $\hat{Y} < Y$. QED.

4. Proof of proposition 5

- Until time $t = 0$ the transition equation reads as follows:

$$K_{t+1} = N s_t \tag{56}$$

$$\frac{K_{t+1}}{N} = \beta \left[(1 - \overline{\tau}) \alpha_L + \frac{\alpha_E}{2} \right] A \left(\frac{K_t}{N} \right)^{\alpha_K} \left(\frac{\bar{E}}{N} \right)^{\alpha_E} - (1 - \beta) \frac{\overline{\tau} \alpha_L + \dfrac{\alpha_E}{2}}{\alpha_K} \frac{K_{t+1}}{N} \tag{57}$$

$$\frac{K_{t+1}}{N} = \frac{\beta \left[(1 - \overline{\tau}) \alpha_L + \dfrac{\alpha_E}{2} \right]}{\left[1 + (1 - \beta) \dfrac{\overline{\tau} \alpha_L + \dfrac{\alpha_E}{2}}{\alpha_K} \right]} A \left(\frac{K_t}{N} \right)^{\alpha_K} \left(\frac{\bar{E}}{N} \right)^{\alpha_E} \tag{58}$$

- At time $t = 0$, if the young households perfectly anticipate the negative shock at time $t = 1$, the transition equation reads as follows:

$$\hat{K}_1 = N \hat{s}_0 \tag{59}$$

$$\frac{\hat{K}_1}{\delta N} = \frac{N}{\delta N} \hat{s}_0 \tag{60}$$

$$\frac{\hat{K}_1}{\delta N} = \frac{\beta}{\delta} \left[(1 - \overline{\tau}) \alpha_L + \frac{\alpha_E}{2} \right] A \left(\frac{K_0}{N} \right)^{\alpha_K} \left(\frac{\bar{E}}{N} \right)^{\alpha_E} - \frac{(1 - \beta)}{\delta} \frac{\delta \overline{\tau} \alpha_L + \dfrac{\alpha_E}{2}}{\alpha_K} \frac{\hat{K}_1}{\delta N} \tag{61}$$

$$\frac{\hat{K}_1}{N}\left[1+\frac{(1-\beta)}{\delta}\frac{\delta\bar{\tau}\alpha_L+\frac{\alpha_E}{2}}{\alpha_K}\right]=\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]A\left(\frac{K_0}{N}\right)^{\alpha_K}\left(\frac{\bar{E}}{N}\right)^{\alpha_E} \tag{62}$$

$$\frac{\hat{K}_1}{N}\left[1+(1-\beta)\,\frac{\bar{\tau}\alpha_L+\frac{\alpha_E}{2\delta}}{\alpha_K}\right]=\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]A\left(\frac{K_0}{N}\right)^{\alpha_K}\left(\frac{\bar{E}}{N}\right)^{\alpha_E} \tag{63}$$

$$\frac{\hat{K}_1}{N}=\frac{\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]}{\left[1+(1-\beta)\,\frac{\bar{\tau}\alpha_L+\frac{\alpha_E}{2\delta}}{\alpha_K}\right]}A\left(\frac{K_0}{N}\right)^{\alpha_K}\left(\frac{\bar{E}}{N}\right)^{\alpha_E} \tag{64}$$

It follows that $\hat{K}_1/N < K_1/N = K_0/N$.

- At time $t=1$, the transition reads as follows:

$$\hat{K}_2=\delta N\hat{s}_1 \tag{65}$$

$$\frac{\hat{K}_2}{\delta N}=\hat{s}_1 \tag{66}$$

$$\frac{\hat{K}_2}{\delta N}=\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]A\left(\frac{\hat{K}_1}{\delta N}\right)^{\alpha_K}\left(\frac{\bar{E}}{\delta N}\right)^{\alpha_E}-(1-\beta)\,\frac{\bar{\tau}\alpha_L+\frac{\alpha_E}{2}}{\alpha_K}\frac{\hat{K}_2}{\delta N} \tag{67}$$

$$\frac{\hat{K}_2}{\delta N}=\frac{\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]}{\left[1+(1-\beta)\,\frac{\bar{\tau}\alpha_L+\frac{\alpha_E}{2}}{\alpha_K}\right]}A\left(\frac{\hat{K}_1}{\delta N}\right)^{\alpha_K}\left(\frac{\bar{E}}{\delta N}\right)^{\alpha_E} \tag{68}$$

To be compared with the transition equation without shock

$$\frac{K_1}{N}=\frac{\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]}{\left[1+(1-\beta)\,\frac{\bar{\tau}\alpha_L+\frac{\alpha_E}{2}}{\alpha_K}\right]}A\left(\frac{K_0}{N}\right)^{\alpha_K}\left(\frac{\bar{E}}{N}\right)^{\alpha_E} \tag{69}$$

One can easily see that, in the aggregate output $A\left(\hat{K}_1/\delta N\right)^{\alpha_K}\left(\bar{E}/\delta N\right)^{\alpha_E}$, $\bar{E}/\delta N > \bar{E}/N$. As far as $\hat{K}_1/\delta N$ is concerned, we must know that $K_0/N > \hat{K}_1/N$ and that $\hat{K}_1/\delta N > \hat{K}_1/N$ but we do not know whether $\hat{K}_1/\delta N > K_0/N$. Since $K_0 = K_1$, we have:

$$\frac{1}{\delta}\frac{\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]}{\left[1+(1-\beta)\,\frac{\bar{\tau}\alpha_L+\frac{\alpha_E}{2\delta}}{\alpha_K}\right]}A\left(\frac{K_0}{N}\right)^{\alpha_K}\left(\frac{\bar{E}}{N}\right)^{\alpha_E} > \tag{70}$$

$$\frac{\beta\left[(1-\bar{\tau})\,\alpha_L+\frac{\alpha_E}{2}\right]}{\left[1+(1-\beta)\,\frac{\bar{\tau}\alpha_L+\frac{\alpha_E}{2}}{\alpha_K}\right]}A\left(\frac{K_0}{N}\right)^{\alpha_K}\left(\frac{\bar{E}}{N}\right)^{\alpha_E} \tag{71}$$

$$\Leftrightarrow \frac{1}{\delta} > \frac{1+(1-\beta)\dfrac{\bar{\tau}\alpha_L + \dfrac{\alpha_E}{2\delta}}{\alpha_K}}{1+(1-\beta)\dfrac{\bar{\tau}\alpha_L + \dfrac{\alpha_E}{2}}{\alpha_K}} \tag{72}$$

$$\Leftrightarrow \frac{1}{\delta} > \frac{2\delta\alpha_K + (1-\beta)\,2\delta\bar{\tau}\alpha_L + (1-\beta)\,\alpha_E}{\delta\left[2\alpha_K + (1-\beta)\,2\bar{\tau}\alpha_L + (1-\beta)\,\alpha_E\right]} \tag{73}$$

$$\Leftrightarrow 2\alpha_K + (1-\beta)\,2\bar{\tau}\alpha_L + (1-\beta)\,\alpha_E > 2\delta\alpha_K + (1-\beta)\,2\delta\bar{\tau}\alpha_L + (1-\beta)\,\alpha_E \tag{74}$$

$$\Leftrightarrow \alpha_K + (1-\beta)\,\bar{\tau}\alpha_L > \delta\alpha_K + (1-\beta)\,\delta\bar{\tau}\alpha_L \tag{75}$$

$$\Leftrightarrow (1-\delta)\,\alpha_K + (1-\delta)\,(1-\beta)\,\bar{\tau}\alpha_L > 0 \tag{76}$$

$$\Leftrightarrow \alpha_K + (1-\beta)\,\bar{\tau}\alpha_L > 0 \tag{77}$$

which is always true. Thus $\hat{K}_1/\delta N > K_0/N$. So the ranking between K_0/N, $\hat{K}_1/N$ and $\hat{K}_1/\delta N$ is the following: $\hat{K}_1/N < K_0/N < \hat{K}_1/\delta N$.

- As a result, $\hat{K}_2/\delta N$ is unambiguously larger than K_1/N and the economy then follows the path determined by the equation

$$\frac{\hat{K}_{t+1}}{\delta N} = \frac{\beta\left[(1-\bar{\tau})\,\alpha_L + \dfrac{\alpha_E}{2}\right]}{\left[1+(1-\beta)\dfrac{\bar{\tau}\alpha_L + \dfrac{\alpha_E}{2}}{\alpha_K}\right]} A\left(\frac{\hat{K}_t}{\delta N}\right)^{\alpha_K}\left(\frac{\bar{E}}{\delta N}\right)^{\alpha_E} \tag{78}$$

and converges to the higher steady state capital stock per head $\hat{K}/\delta N$.

7 References

1. Gerlagh, R. and B. van der Zwaan, (2001): "The effects of ageing and an environmental trust fund in an overlapping generations model on carbon emission reductions", *Ecological economics*, 36 , 311-326.

2. Jouvet, P.-A., Ph. Michel and G. Rotillon (2004). "Optimal growth with pollution : how to use pollution permits ?", *Journal of Economic Dynamics and Control*, forthcoming.

3. Lambrecht, S. (2005). "Maintaining environmental quality for overlapping generations", revised version of *CLIMNEG Working Paper n° 59*, 2004

4. Ono, T. (2002), "The effects of emission permits on growth and the environment", *Environmental and Resource Economics* 21, 75-87.

5. Ono T. and Y. Maeda (2001). " Is aging harmful for the environment ?", *Environmental and Resource Economics*, 20 (2).

Environmental Economics & Management Memoranda

30. Stephane LAMBRECHT. The effects of a demographic shock in an OLG economy with pay-as-you-go pensions and property rights on the environment: the case of selfish households. January 2005.

29. Stephane LAMBRECHT. Maintaining environmental quality for overlapping generations: Some Reflections on the US Sky Trust Initiative. May 2005.

28. Thierry BRECHET, Benoît LUSSIS. The contribution of the Clean Development Mechanism to national climate policies. April 2005.

27. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intergenerational transfers of pollution rights and growth. May 2005.

26. Maryse LABRIET, Richard LOULOU. From non-cooperative CO_2 abatement strategies to the optimal world cooperation: Results from the integrated MARKAL model. April 2005.

25. Marc GERMAIN, Vincent VAN STEENBERGHE, Alphonse MAGNUS. Optimal Policy with Tradable and Bankable Pollution Permits : Taking the Market Microstructure into Account.*Journal of Public Economy Theory*, 6(5), 2004, 737-757.

24. Marc GERMAIN, Stefano LOVO, Vincent VAN STEENBEGHE. De l'impact de la microstructure d'un marché de permis de polluer sur la politique environnementale. *Annales d'Economie et de Statistique*, n° 74 – 2004, 177-208..

23. Marc GERMAIN, Alphonse MAGNUS, Vincent VAN STEENBERGHE. Should developing countries participate in the Clean Development Mechanism under the Kyoto Protocol ? The low-hanging fruits and baseline issues. December 2004.

22. Thierry BRECHET et Paul-Marie BOULANGER. Le Mécanisme pour un Développement Propre, ou comment faire d'une pierre deux coups. *Regards Economiques*, Ires n° 27, janvier 2005.

21. Sergio CURRARINI & Henry TULKENS. Stable international agreements on transfrontier pollution with ratification constraints. In C. Carrarro and V. Fragnelli (eds.), *Game Practice and the Environment*. Cheltenham, Edward Elgar Publishing, 2004, 9-36. (also available as CORE Reprint 1715).

20. Agustin PEREZ-BARAHONA & Benteng ZOU. A comparative study of energy saving technical progress in a vintage capital model. December 2004.

19. Agustin PEREZ-BARAHONA & Benteng ZOU. Energy saving technological progress in a vintage capital model. December 2004.

18. Matthieu GLACHANT. Voluntary agreements under endogenous legislative threats and imperfect enforcement. November 2004.

17. Thierry BRECHET, Stéphane LAMBRECHT. Puzzling over sustainability: an equilibrium analysis. November 2004.

16. Vincent VAN STEENBERGHE. Core-stable and equitable allocations of greenhouse gas emission permits.. October 2004. (also available as CORE DP 2004/75)

15. Pierre-André JOUVET Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending. A political economy approach. September 2004. (also available as CORE DP 2004/68.)

14. Thierry BRECHET, Marc GERMAIN, Vincent VAN STEENBERGHE. The clean development mechanism under the Kyoto protocol and the 'low-hanging fruits' issue. July 2004. (also available as CORE DP 2004/81).

13. Thierry BRECHET, Philippe MICHEL. Environmental performance and equilibrium. July 2004. (also available as CORE DP 2004/72).

12. Luisito BERTINELLI, Eric STROBL. The Environmental Kuznets Curve semi-parametrically revisited. July 2004. (also available as CORE DP 2004/51).

11. Axel GOSSERIES, Vincent VAN STEENBERGHE. Pourquoi des marchés de permis de polluer ? Les enjeux économiques et éthiques de Kyoto. April 2004. (also available as IRES discussion paper n° 2004-21).

10. Vincent VAN STEENBERGHE. CO_2 Abatement costs and permits price : Exploring the impact of banking and the role of future commitments. December 2003. (also available as CORE DP 2003/98).

9. Katheline SCHUBERT. Eléments sur l'actualisation et l'environnement. March 2004.

Environmental Economics & Management Memoranda

8. Marc GERMAIN. Modélisations de marchés de permis de pollution. July 2003.
7. Marc GERMAIN. Le Mécanisme de Développement Propre : Impacts du principe d'additionalité et du choix de la baseline. January 2003.
6. Thierry BRECHET et Marc GERMAIN. Les affres de la modélisation. May 2002.
5. Marc GERMAIN and Vincent VAN STEENBERGHE. Constraining equitable allocations of tradable CO_2 emission quotas by acceptability, *Environmental and Resource Economics*, (26) 3, 2003.
4. Marc GERMAIN, Philippe TOINT, Henry TULKENS and Aart DE ZEEUW. Transfers to sustain dynamic core-theoretic cooperation in international stock pollutant control, *Journal of Economic Dynamics & Control*, (28) 1, 2003.
3. Thierry BRECHET, Marc GERMAIN et Philippe MONTFORT. Spécialisation internationale et partage de la charge en matière de réduction de la pollution. (also available as IRES discussion paper n°2003-19).
2. Olivier GODARD. Le risque climatique planétaire et la question de l'équité internationale dans l'attribution de quotas d'émission échangeable. May 2003.
1. Thierry BRECHET. Entreprise et environnement : des défis complémentaires ? March 2002.

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Chair Lhoist Berghmans in Environmental Economics and Management
Center for Operations Research & Econometrics (CORE)
Université catholique de Louvain (UCL)
Voie du Roman Pays 34
B-1348 Louvain-la-Neuve, Belgium

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