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Air Pollution, Tradable Emission Permits, Environmental Maintenance and Theoretical Overlapping Generations General Equilibrium Model

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Abstract: This paper presents within the framework of an Overlaping Generation (OLG) model, how Envinronmental as production factor an other linked-assumptions can be introduced step by step in a theoretical general equilibrium model. Indeed, in the first part, there is no environmental policy in the presence of externality associated with pollution. Then, when an environmental policy is decided and introduced by the Public Authority into the economy through a System of Tradable Emission Permits (STEP), we assume a three factors or '3-dimensions' OLG General Equilibrium model : Capital – Labor – Environment (Where private ownership of Environment through property rights or emission permits are treated as a production Factor). However, the stydy of tradable emission permits characteristics showed that this instrument of environmental policy can also be considered as a financial (an investment) asset for households.

Key words: Tradable Emission permits, Environmental Maintenance, Pollution, Overlapping Generations Model, General Equilibrium, Intergenerational Equity, Environmental Debt.

JEL Classification: D62, D91, Q50, C68.

Introduction

During the last 10 years Kyoto (1997) and Bali (2007) international concern about climate change has been growing more and more. This has brought about the possibility of quantitative restrictions as a means of combating climate warming. One such restriction is the introduction of tradable emission permits, this makes possible the definition of cleanliness limits for the environment. In effect, taking into account external factors, economic theory has proposed them as a way of internalising and/or achieving the social optimum in a market economy, (Coase, (1960)), if they were not already in existence.

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Since the Kyoto Protocol (1997) the majority of industrialised countries have agreed to reduce Greenhouse Gas (GHG) emissions by about 5% between 2008-2012, using 1990 as the reference date. The European Union (EU) – so France – has decided to apply these restrictions to the sectors of activity defined in the Annexe to the Kyoto Protocol: Energy (refineries, fossil fuel), metallurgical plants, mineral industries (cement, glassworks, ceramic plants) and paper pulp raising the level to 8%.

Concerning the method used, as emphasised by Jouvet et al. (2002), the advantage of an emission permit system comes from the fact that it operates ex-ante on the environment and allows a quantity to be fixed leaving the price to adjust itself. So the permit gives a wide flexibility in terms of the adaptation and changes in the structure of the market or changes in the macroeconomic environment.

The question of economic/environmental policies aimed at combating GHG producing climate warming has been the object of a particularly growing attention in the last few years. The application of these policies using permits to pollute by means of a '*pollution permit market poses a certain number of difficulties (...) about the initial allocation of the permits, (...) about the macroeconomic consequences'* (Jouvet et al. (2002), p.64,). In addition due to the long term effects of GHG, as emphasised by Rasmussen (2003), *'environmental policies are considered as a very long time frame, which naturally raise the question of intergenerational equity'*. Taking into account the intergenerational dimension, the environmental policies imply the use of means adapted so that the theoretical models and/or application of general equilibrium to overlapping generations in order to evaluate the long term macroeconomic impacts of the introduction of permits to pollute introduced into an economy.

For all that overlapping generation models (OLG) constitute an analytical framework allowing an alternative mode of representation for the agents characterised by the realities of the cycle of life. A theoretical framework which describes dynamic growth models and studies the distribution of intergenerational revenue. As outlined by Shilling (1965) *'using Infinite Life Agent model with environmental problems, involves a fallacy of composition on the intergenerational fairness. Consequently, abatement policies should be seen in the context of decisions involving intergeneration redistribution rather than inter-temporal saving.'*

On the contrary to the framework of infinitely long lived representative agents (Ramsey (1928)) maximising an inter-temporal utility, it no longer disregards – in the theoretical/analytical framework – demographic realities which have the essential marks of a life cycle. Alternatively, from this, we can think of a representative individual with a finite longevity, in a coherent framework and indispensable to the optimisation dynamics over a discrete time span.

As outlined by Bréchet et al (2005), '*the existence of environmental externalities legitimate such as environmental policy'*. Many workers have been interested in the instruments of internalisation of externalities showing intergenerational characteristics, see: Jouvet et al (2006), Lambrecht (2005), Jouvet et al (2002), Grimaud (1999). Stockey (1998), Ono (1996), John et al (1994). In Jouvet et al (2006) pollution is regulated by a system of tradable emission permits under political constraints and the authors develop an analytical framework in which the problem of the compatibility of the instrument with the first order optimum is present and they establish the conditions for optimality. Jouvet et al (2002) consider the question of the effects of the introduction of tradable emission permits principally angled on the variation of the number of permits against the accumulation of long term capital.

Ono (1996) and John et al (1994) implement environmental policies by applying financial controls on the polluting production activities on the one hand and de-pollution subsidies on the other. Ono (2002), Grimaud (1999) and Stockey (1998) introduce pollution permits in order to obtain an optimum allocation of capital and the protection of the environment. However they do not consider the effects in the variation in the number of permits on the growth of capital reserves or on the quality of the environment. Lambrecht (2005) like Ono (2002) considers that the initial introduction of a permit system would be through sales to companies. Lambrecht (2005) shows how the introduction of a permit system could generate capital accumulation compared to a laissez-faire equilibrium. Both authors an environmental protection policy based on investment in the operation of environmental maintenance, financed by young model households.

These reference models reflect a treatment of generally recognised externalities using a specific instrument. Whilst our work is in the same sense of their objective which is the combat against environmental pollution, we differ by coupling a fiscal system and an emission permit. The source of financing from the taxation system is different from the ones used in the previously cited models. Our approach is based principally on that of Jouvet et al (2002) and Jouvet et al (2006) concerning the instrument of environmental policy as well as the methodology of the resolution about the steady state. As Ono (2002) and Lambrecht (2005) we then tackle the question of environmental maintenance. However our approach differs from these authors by the origin of the source of financing of the environmental fiscal system.

Jouvet et al propose in their theoretical approach that the permit appears as a private charge on the environment. Following Beltrati (1996), they imagine that this instrument will have a market value, perhaps assimilated into a financial asset, so the financing must be in consequence be made in order to achieve an economic equilibrium. They underline this as follows,*'It is moreover the main idea of Beltrati (1996) which imagines that pollution permits serve as support to savings and are used as financial asset by consumer-producers that permits the use of the environment in a domestic production process.'*

We follow this reasoning and our suppositions are similar Jouvet et al (2002) and Musa et al (1995) that private household ensure environmental cleanliness and that pollution permits represent a private charge; the difference compared to Jouvet et al

(2002) is that it is the young households which acquire the environmental cleanliness charges. Enterprises using the environment as a supplementary factor in their specific production activity.

With the aim of making an exploratory study of the effects of the introduction of a tradable emission permit system on the above basis as well as the investment process and environmental maintenance, this paper proposes a theoretical model of overlapping generation agents with the particularity that it allows us to consider an aspect of intergenerational equity based on *the ideas of environmental debt and international solidarity.* In addition this permits the inclusion in the theoretical framework adopted, the question of international public good and the environment as a whole. To our knowledge this concept has not yet been broached within the framework of overlapping generation models.

The economy is represented by a production sector and an aggregate good which is called a “numeraire”. The proposed model is calibrated on the 2004 social accounting matrix of France and is worked out at the stationary state (without outside shocks in the numerical version of the model). The theoretical analyses made around the steady state, with the initial allocation modality adopted, allows the establishment of stable conditions, and to determine the characteristics of the steady state using the work of Galor and Rider (1989) within the framework of overlapping generation models.

Some new aspects

This paper highlights the fact that the general equilibrium is not neutral, from the introduction of a system emission permits regarding an economy initially lacking environmental policy objectives. We propose in our approach, an evolving model in two parts, both made up under GAMS (see parameters and variables in the annexe):

- The first part (section 2) shows an economy in which we demonstrate the role of Public Authorities in the dynamic model of an overlapping generations general equilibrium with the usual objectives of economic policy (financing the public good for the area, effected by a system of pension distribution); such an economy is characterised by the absence of any environmental protection policy; this situation is called ‘Business as Usual (BAU). A numerical model developed in parallel is called MEGGI-2.
- In section 3 we introduce an environmental policy implemented by a system of tradable emission permits system, which explicitly translates the definition of environmental cleanliness or properties rights and the attribution of these rights uniquely onto the ‘young’ in our economy. Then a specific taxation policy is introduced, based on an upstream emission permit system and the hypotheses adopted. The whole constituting a coupling of taxes and permits for an environ-

mental policy with varied and specific objectives that are described at the end of the paper. The initial model is thus modified and transformed into a 3-dimensional or 3-input model (Capital, Work, Environment). This version is also constructed using GAMS and called MEGGI-3.

The final part of the paper is organised as follows: section 4 treats the reconstitution of the general equilibrium of the model with and without an environmental policy; section 5 present the general equilibrium of the system; section 6 treats the analyses around the steady state and the last section is the conclusion and the annexe gives a succinct presentation of aspects linked to the techniques of numeric simulations, the data base and the parameters used to calibrate the model.

The Business as Usual Economy BAU

Generalities

We assume an overlapping generations model (OGM) as Diamond (1965) representing an aggregate good serving both investment needs and household consumption. Within the framework of this model industrial production activities produce a negative environmental externality (pollution comprised mainly of Greenhouse gases. Even though this constitutes a 'public ill', and Public Authorities do not institute any regulatory mechanism on this externality which is a source of desutility.

Households Behaviour

Basic Hypotheses

The agents have a finite live span comprising 2 periods respectively youth *t* active period - and old age *t*+1 inactive period – (H_1) for each period *t*, identical agents are born with a constant size and a unit mass ($N_t = 1$). We then assume that the active population – constituted essentially of the young with a quantity (L_t) – gives an inelastic unit of work, receiving in return a wage w_t. This salary serves in this version of model (Eq_1) for domestic consumption - c_t, and savings s_t (H_2). In the second cycle of life (retirement), the agents consume b_{t+1} (Eq_2) which corresponds to the net return on the savings accumulated during the previous period of activity to which must be added the transfer from Public Authorities of the retirement pension (H_3). We make the hypothesis that there are no differences in the treatment of revenues received by the agents in a given cohort and that all the gross salaries, pensions and interest on savings are taxable (H_4). Finally that for each period there is a tax, identical for all the generations and this is the portion of the budget which the Public Authorities use to finance publics expenditures (λ_t).

In this first part of the model, we assume that the variables and parameters used are doubly indexed on the one hand in time (index *t*), and on the other the context in which how the economic policy is applied (*'BAU'*).

These relationships are recapitulated in the maximisation programme below:

$$\begin{cases} Max\left\{U\left(c_t, c_{t+1}\right)\right\} \\ c_t + s_t = w_t\left(1-\lambda_t\right)\left(1-Tau_t\right) \\ b_{t+1} = \left[1+r_{t+1}\left(1-\lambda_{t+1}\right)\right]s_t + TRF_{t+1}\left(1-\lambda_{t+1}\right) \end{cases} \quad (1)$$

In the model as well as the simulations made, we have integrated in the functional form of the utility equation a fixed parameter which is the level of preference for the present, which measures the degree of consumer impatience of a representative household.

Intertemporal Optimisation

The problem of optimisation within the OLG is resolved by constructing the relationship of Intertemporal Budgetary Constraints (IBC) obtained by the equalisation of the sums of consumption actualised revenues.

In this first part we have specified a logarithmic function of utility.

$$U\left(c_t, c_{t+1}, \psi\right) = \log\left(\psi c_t\right) + \varphi \log\left(\psi b_{t+1}\right) \quad (2)$$

Where $\psi \in (0,1)$ represents the index of environmental quality. The closer this index approaches the maximum possible value, the better will be the environment. Inversely, as we move away from this maximum value the impact on agent's utility for each period of life will be greater.

From this the IBC is:

$$c_t + \frac{b_{t+1}}{\left[1+r_{t+1}\left(1-\lambda_{t+1}\right)\right]} = w_t\left(1-\lambda_t\right)\left(1-Tau_t\right) + \frac{TRF_{t+1}\left(1-\lambda_{t+1}\right)}{\left[1+r_{t+1}\left(1-\lambda_{t+1}\right)\right]} \quad (3)$$

Where:

- TRF_{t+1}: Transfer of money received as revenue in the second part of the life cycle;
- $TRF_t = Tau_t \cdot w_t$.
- r_{t+1}: Interest rate between the period t and t+1, on the capital market;
- φ: Time Preference rate.

Optimal Consumption

Writing the following expression as being the life cycle revenue:

$$RiCVi_t = w_t\left(1-\lambda_t\right)\left(1-Tau_t\right) + \frac{TRF_{t+1}\left(1-\lambda_{t+1}\right)}{\left[1+r_{t+1}\left(1-\lambda_{t+1}\right)\right]} \quad (4)$$

Optimal consumption in the first and second periods are established as:

$$c_t^{BAU} = RiCVi_t\left(\frac{1}{1+\varphi}\right) \tag{5}$$

$$b_{t+1}^{BAU} = \varphi \cdot c_t^{BAU} \cdot \left[1 + r_{t+1}\left(1 - \lambda_{t+1}\right)\right] \tag{6}$$

Relationship (6) which expresses itself as a function of optimal consumption in the first period is 'Euler's Inter-temporal Equation'. This equation translates implicitly the hypothesis that there is no inheritance as all the savings accumulated during the first period is used. Applying $N_t = N_{t-1}$ and knowing that the accepted consumption ($C_t^{BAU} = N_t c_t^t + N_{t-1} b_t^{t-1}$) during a given period t is the sum of the coexisting generations at each period, the agreed consumption can then be written as:

$$C_t^{BAU} = N_t RiCVi_t\left(\frac{1}{1+\varphi}\right) + N_t\left(\frac{1}{1+\varphi}\right) RiCVi\left[1 + r_{t+1}\left(1 - \lambda_{t+1}\right)\right] \tag{7}$$

Thus:

$$C_t^{BAU} = \frac{N_t RiCVi_t}{\left(1+\varphi\right)}\left(1 + \varphi\left[1 + r_{t+1}\left(1 - \lambda_{t+1}\right)\right]\right) \tag{8}$$

Enterprises

Production

The production (Y_t) of an accepted good at a unit price by a representative enterprise operating in a pure and perfect competition and due a technology (with a constant return to scale ($0<\alpha<1$) Cobb-Douglas.

$$Y_t^{BAU} = AK_t^{\alpha} L_t^{1-\alpha} \varsigma_t \tag{9}$$

Where $A > 0$a parameter of scale and $K_t > 0$, $L_t > 0$ are respectively the capital and Labor employed during the period t. The intensity of the pollution is defined by $\varsigma_t \in (0,1)$.

This production generates a quantity of emission (Em_t) at each period as the following expression:

$$Em_{\mathrm{t}} = \varsigma_t^{1/\theta} Y_t \tag{10}$$

The expressions (9) and (10) allow a more general expression of the intensity of the pollution emitted during a given period t:

$$\varsigma_t = \left(\frac{Em_t}{AK_t^{\alpha} L_t^{1-\alpha}} \right)^{\frac{\theta}{1+\theta}} \tag{11}$$

As there is no environmental protection policy, pollution is at a maximum, corresponding to the case where pollution intensity has its maximum value ($\varsigma_t = 1$) so:

$$Em_t = Y_t^{BAU} \qquad with \qquad Y_t^{BAU} = AK_t^{\alpha} L_t^{1-\alpha} \tag{12}$$

Then we look at the variables one by one, and weight their level by work unit (L_t), which in reality represents the active young population in the economy during a given period.

The aim of a company is classically to maximise its profit, knowing that $\left(k_t^{\alpha} = K_t^{\alpha} / L_t^{\alpha} \right)$:

$$\pi_t = Ak_t^{\alpha} - \left(w_t L_t + \left(r_t + \delta \right) K_t \right) \tag{13}$$

This is achieved by equalising the marginal productivity of the factors employed in the production process at their real cost. The capital is not entirely depreciated either, In order to simplify, we assume there is no cost of capital adjustment.

Necessary Conditions for Optimality

Taking into account the decision variable K_t, L_t:

$$\{ \underset{K_t, L_t}{Max} \left\{ \pi_t^{BAU} \right\} \quad \text{et} \quad \begin{Bmatrix} \frac{\partial \pi_t^{BAU}}{\partial X_i} = 0 \\ X_{i,t} = K, L \end{Bmatrix} \tag{14}$$

The normal conditions of optimality allow us to obtain the relationship between the rate capital remuneration and salary levels of the economy under consideration:

$$r_t^{BAU} = \alpha A k_t^{\alpha-1} - \delta \tag{15}$$

$$w_t^{BAU} = \left(1 - \alpha \right) Ak_t^{\alpha} \tag{16}$$

With:

- α: the rate of capital in production;
- δ: Capital depreciation rate
- π_t: Firms profits.

Investment Equation

The function of investment translates as the accumulation of capital in the economy in which the savings made by the young during their active period (assume t) finance the capital of the next period (period $t + 1$ with $s_t = K_{t+1}$):

$$I_t^{BAU} = K_{t+1} - (1-\delta) K_t \qquad [14] \tag{17}$$

The Public Authority

Budget of the State and publics expenditures

Publics expenditures and retirement income are financed by the funds held by Public Authority. As stated above, the re-sources of these funds are made of portion of taxes (λ_t) imposed on retirement income, the gross salaries of the active population and on the interest on saving made by the retired during their previous period of activity (period t - 1).

The budget of the state serves to finance the public good and ensure a policy of redistribution by the payment of pensions to inactive households.

During the present period t, the equation of public expenditure (GP_t) is hence:

$$GP_t^{BAU} = \lambda N \left[w_t \left(1 - Tau_t\right) + r_t s_{t-1} + TRF_t \right] \tag{18}$$

Retirement funds held by the state

The funds are fed by the proceeds from taxes on gross salaries and serve to finance the transfers received by each agent during the second part of their life (knowing that $N_t = L_t$):

$$TRF_t^{BAU} N_{t-1} = p_t w_t L_t \Rightarrow TRF_t^{BAU} N_t = p_t w_t L_t \Rightarrow TRF_t^{BAU} N_t = p_t w_t N_t \tag{19}$$

The quality of the environment

As initially assumed, production is at the origin of the pollution present in the atmosphere. At each moment, the concentration $(H_t > 0)$ for all of the GHG as shown below:

$$H_t = (1-\vartheta) H_{t-1} + \phi\psi\left(c_{t-1}^{t-2} + c_{t-1}^{t-1}\right) + \mu Em_{t-1} \tag{20}$$

Where ϑ is the rate of natural absorption of the atmosphere and ϕ is a control parameter of the negative externality, here, household consumption. Being given the variable of the level of environmental quality $\overset{\frown}{EQ}$ in the absence of maintenance operations and in consideration that there exists a natural quantity $\overset{\frown}{EQ}$ of GHG present in the atmosphere even without of all human activity, we may write the following valuable relationship period for all periods:

$$EQ_t = \widehat{EQ} - H_t \tag{21}$$

It is easily verifiable from the 2 relationships established above the global movement of the level of environmental quality at period t is:

$$EQ_t = EQ_{t-1} + \vartheta\left(\widehat{EQ} - EQ_{t-1}\right) - \phi\psi\left(c_{t-1}^{t-2} + c_{t-1}^{t-1}\right) - \mu Em_{t-1} \tag{22}$$

At any steady state

In the presence oh GHG due to production activities and consumption we obtain as an expression of the stationary quality of the environment after the transformation using equations (5) and (6):

$$EQ^s = \widehat{EQ} - \frac{\mu}{\vartheta} Em - \frac{\varphi\phi}{\vartheta} RiCVi\left(\frac{1}{1+\varphi}\right)\left\langle 1 + \vartheta\left\{1 + r\left(1-\lambda\right)\right\}\right\rangle \tag{23}$$

From this equation (23); we establish the following conclusions:

Proposition

In the absence of any environmental policy and considering everything else to be otherwise equal, the stationary quality of the environment so modelled is a positive function of the natural concentration of GHG present in the atmosphere with no human activity in production or consumption and negative for the quantity of pollution emitted, of anticipated consumer revenues depending on the context of economy employed or authorised within the economy by the Public Authority.

Definition of the BAU Equilibrium

An equilibrium is defined by as follows $\left\{EQ_t, k_t, c_t, s_t, w_t, r_t, GP_t\right\}_{t=0}^{\infty}$ so that the households taking into account the initial conditions $\left(s_{-1} = k_0, EQ_0 = \widehat{EQ}\right)$ maximise their inter-temporal utility, under the defined constraints, companies maximise their profits and the different markets are in equilibrium (capital $s_t = K_{t+1}$, Labor $L_t = N_t$, and goods $Y_t = C_t + I_t + GP_t$).

Model with environmental policies objectives

Generalities

The externality constituted by GHG emissions coming from production activities of firms decreses households welfare. It presents various potential risks and known effects to the environment. The environment is considered to be a public good. We assume in this second part of the model that the Public Authority as a member of a supranational organisation has decided on the introduction of quantitative limitation objectives, implemented in the economy as an instrument of environmental policy following an international mobilisation.

The notions of environmental debt and international solidarity are introduced in the model, since we assume that the actual generations will inherit a 'debt' contracted because of the *laissez-faire* policy in the production and consumption operated under the previous system.

Instrument of environmental policy

Within the economy a policy of reducing emissions is applied, controlled by the Public Authority under the form of a system of tradable emission quotas which must be respected. As this is unavoidable a system of tradable emission permits is established (H_5).

Modality of the initial allocation of permits

We make the hypothesis that properties rights are in this case clearly defined on the environment, that they are acquired by young households from the Public Authority and then become the object of transactions in a market organised for this (H_6).

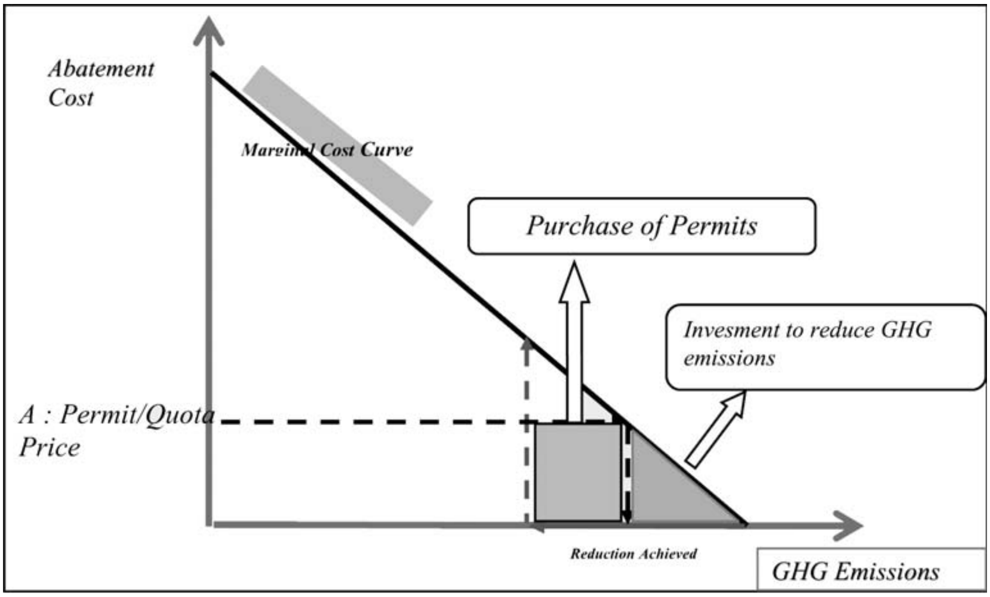
The hypotheses close to the one that we have adopted on the modality of the initial allocation of tradable emission permits have already been made within the framework of an overlapping generational model with the existence of environmental externalities. In effect in John et al (1994), John et al (1995), and Ono (2002) the authors consider the existence of a public authority representing young households operating an environmental maintenance policy to their advantage. In the frame of this model at each period the properties rights that the Government transfers to households at price p_t generates an income $\left(p_t\overline{E}\right)$; these charges generated at the start of the period from the environment, correspond exactly to a part of the total quota of emission charges fixed exogenously (H_7) by a supranational ruling. This allows the efficient achievement of the initial objectives established for GHG reduction. The quota of authorised emissions for each period and the permits, correspond to the quantity asked for by the enterprises $\left(p_t\overline{E}\right)$.

Complementary hypotheses and proposition

H_8

The households then resell emission permits to enterprises at a price q_t. We assume that the price of the permit sold by the households is higher than the purchase price ($q_t > p_t$), so $\frac{q_t}{p_t} > 1$; this hypothesis allows the possibility of the existence a single tax $(\zeta \in]0,1[)$ which is imposed on the household on the 'added' value $\left(d_t = (q_t - p_t)E_t\right)$.

Graph 1.



We have interpreted this added value as a gross revenue from the resale of emission permits to enterprises which are under the obligation to buy them as part of the production cost. We keep the flexibility of a system which also allows an enterprise to invest in technology which respects official standards and reduces GHG emissions.

However as investment in a 'clean' technology may eventually be considerable, a choice can be made between immediate investment and spreading the cost over several periods. When all the enterprises arrive at investment to reduce their emissions, the price of all the permits represented by the quota is situated at point A in Graph 1.

H_9

i. The total value of the properties right $\left(p_t \overline{E}\right)$ passed on to young households and the funds made up from the tax $\left(\xi d_t E_t\right)$, feeds the budget (GP_t^{ME})of the state which is allocated to operating environmental maintenance.
ii. Following on from the model we consider that the income from the tax could used for two objectives:

1. At a cost of implementing a passive policy, that is to say in the absence of administrative costs $\left(p_t\overline{E}\right)$ could used for environmental maintenance operations on a national, regional basis (carbon sinks, reforestation ..), and investment in renewable energy sources (wind farms ….etc,).
2. The income from the tax collected could feed a common supranational regulatory body which would decide the orientation of environmental policy to be applied by the countries which belonged to it. This fund could used to help '*sustainable development' of* the southern countries which suffer from the external effects of pollution generated by the industrialised countries (*international solidarity*) or the payment of an '*environmental debt'*.

iii. If $\frac{q_t}{p_t} \equiv 1$, the income is almost nothing $\left(\xi d_t E_t\right)$, The Public Authority is limited to carrying out environmental maintenance and cannot raise sufficient funds to participate in funding durable development or paying environmental debt. If the Public Authority wishes to maintain its participation in these operations, this decision will create an excess of expenditure as there are insufficient tax receipts. Consequently it has the choice between creating a deficit to be covered by future generations (creating an intergenerational inequity) or not investing in environmental maintenance equivalent to the level of tax raised $\left(\xi d_t E_t\right)$

Proposition

Financial operations in the frame of environmental maintenance in a national territory generate non negligible beneficial effects which qualify as positive effects for intergenerational well being; participating in international solidarity operations allow debt relief of future generations.

Enterprises and GHG emission dynamics

Production function in 3-dimensions

Firms rent the environment to households assuring for each period the production of an aggregate good, due the so called neoclassical production technology, equally as well at a constant return to scale as in the initial model. However three factors are used in the second part: Physical capital (K_t), Labor (L_t) and Environment (E) (the emission permit represents the demands of the environmental factor) (H8). The use of emission permits in production translates a real demand of the environmental factor as the use engenders a controlled degradation of the quality of the environment by the introduction of emission quotas. For each period the production function is represented by:

$$F\left(K_t, L_t, E_t\right) = Y_t^{WE} = AK_t^{\alpha_K} L_t^{\alpha_L} E_t^{\alpha_E} \qquad \textit{With} \quad \sum \alpha_i = 1 \quad \left(i = K, L, E\right) \quad (24)$$

This equation may also be written as:

$$Y_t^{WE} = AK_t^{\alpha} L_t^{\beta} E_t^{1-\alpha-\beta} \qquad with \quad \alpha+\beta+\gamma=1 \quad où \quad \gamma=1-\alpha-\beta \tag{25}$$

The problem of the representative firm consists in maximising its profit as the new function below:

$$\pi_t^{WE} = AK_t^{\alpha} L_t^{\beta} E_t^{1-\alpha-\beta} - \left\{ w_t L_t + \left(r_t + \delta\right) K_t + q_t E_t \right\} \tag{26}$$

$$\frac{\partial \pi_t}{\partial x_i} = 0 \quad where \quad x_i = \left(K_t, L_t, E_t\right) \tag{27}$$

From this equation (28) new expressions for marginal productivity are derived below expressed in variables per head:

$$r_t^{we} = \alpha A k_t^{\alpha-1} e_t^{\gamma} - \delta^{we} = F_K\left(k_t, e_t\right) \tag{28}$$

$$w_t^{we} = \beta A k_t^{\alpha} e_t^{\gamma} = F_L\left(k_t, e_t\right) \tag{29}$$

$$q_t^{we} = \gamma k_t^{\alpha} e_t^{\gamma-1} = F_E\left(k_t, e_t\right) \tag{30}$$

Where $r_t^{we}, w_t^{we}, q_t^{we}$ are respectively the new interest rates, wages and the unit price of tradable emission permits. $e_t = E_t / L_t$ represents the emissions per head.

Investment equation

This given by the expression identical to that of equation (14)

$$I_t = K_{t+1} - (1-\delta)\, K_t \tag{14bis}$$

Dynamics of GHG emissions and pollution accumulation taking into account

At each period *t,* firms have the right to emit a quota of GHG equivalent to the amount of permits held and bought previously at the start of the period from households which had initially received the properties rights, or from companies which had not used their quota during the period. Pollution is produced by the use of tradable emission permits during the production process, hence the negative correlation between the permits and the quality of the environment. As Jouvet et al (2002) p.66, '*the level of pollution at a date t depends on the level of pollution of the preceding period.*' And the requirements for emission permits needed by firms *'during the current period'*.

Taking ϑ the natural level of pollution absorption we can assume that the total level of pollution follows the following behaviour:

$$H_{t+1} = \left(1-\vartheta\right) H_t + \phi\psi N_t \left(c_t^t + \Gamma c_t^{t-1}\right) + \mu E_t \tag{31}$$

Where $\Gamma \in (0,1)$ represents the probability that an individual dies before the end of the second part of the model due to the bad effects of externalities that the agent had to suffer, and to which elderly people are more vulnerable. Equally the decision of the Public Authority to invest in environmental maintenance may affect the available statistics which indicate an increase in mortality due to the impact of pollution on the environment (climate warming, various pollutants).

Behaviour of other institutional components of the model

Households

Generalities

The general characteristics concerning the life cycle of the agents remain identical to those of *§2.b i.*

Optimisation Programme:

The representative consumer in a cohort maximises preferences which is expressed by the inter-temporal utility function below. This is written based on the consumption over the two periods but also as a parameter $\vartheta \in \left(0,1\right)$ which affects in this present case the consumption during period t. This expression is an indexed coefficient of the quality of the environment. It reflects the sensitiveness of consumers to the conditions in which they consumed in their youth, a period when they must show their eco-citizen behaviour. As they have effective rights with regard to the environment. The utility to the household function is synthesised by:

$$\underset{c_t^{we}, b_{t+1}^{we}}{Max} \left\{U\left(c_t^{we}, b_{t+1}^{we}, \vartheta\right)\right\} \quad où \quad \vartheta = f\left(EQ_i\right) \quad \forall i \in \left\{t\right\} \tag{32}$$

$$w_t^{we}\left(1-\lambda_t^{we}\right)\left(1-Tau_t^{we}\right) + \left[q_t\left(1-\xi_t\right) - p_t\right] E_t = c_t^{we} + s_t^{we} \tag{33}$$

$$\left[1 + r_{t+1}^{we}\left(1-\lambda_{t+1}^{we}\right)\right] s_t^{we} + TRF_t^{we}\left(1-\lambda_{t+1}^{we}\right) = b_{t+1}^{we} \tag{34}$$

Equations (34), (35) are the budgetary restrictions which take into account the modality of the initial allocation of the defined permits.

Proposition

The introduction of tradable emission permits into the economic circuit and the definition of properties rights on the environment changes the way revenues are apportioned in young households.

Here, in effect the net salary the young population receive as reward for their offer of work serves for the consumption of goods c_t^{we}, as savings as well as the propoerties rihghts on the environment $p_t E_t$. This revenue is increased by the net amount $q_t^{we}\left(1-\xi_t\right)E_t$.

So taking into account of the fact that tradable emission permits is a financial asset (supporting savings), the modality of the initial allocation adopted will favour saving, if consumption in the presence of the environmental policy remains equivalent to the consumption in BAU situations, all other things being equal. The following expression relates to the modified savings of the OLG representative agent.

$$s_t^{we} = w_t^{we}\left(1-\lambda_t^{we}\right)\left(1-Tau_t^{we}\right)+\left[q_t\left(1-\xi_t\right)-p_t\right]E_t - c_t^{we} \qquad (35)$$

On retirement, the agents consume b_{t+1}^{we} which correspond to the net return on the new expression of accumulated savings s_t^{we} during the active period and to the net amount transferred to the public authority. In this age group, as a result of this, due to the modality of the initial allocation adopted on environmental rights, that the agents in this age category lose the right to acquire environmental rights.

The following function given below allows us to measure households utility:

$$U\left(c_t^{we}, b_{t+1}^{we}, \vartheta\right) = U(c_t^{we}, \vartheta) + \left(\frac{1}{1+\varphi}\right)U\left(b_{t+1}^{we}\right)$$

$$U\left(c_t^{we}, \vartheta\right) = \left(\frac{1}{1-\frac{1}{\sigma}}\right)\vartheta\left(c_t^{we}\right)^{1-\frac{1}{\sigma}} \text{ et } U\left(c_t^{we}, \vartheta\right) = \left(\frac{1}{1-\frac{1}{\sigma}}\right)\left(b_{t+1}^{we}\right)^{1-\frac{1}{\sigma}} \qquad (36)$$

- $\sigma \neq 1$ represents the elasticity of the inter-temporal substitution;
- φ is the time preference rate ($\varphi \in (0\ 1)$).

Optimal Consumption

Households maximize their utility under budget constraints (equations (34, (35)):

The programme of maximisation of the utility to the representative household budget is constrained as

$$\begin{cases} \partial U\left(c_t^{we}, b_{t+1}^{we}\right) \\ s/c \\ \left[34\right] \quad et \quad \left[35\right] \end{cases} \qquad (37)$$

This leads to the optimal choice of consumption (marginal rate of substitution between consumption in the first and second periods) over the life cycle of an individual:

$$\frac{U_c}{U_b} = \left\{ \frac{1 + r_{t+1}\left(1 - \lambda_{t+1}\right)}{\vartheta\left(1 + \varphi\right)} \right\} \tag{38}$$

Consequently, consumption during the first and second periods is:

$$c_t^{we} = RiCVi_t^{we} \left\langle 1 - \frac{\left\{ \frac{\left[1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}^{we}\right)\right]^{\sigma-1}}{\left[\left(\vartheta\right)\left(1 + \varphi\right)\right]^{\sigma}} \right\}}{1 + \left\{ \frac{\left[1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}^{we}\right)\right]^{\sigma-1}}{\left[\left(\vartheta\right)\left(1 + \varphi\right)\right]^{\sigma}} \right\}} \right\rangle \tag{39}$$

After several manipulations equation (38) above gives:

$$c_t^{we} = \left\langle \frac{RiCVi_t^{we}}{1 + \left\{ \frac{\left[1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}^{we}\right)\right]^{\sigma-1}}{\left[\left(\vartheta\right)\left(1 + \varphi\right)\right]^{\sigma}} \right\}} \right\rangle$$

$$c_{t+1}^{we} = \left\langle \frac{RiCVi_t^{we} \left\{ \frac{\left[1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}^{we}\right)\right]}{\vartheta\left(1 + \varphi\right)} \right\}^{\sigma}}{1 + \left\{ \frac{\left[1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}^{we}\right)\right]^{\sigma-1}}{\left[\left(\vartheta\right)\left(1 + \varphi\right)\right]^{\sigma}} \right\}} \right\rangle \tag{40}$$

Where the Wealth Life Cycle ($RiCVi_t^{we}$):

$$RiCVi_t^{we} = w_t^{we}\left(1 - \lambda_t^{we}\right)\left(1 - Tau_t\right) + \left[q\left(1 - \xi_t\right) - p_t\right]E_t + \frac{TRF_{t+1}^{we}\left(1 - \lambda_{t+1}^{we}\right)}{1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}\right)} \tag{41}$$

Total Optimal Consumption in the economy

$$C_t^{we} = N_t c_t^{we} + N_{t-1} b_t^{we.t-1} \quad ;Or, \quad N_t = N_t^{t-1} \quad ;\Longrightarrow C_t^{we} = N_t \left(c_t^{we} + b_t^{t-1}\right) \qquad (42)$$

The State

With the hypothesis of tax financing environmental maintenance, the budget of the public authority having policies of environmental maintenance and participation in international solidarity or the acceptance of environmental debt is expressed as:

$$GP_t^{we} = \lambda_t^{we}\left[w_t^{we}\left(1 - Tau_t^{we}\right) + r_t^{we} s_{t-1}^{we} + TRF_t^{we}\right] + N_t E_t \left(p_t + \xi_t d_t\right) \qquad (43)$$

Environmental Maintenance

Achieving environmental maintenance by the Public Authority during period t has an direct influence on the parameter $\vartheta \in (0,1)$, as the maintenance improves the quality of the environment. The coefficient ϑ because of this fact approaches its maximum value, for a maximum utility on the one hand and on the other when this maintenance is done at optimal level, it makes an improvement in the quality of the environment in the period in question. But equally, at a level of constant emissions, the quality of the environment during period $t+1$ is transmitted to the following generation, hence the positive intergenerational effect postulated. In addition when the young populations are retired the will be consuming in better conditions.

Dynamics of Capital Accumulation

From the hypotheses postulated previously, the agents born during the current period t and who are supposed to be in an active period, save some of their revenue. The total savings of the cohort of active young people constitutes the accepted savings S_1 in the economy. This total savings constitutes the Capital of period t+1:

$$S_t^{we} = s_t^{we} N_t = K_{t+1} \qquad (44)$$

With

$$w_t^{we}\left(1-\lambda_t^{we}\right)\left(1-Tau_t^{we}\right) + \left[q_t\left(1-\xi_t\right) - p_t\right]E_t = RiCVi_t - \frac{TRF_{t+1}^{we}\left(1-\lambda_{t+1}^{we}\right)}{1+r_{t+1}^{we}\left(1-\lambda_{t+1}\right)}$$

The savings of the agent born in t is:

$$s_t^{we} = \left\langle RiCVi_t^{we}\left\{\frac{\left\{\frac{\left[1+r_{t+1}^{we}\left(1-\lambda_{t+1}\right)\right]^{\sigma-1}}{\left[\vartheta\left(1-\varphi\right)\right]^{\sigma}}\right\}}{1+\left\{\frac{\left[1+r_{t+1}^{we}\left(1-\lambda_{t+1}\right)\right]^{\sigma-1}}{\left[\vartheta\left(1-\varphi\right)\right]^{\sigma}}\right\}}\right\} - \frac{TRF_{t+1}^{we}\left(1-\lambda_{t+1}^{we}\right)}{1+r_{t+1}^{we}\left(1-\lambda_{t+1}\right)}\right\rangle \qquad (45)$$

From the parameter calibration values of the model this expression of the savings is indeed an increasing function of revenue (included in the equation of $RiCVi_t$ and non-decreasing with the interest rate.

Reconstitution of the General Equilibrium

The equilibriums in the different markets are thus determined as follows:

Labour Market

The active population is equal to the number of agents in the cohort, which enters into the model at the start of the period *t :* Equality is found on the labour market for each period:

$$N_t = L_t \tag{46}$$

Emission Permit Market

The quantity of permits on offer, on the basis of attributed charges, is equal to the number of permits required by the companies:

$$\overline{E} = E_t \tag{47}$$

Goods and Services Market

The equilibrium between the offer and the demand on this market is verified when:

$$Y_t^{we} = C_t^{we} + I_t^{we} + GP_t^{we} \tag{48}$$

From Walras's law, in an economy where there are n markets, if n-1 markets are in equilibrium, then the nth market in this case that of capital, it also is in equilibrium. In consequence this principle leads us to consider that equilibrium is achieved on the capital market.

We assume as in Schubert (2000) that in the initial period of the economy or in the one preceding the actual period t, there was a pre-existing savings S_{-1} which allowed the financing of an initial stock of capital (K_0) and following on more generally that the savings of the young population finance the capital stock which allows investment, so that at each period *t* we can have the equilibrium relationships $S_t^{we} = s_t^{we} N_t = K_{t+1}$ (44).

Equilibrium of the decentralised economy

In this section we are going to determine growth path obtained in competitive situations after the introduction of the instruments of environmental policy.

From equation (44) $S_t^{we} = S_t^{we} N_t = K_{t+1}$;

Taking the expressions of variables per head, as it is assumed the size of the generations stays the same, we obtain:

$$s_t^{we} = k_{t+1} \tag{49}$$

Substituting:

$$\left\{ \frac{\left[1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}\right)\right]^{\sigma-1}}{\left[\vartheta\left(1-\varphi\right)\right]^{\sigma}} \right\} = \Upsilon_t^{we}$$

$$k_{t^{\cdot\cdot}+1}^{we} = \left\{ RiCVi_t \left(\frac{\Upsilon_t^{we}}{1 - \Upsilon_t^{we}} \right) - \frac{TRF_t\left(1 - \lambda_{t+1}^{we}\right)}{1 + r_{t+1}^{we}\left(1 - \lambda_{t+1}^{we}\right)} \right\} \tag{50}$$

The dynamic written above takes equation (28) into account.

$$k_{t+1}^{we} = RiCVi_t^{we} \left\{ \frac{\dfrac{\left[1 + \left(F_K\left(k_{t+1}^{we}, e_{t+1}\right) - \delta\right)\left(1 - \lambda_{t+1}^{we}\right)\right]^{\sigma-1}}{\left[\vartheta\left(1-\varphi\right)\right]^{\sigma}}}{1 - \dfrac{\left[1 + \left(F_K\left(k_{t+1}^{we}, e_{t+1}\right) - \delta\right)\left(1 - \lambda_{t+1}^{we}\right)\right]^{\sigma-1}}{\left[\vartheta\left(1-\varphi\right)\right]^{\sigma}}} \right\} \tag{51}$$

Some analyses concerning the stationary state of the dynamic model (MEGGI-3)

Generalities

Looking again at capital accumulation in the economy it is possible to express as a function of the variables and parameters, on what the initial savings depend, if the relative prices and the stock emission permits are known.

Calling χ_t^{we} the total savings of a representative agent:

$$\chi_t^{we} = s_t^{we} - \left[q\left(1 - \xi_t\right) - p_t\right]E_t = \chi\left(w_t, r_{t+1}, E_t\right) \tag{52}$$

From equations (30 and (44) the capital dynamic is established by:

$$K_{t+1}^{we}=\chi_t^{we}+\left[\left(1-\xi_t\right)F_E\left(k_t^{we},e_t\right)-p_t\right]E_t \tag{53}$$

In all stationary equilibrium:

$$K^{we}=\chi^{we}\left(F_L\left(k,e\right),F_k\left(k,e\right),E\right)+\left[\left(1-\xi\right)F_E\left(k,e\right)-p\right]E \tag{54}$$

$$H=\frac{\phi\psi}{\vartheta}\left(c^1+\Gamma c^2\right)+\frac{\mu}{\vartheta}E \tag{55}$$

Such that:

$$K^{we}\left\{1-\left[\left(1-\xi\right)F_E\left(k,e\right)-p\right]\frac{E}{K^{we}}\right\}=\chi^{we}\left(F_L\left(k,e\right),F_k\left(k,e\right),E\right) \tag{56}$$

General form characterising approximately to the stationary states of Diamond[14], allowing a stock level of capital to be achieved being the solution to the above equations.

Clarifications about the nature of the stationary state

We can establish the relationship:

$$\left\{1-\left[\left(1-\xi\right)F_E\left(k,e\right)-p\right]\frac{E}{K^{we}}\right\}=\frac{\chi^{we}\left(F_L\left(k,e\right),F_k\left(k,e\right),E\right)}{K^{we}} \tag{57}$$

Galor & Ryder (1989) (see De La Croix&Michel(2002), Jouvet et al(2002) or Jouvet et Prieur(2006)) as a sufficient condition within the framework of an overlapping generations model that there is *'an interior steady state'* if:

$$\lim_{K^{we}\to 0}\frac{\chi^{we}}{K^{we}}>1 \tag{58}$$

Verification

From the fixed parameters which allow a numerical solution of the model it can be established that:

$$\begin{cases}\left\{1-\left[\left(1-\xi\right)F_E\left(k,e\right)-p\right]\frac{E}{K^{we}}\right\}=\frac{\chi^{we}\left(F_L\left(k,e\right),F_k\left(k,e\right),E\right)}{K^{we}}\\ Si\quad K\to 0,\ -\frac{e}{K}\to-\infty\quad\left[\left(1-\xi\right)F_E\left(k,e\right)-p\right]\frac{E}{K^{we}}\to 0\end{cases} \tag{59}$$

As well as:

$$\lim_{K^{we} \to 0} \frac{\chi^{we}}{K^{we}} = 1 \tag{60}$$

A result that leads us to conclude that the assumption concerning the modality of the initial allocation postulated is not verified in the case of Galor & Ryder under the conditions of the existence of an *interior stationary state* (non trivial or non degenerate) within the framework of overlapping generation models, there is thus on one hand one or more trivial or degenerate stationary state; or on the other hand an unstable stationary state which simply corresponding to a point.

Stability or instability of the stationary state

We are the in the case of a 3-dimensional model, presenting 2 stock variables.

Looking again at equation (54) and then differentiating it we obtain the dynamic of capital at stationary equilibrium:

$$\frac{\partial K^{we}}{\partial E} = \frac{\chi_1 F_{LE} + \chi_2 F_{KE} + \chi_3 + \chi_4 \left[\left(1 - \xi_t\right) E F_{EE} + F_E \right] - \chi_5 p}{1 - \chi_1 f_{LK} + \chi_2 f_{KK} + \chi_4 E f_{EK}} \tag{61}$$

From this result, the stationary state is stable if:

$$1 - \chi_1 f_{LK} + \chi_2 f_{KK} + \chi_4 E f_{EK} > 0 \tag{62}$$

Conclusion

We have a model in two parts based on applied study. The first part is without a environmental policy objective in the presence of negative externality, followed by the introduction of an emission permit system. The modality of initial allocation used is the allocation of a cleanliness charge on young populations. The particularity of the applied study lies in the fact that we specifically postulate, the introduction a level of tax on the released margin from which product in the budget of the state environmental maintenance operations are financed, this has the effect of generating intergenerational well being, that we consider cannot be dissociated from and more effective if the state participates as well in international solidarity operations on the environmental plan on the one hand and if the public authority does not acquit itself of environmental debt.

Then we have found with the hypotheses adopted a particular equilibrium solution and we have study the conditions for stability, then the effects of variation in levels of emission quotas introduced into the regulation process. It would however be interesting to study as well other tradable emission permits initial allocation following on from that studied by Jouvet et al (2002).

NOTES

[1] This refers to Beamais & Chiroleu-Assouline(2002), Économie de l'environnement, Bréal, Collection Amphi.

[2] General Algebraic Modelling System

[3] Cf. Model of Diamond (1958), p.449, in Truman F. Bewley 2007 General Equilibrium, Overlapping Generations Models and Optimal Growth Theory, Harvard university Press, Cambridge or Schubert (2000), pp. 270-285.

[4] (Hi*)* for hypothesis *i*.

[5] To simplify the writing of the equations $\forall x$, variable index in t, or $\forall \varepsilon$ parameter of the model indexed in t considered as in this first part of the model x_t^{BAU} and ε_t^{BAU}, for parameters not indexed in t, consider as ε^{BAU}.

[6] Cf. Obstfeld, M., Kenneth, R. (1997), Foundations of international macroeconomics, The MIT Press, 2ème edition, Cambridge.

[7] The aggregate consumption is called C_t^{BAU}.

[8] Even though consumption is at the origin of pollution, we assume here that emissions are linked only to production.

[9] For example for Capital: $kt = K_t / L_t$

[10] Actual policy for interest rates, level of taxes introduced and applied on the revenues of agents .

[11] variables and parameters of this 2nd part are assumed to be indexed on x_t^{WE}, ε_t^{WE}, ε^{WE}, $\forall x_t$, ε_t, ε where WE signifies With Environment.

[12] The European Union has incorporated a directive which aims to achieve the objectives fixed in the Kyoto protocol.

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