Intergenerational transfers of pollution rights and growth

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Abstract

We develop an overlapping generations growth model in which the individuals care about the environment. Many environmental policies suffer from institutional failures. We focus on the failure resulting from the delegation by the government of the exercise of the environmental policy to an administrative department. Though motivated by the department's expertise, the delegation principle may give rise to a conflict with social welfare maximization. This paper proposes an original policy mechanism of transfers of pollution rights capable of circumventing these failures and decentralizing optimal growth at competitive equilibrium.

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1 Introduction

Many environmental issues span long time periods and dynamics is of crucial importance. Being short-lived, private agents generally neglect the long term impacts of their decisions. According to Solow (1986), this provides a rationale for using the overlapping generations model (OLG) of growth instead of the infinite-lived agent one. John and Pecchenino (1994) analyze the link between growth and the environment in such a model and highlight the Paretian inefficiency of the competitive equilibrium. This inefficiency, which is clearly the result of the agents' inability to internalize environmental externalities, justifies the environmental policy. Since this seminal contribution, many articles focus on the way to deal with intergenerational externalities. John *et al.* (1995), Ono (1996) and also Jouvet *et al.* (2002) mainly pay attention to the role of environmental policy in the long run by proposing some public policy devices so as to decentralize the golden rule. John *et al.* (1995) and Ono (1996) use direct or indirect fiscal instruments on polluting activities or subsidies on maintenance. Jouvet *et al.* (2002) define property rights on the environment and analyze their effectiveness in decentralizing the long term social optimum.

Our study is closer to a recent paper by Jouvet *et al.* (2005) in which the environmental policy is the instrument for decentralizing the optimal growth. The policy they consider consists in setting a quota on emissions, creating and auctionning the corresponding amount of pollution rights. However, this result crucially depends on the fact that the competent autority is able to choose the quota which maximises social welfare. In this article, we challenge the robustness of this result by recognizing that many environmental policies actually suffer from institutional failures that potentially affect the fixation of the emission quota. We are particularly interested in the failure resulting from the widespread delegation by the governments of the exercise of the environmental policy to an administrative department. Though motivated by the department's expertise, the delegation principle may give rise to a conflict with social welfare maximization. The contribution of our article lies in the proposition of an original policy mechanism capable of circumventing these failures and decentralizing optimal growth at competitive equilibrium.

The paper is organized as follows. The institutional framework is presented in section 2. In section 3, we expose the agents' choices and define the competitive equilibrium. The following section characterizes the social optimum. It then sheds light on the way to achieve this centralized solution from the decentralized economy. Dynamic properties are analyzed in section 5. Some numerical illustrations are also conducted. The last section concludes.

2 A framework with institutional failures

This paper develops an overlapping-generations framework *à la* Allais (1947), Samuelson (1958), Diamond (1965) in which the objectives and the conduct of the environmental policy falls to two institutions: the government and an environmental agency. We present their respective missions and explain how they interact.

In many countries, we observe that the government delegates the conduct of the environmental policy to an administrative department, which we shall refer to as the environmental agency. This delegation is justified by the agency's expertise in managing and monitoring emissions at the firms' level and in designing policy instruments. In our model the agency's mission consists in refraining firms' pollution by setting each period an emission quota. This quota corresponds to the amount of emission permits sold to the firms. There are pervasive reasons for the agency's quota to fail matching the society's most preferred level of pollution. Firstly, what is technically feasible according to engineers does not always coincide with the recommendations of a cost-benefit economic approach. Secondly, an agency may be influenced by lobbying pressures, either from environmentalists or from polluting sectors. Thirdly, pressures can also come from worldwide competition and induce eco-dumping. And, fourthly, whenever adjustments of the quota are required by economic or environmental circumstances, it is often observed that bureaucratic inertia slows down the adjustment process.

The question we address in this paper is whether there exists a mechanism which enables a government delegating the conduct of the environmental policy to an agency to circumvent the inefficiencies which will most probably appear. The proposed mechanism is described hereafter.

The proposed mechanism. *In accordance with the policy delegation principle, the government is not entitled to issue or withdraw pollution rights, but we assume that:*

1. *it is entitled to transfer rights between at most two periods, backward or forward* [1],
2. *it can apply this transfer each period and,*
3. *it cannot choose an explosive path of transfers* [2].

Let us illustrate the above proposal and consider the amount of emission rights issued over periods t and $t+1$. The emissions before period t and those after $t+1$ are assumed given. When the government transfers pollution rights between these two periods, the aggregate volume issued in t and $t+1$ is unchanged, thereby respecting the delegation principle.

The transfers can flow in two directions. Consider first that, at period t, the government discovers that the emissions quota S_t, fixed by the agency, falls short the optimal emissions level. According to our mechanism it can fill the gap by taking an amount $\Lambda_t > 0$ of emission rights from the next period quota issue, S_{t+1}. In the opposite case when the quota S_t exceeds the optimal level, the government has the opportunity to transfer the surplus to the next generation ($\Lambda_t < 0$). Hence, given the previous transfer Λ_{t-1}, actual emissions at period t write:

$$P_t = \Lambda_t + S_t - \Lambda_{t-1} \tag{1}$$

with $\Lambda_t \lesseqgtr 0 \ \forall t$.

As soon as the government operates non zero transfers, it signals the necessity for the agency to modify the pollution rights issue. On the one hand, operating on behalf of the government the agency is supposed follow its directives but, on the other hand, the above-mentioned failures (lobbying pressures, eco-dumping, bureaucratic inertia...) are likely to slow down the whole process. In our model we assume that the agency adapts the current quota on the basis of the government transfers of the previous period, but only up to an adjustment parameter $\phi \in (0, 1)$. The level of ϕ is inversely related to the pervasiveness of the institutional failures. Without loss of generality, at any period t, the adjustment process can be written as:

$$S_t = S(\Lambda_{t-1}) = S + \phi\Lambda_{t-1} \tag{2}$$

[1] Considering more than two periods would not change the properties of the model.

[2] This constraint closely parallels a no Ponzi game condition.

Through this adjustment process, the magnitude of the government transfers is related to the pervasiveness of the agency's failures. Combining (1) and (2) we have that transfers at time t read

$$\Lambda_t = P_t - S + (1 - \phi)\Lambda_{t-1} \tag{3}$$

The lower ϕ, the higher the degree of rigidities, the more sluggish the agency's adjustment and the larger the governmental transfers.

The course of action of the institutions therefore influences the volume of permits exchanged on the market, and so the pollution level. Formally, according to (3) the supply of pollution rights at period t, P_t, is determined by the quota S and the government transfers Λ_{t-1} and Λ_t.

Finally we assume that the government recycles the proceeds of the sale of permits to the households and decides the allocation between the old and the young. In the model, the variable $\mu_t \in (0, 1)$ is the share of permits revenue given to the young. The government budget is always balanced.

3 The competitive equilibrium

3.1 The firms

Let us consider a constant return to scale technology of production with three factors: capital (K), labor (L) and emissions (E). This technology allows to produce an homogeneous good (Y), the numeraire, used both for consumption and investment.We assume a Cobb-Douglas specification:

$$Y_t = K_t^{\alpha_K} L_t^{\alpha_L} E_t^{\alpha_E} = L_t k_t^{\alpha_K} e_t^{\alpha_E}$$

where k_t and e_t represent capital intensity and emissions per unit of labor.

Capital depreciation is complete at each period. Profit maximization gives the usual conditions between the production factors marginal productivities and their price:

$$w_t = \alpha_L k_t^{\alpha_K} e_t^{\alpha_E} \tag{4}$$

$$R_t = \alpha_K k_t^{\alpha_K - 1} e_t^{\alpha_E} \tag{5}$$

$$q_t = \alpha_E k_t^{\alpha_K} e_t^{\alpha_E - 1} \tag{6}$$

where w_t is the real wage rate, R_t is the interest factor and q_t is the price of the permits.

The use of environment in production generates pollution which affects the quality of the environment. We define the variable Q_t as an index of the environmental quality. This index follows a specific law of motion influenced by the pollution level [3]:

$$Q_{t+1} = (Q_t - E_t)^{1-\Gamma} \overline{Q}^{\Gamma} \tag{7}$$

where $\overline{Q}$ is the stationary level of the environmental quality in the absence of human activity.

3.2 The households

The population is constant and normalized to 1 ($N = 1$). Each individual lives for two periods, youth and old age. The young agent is endowed with one unit of labor which he supplies inelastically for a real wage w_t. He also receives his share μ_t of the revenue raised by the sale of the emissions rights to the firms: $q_t P_t$, where q_t is the market price for the rights. There are two possible uses for his first-period total income, savings s_t and consumption c_t. He then faces the following budget constraint:

$$w_t + \mu_t q_t P_t = c_t + s_t \tag{8}$$

When old, his revenue comes from capital income $R_{t+1} s_t$, where R_{t+1} is the interest factor, and his share $(1 - \mu_{t+1})$ of the sale of the rights in period $t+1$, $q_{t+1} P_{t+1}$. He consumes all his second-period revenue d_{t+1}. This is summarized by the old-age budget constraint:

$$R_{t+1} s_t + (1 - \mu_{t+1}) q_{t+1} P_{t+1} = d_{t+1} \tag{9}$$

where P_t and P_{t+1} are defined by the dynamical constraint of the agency defined by (3).

[3] This formulation is inspired from Mirman's works (of which Levhari and Mirman (1980), Fisher and Mirman (1992), (1996)). It boils down to assume that the dynamics of the environmental quality is similar to the ones of a natural renewable resource whose stock is affected by extraction.

The individual's preferences are defined on youth and old-age consumption and on the environmental quality when old. They are specified as follows:

$$U_t(c_t, d_{t+1}, Q_{t+1}) = (1-\beta)\log c_t + \rho\left(\beta \log d_{t+1} + \delta \log Q_{t+1}\right) \tag{10}$$

where ρ is the discount factor.

The problem of the representative agent[4] consists in choosing the amount of savings that maximizes his utility with respect to the budget constraints,

$$\max_{s_t} (1-\beta)\log c_t + \rho\beta \log d_{t+1} + \rho\delta \log Q_{t+1}$$

$$s.t. \begin{cases} c_t = w_t + \mu_t q_t P_t - s_t \\ d_{t+1} = R_{t+1} s_t + (1-\mu_{t+1}) q_{t+1} P_{t+1} \end{cases}$$

The first-order condition reads:

$$\frac{1-\beta}{w_t + \mu_t q_t P_t - s_t} = \frac{\rho\beta R_{t+1} s_t}{R_{t+1} s_t + (1-\mu_{t+1}) q_{t+1} P_{t+1}} \tag{11}$$

This equation typically describes the trade-off between consumptions over the life-cycle. Rearranging it, we get the saving decision:

$$s_t = \frac{1}{1-\beta(1-\rho)} \left(\beta\rho(w_t + \mu_t q_t P_t) - (1-\beta) \frac{(1-\mu_{t+1}) q_{t+1} P_{t+1}}{R_{t+1}} \right) \tag{12}$$

The youth and old-age consumption levels directly stem from (12):

$$c_t = \frac{1-\beta}{1-\beta(1-\rho)} \left(w_t + \mu_t q_t P_t + \frac{(1-\mu_{t+1}) q_{t+1} P_{t+1}}{R_{t+1}} \right) \tag{13}$$

$$d_{t+1} = \frac{\beta\rho R_{t+1}}{1-\beta(1-\rho)} \left(w_t + \mu_t q_t P_t + \frac{(1-\mu_{t+1}) q_{t+1} P_{t+1}}{R_{t+1}} \right) \tag{14}$$

At the household's optimum, saving is an increasing function of the first period income and a decreasing function of the revenue in old age. When the agent anticipates a high revenue from the sale of pollution rights when old, he has less incentives to save in order to build up a retirement's income. Consumptions are proportional to the present value of the income over the life-cycle[5].

We now turn to the intertemporal equilibrium.

[4] Let us note that the decisions of the households have no impact on the environment.

[5] This income (which corresponds to the term in brackets in (13) and (14)) is determined by the computation of the intertemporal budget constraint of the agent.

3.3 The intertemporal competitive equilibrium

Definition. *Given the policy instruments* $(S_t,\, \Lambda_t,\, \mu_t)_{t=0}^{+\infty}$ *the equilibrium is defined by the per capita variables* $\{c_t,\, d_t,\, s_t\}_{t=0}^{+\infty}$*, the aggregate variables* $\{K_t,\, L_t,\, E_t,\, Q_t\}_{t=0}^{+\infty}$ *and the prices* $\{w_t,\, R_t,\, q_t\}_{t=0}^{+\infty}$ *such that:*
- households and firms are at their optimum (the first-order condition of the representative agent (11) *and the three conditions for profit maximization* (4, 5, 6) *are satisfied),*
- all the markets clear, i.e. $L_t = N = 1$, $k_{t+1} = s_t$ *and* $E_t = P_t$.

As far as the intertemporal equilibrium is concerned, we just characterize capital accumulation and determine consumption decisions at equilibrium. For that we substitute in equations (12), (13) and (14) the prices at equilibrium and we use the markets equilibrium conditions. Hence, the dynamic equation characterizing capital accumulation at equilibrium writes:

$$k_{t+1} = \frac{\beta\rho\alpha_K(\alpha_L + \alpha_E\mu_t)}{(1-\beta(1-\rho))\alpha_K + (1-\beta)\alpha_E(1-\mu_{t+1})} k_t^{\alpha_K} P_t^{\alpha_E} \tag{15}$$

In the same way, we obtain the consumption decisions at the first and the second period:

$$c_t = \frac{(1-\beta)(\alpha_L + \alpha_E\mu_t)(\alpha_K + \alpha_E(1-\mu_{t+1}))}{(1-\beta(1-\rho))\alpha_K + (1-\beta)\alpha_E(1-\mu_{t+1})} k_t^{\alpha_K} P_t^{\alpha_E} \tag{16}$$

$$d_{t+1} = (\alpha_K + \alpha_E(1-\mu_{t+1})) k_{t+1}^{\alpha_K} P_{t+1}^{\alpha_E} \tag{17}$$

Having characterised the competitive equilibrium we now turn to the study of the optimum.

4 Policy instruments and welfare

We first define the optimal solution, namely, the one which maximises social welfare and then we discuss the ways to achieve the optimal growth path from the decentralized economy.

4.1 Social optimum

The optimal solution is given by the sequences $\{c_t\}$, $\{d_t\}$ and $\{P_t\}$ which maximize the discounted sum of the utilities of all the generations under the resource constraint of the economy, the dynamics of the environmental quality being given. The problem can be written as follows:

$$\max_{\{c_t,d_t,P_t\}} \sum_{t=o}^{\infty} \rho^t \left((1-\beta)\log c_t + \beta \log d_t + \delta \log Q_t\right)$$
$$s.t. \begin{cases} k_t^{\alpha_K} P_t^{\alpha_E} = c_t + d_t + k_{t+1} \\ Q_{t+1} = (Q_t - P_t)^{1-\Gamma}\overline{Q}^{\Gamma} \end{cases}$$

We solve this problem with dynamic programming. In this purpose let us define the following value function:

$$V(k_t, Q_t) = B \log k_t + D \log Q_t + G$$

The Bellman equation associated with this problem writes:

$$V(k_t, Q_t) = \max_{c_t,d_t,P_t} (1-\beta)\log c_t + \beta \log d_t + \delta \log Q_t + \rho V(k_{t+1}, Q_{t+1})$$

The resolution (see appendix 1) leads to the optimal allocation of resources between consumptions and investment, and the pollution level:

$$c_t^* = (1-\beta)(1-\rho\alpha_K)\,(k_t^*)^{\alpha_K}\,(P_t^*)^{\alpha_E} \tag{18}$$

$$d_t^* = \beta(1-\rho\alpha_K)\,(k_t^*)^{\alpha_K}\,(P_t^*)^{\alpha_E} \tag{19}$$

$$k_{t+1}^* = \rho\alpha_K\,(k_t^*)^{\alpha_K}\,(P_t^*)^{\alpha_E} \tag{20}$$

$$P_t^* = \frac{\alpha_E(1-\rho(1-\Gamma))}{\alpha_E + \delta\rho(1-\Gamma)(1-\rho\alpha_K)} Q_t^* \tag{21}$$

Consumptions and investment are proportional to output. Investment raises with the share of capital in production. The allocation of global consumption between old and young at period t depends on the weight (β) of each consumption in the preferences. The optimal level of emissions is an increasing linear function of the environmental quality. It follows that along the optimal path, an increase in the environment allows a rise in pollution. Let us re-write equation (21) as follows to simplify notations: $P_t^* = \nu Q_t^*$, with

$$\nu = \frac{\alpha_E(1-\rho(1-\Gamma))}{\alpha_E + \delta\rho(1-\Gamma)(1-\rho\alpha_K)} \tag{22}$$

The share of the environment allocated to production is increasing in the share of pollution in production (α_E) but decreasing in both the weight of the environment in the preferences (δ) and the marginal damage of pollution on the environmental quality $(1-\Gamma)$.

The key question is now to see whether the government is able to drive the economy to this optimal solution by transferring emission rights between generations and redistributing the income from the sale of rights.

4.2 Decentralizing the optimum

The agency is unable to freely adjust its quota to the optimal level. Therefore the role of the government is to fix the intergenerational transfers and to redistribute the proceeds of pollution rights sale in such a way that the equilibrium path of the economy coincides with the optimal one. This is equivalent to choosing the values of the instruments (Λ_t, μ_t) in order to have the equilibrium decisions $\{(3),(15),(16),(17)\}$ matching their optimal expressions $\{(18),(19),(20),(21)\}$.

Proposition. *If* $\alpha_K \in [\frac{\beta-\alpha_E}{1+\beta\rho}, \frac{\beta}{1+\beta\rho}]$*, the implementation of a policy consisting in (i) making intergenerational transfers of pollution rights* $\{\Lambda_t\}$ *and (ii) distributing among the households the proceeds* $(q_t P_t^*)$ *of the sale of rights* $\{\mu_t\}$*, decentralizes the optimal growth in a competitive equilibrium; the optimal values of governmental instruments are given by:*

$$\Lambda_t^* = P_t^* - S + (1-\phi)\Lambda_{t-1}^*$$

$$\mu^* = \frac{\alpha_K + \alpha_E - \beta(1-\rho\alpha_K)}{\alpha_E}$$

Proof. *see appendix 2* ■

The condition on the parameters guarantees that $\mu \in (0,1)$.

Through the operation of intergenerational transfers of pollution rights $\{\Lambda_t^*\}$, the government is therefore able to overcome the inefficiency of the agency's quota $\{S_t\}$. These transfers ensure that the economy achieves the socially preferred pollution level P_t^*. The sale of the corresponding amount of pollution rights generates a revenue $q_t P_t^*$ accruing to the government.

The latter is responsible for the distribution of this revenue to the households. The sharing rule among old and young $\{\mu^*\}$ is another policy instrument of the government. It works like a lump-sum transfers scheme in the standard overlapping generations model *à la* Diamond (1965). It is well-known that, in the Diamond model without environmental concerns the optimality of the decentralized solution can be restored with appropriate lump-sum transfers between generations. The households' incomes profile are then affected and, consequently, their decisions. Through this channel, the government influences their consumption and saving plans. The μ^* sharing rule guarantees that individual decisions lead to the optimum.

Since the pollution and the classical OLG externalities are internalized, the competitive equilibrium decentralizes the whole socially optimal path of the economy.

5 Dynamic analysis

Given the governmental policy, the intertemporal equilibrium coincides with the optimal solution both on the transition and in the long run. First, we conduct an analysis of these equilibrium dynamics. Second, with numerical simulations we describe the time profile of the policy instruments, both the intergenerational transfers $\{\Lambda_t\}$ and the quota $\{S_t\}$, and we compare the optimal solution with two other regimes of public intervention.

5.1 Properties of the equilibrium

Economic dynamics are described by the system of equations in the two state variables (k_t^*, Q_t^*)

$$\begin{cases} k_{t+1}^* = \rho\alpha_K \left(k_t^*\right)^{\alpha_K} \left(\nu Q_t^*\right)^{\alpha_E} \\ Q_{t+1}^* = \lambda (Q_t^*)^{1-\Gamma} \end{cases}$$

with

$$\lambda = \left(\frac{\rho(1-\Gamma)(\alpha_E + \delta(1-\rho\alpha_K))}{\alpha_E + \delta\rho(1-\Gamma)(1-\rho\alpha_K)}\right)^{1-\Gamma} \overline{Q}^{\Gamma}$$

Notice that the dynamics of environmental quality is independent from the dynamics of capital.

Existence of the steady state

Let us consider now stationary paths. A non-trivial steady state (k^*, Q^*) solves the following system of equations:

$$\begin{cases} k^* = \rho\alpha_K (k^*)^{\alpha_K} (\nu Q^*)^{\alpha_E} \\ Q^* = \lambda (Q^*)^{1-\Gamma} \end{cases}$$

We can easily determine the expression of Q^* and the corresponding expression of k^*. We show that there exists a unique non-trivial steady state equilibrium (k^*, Q^*) characterized by the following values:

$$(k^*, Q^*) = \left((\rho\alpha_K (\nu\lambda^{\frac{1}{\Gamma}})^{\alpha_E})^{\frac{1}{1-\alpha_K}}, \lambda^{\frac{1}{\Gamma}} \right) \tag{23}$$

We also can determine the steady state level of the policy instruments for both the agency and the government:

$$(S^*, \Lambda^*) = \left(\nu\lambda^{\frac{1}{\Gamma}}, \frac{\nu\lambda^{\frac{1}{\Gamma}} - S}{\phi} \right) \tag{24}$$

In the long run, the agency tends to fix the quota S_t at the optimal level: $S_t \rightarrow S + \phi\Lambda^* \equiv P^*$. As we can see, the sign of the transfers in the long run depends on the position of S with respect to P^*, but their magnitude is influenced both by this gap and the value of ϕ. If by chance the agency sets S equal to P^* the mechanism of transfers is operative on the transition but it is inoperative in the long run ($\Lambda^* = 0$).

Stability of equilibrium

Since the dynamics of environmental quality are independent from the dynamics of capital, the analysis of stability boils down to the analysis of the dynamics of Q_t. We know that these dynamics are globally stable and converges towards Q^*.

5.2 Numerical simulations

Let us assume that the constant and rigid part of the quota S is set at an arbitrarily high level but inferior to the stationary emissions level: $S < P^*$. From equation (3) optimal pollution satisfies

$$P_t^* = \underbrace{\left(S + \phi\Lambda_{t-1}^*\right)}_{\text{agency's } S_t} + \underbrace{\left(\Lambda_t^* - \Lambda_{t-1}^*\right)}_{\text{government's net transfer}} \tag{25}$$

Time profile of the policy instruments

The dynamics of the two instruments $\{S_t, \Lambda_t\}_{t=0}^{\infty}$ can be analysed by distinguishing three different phases (see figure 1). During the first three periods t_0, t_1 and t_2, the agency's quota remains above the optimal level of emissions ($S_t > P_t^*$). Thus, in order to reach the pollution target, the government transfers rights from the current period to the next, $\Lambda_t = P_t^* - S_t < 0$. One period later the agency adjusts the quota downward ($S_{t+1} < S_t$), but this revision is only partial ($S_{t+1} > P_{t+1}^*$) and forces the government to transfer more rights to the next period ($|\Lambda_{t+1}| < |\Lambda_t|$). Therefore, this first phase is characterized by increasing forward transfers of by the government (Λ_t < 0, $|\Lambda_t|$ is increasing) in order to compensate for the incomplete adjustment of the agency's quota to the moving target.

From period t_3 onwards, the agency's quota falls below optimal emissions ($S_t < P_t^*$, $\forall t \geq t_3$) and the government intervention goes the other way round. The government's net transfer $\Lambda_t - \Lambda_{t-1}$ is now positive and increasing (see equation (25))

Over the four periods t_3 to t_6, the government fills the gap $P_t^* - S_t > 0$ by simply reducing its forward transfers ($\Lambda_t < 0$, $|\Lambda_t|$ is decreasing). This is enough to switch the government's net transfert to a positive value. In reaction, the agency adjusts its quota upward. After period t_7 the increase in the government's net transfers goes but the transfers are now positive. This means that the mechanism of transfers runs now from one period ahead to the current period. The agency continues to adjust its quota upward.

In the long run, the agency's revision process guarantees that the emissions quota tends to the optimal pollution level ($S_t \to P^*$). The transfers Λ_t converge towards a stationary positive level Λ^* and the government's net transfer is nil.

Non-optimal policies

It is interesting to study how the economy departs from the optimal growth path under non optimal policies. Let us consider the optimal policy as the reference case. What would happen in the absence of transfers (*i.e.* $P_t = S$, $\forall t$)? Under this assumption we consider two cases which differ according to the level of S: a high-S case which we will refer to as the weakly green policy and a low-S case which we will refer to as a strongly green policy. The time profiles for capital stock and environmental quality under these scenarios are given in figures 2a and 2b.

The strongly green policy leads to a high level of the environmental quality in the long run, but this level outreaches the level which maximizes the social welfare. Yet, this does not hold in the short term. The economy first experiences a transitory phase of under-accumulation of environmental quality. We know that the optimal emission target moves together with both the environmental and the economic growth processes. Actually, even if the fixed quota is too restrictive on the long run it reveals in excess of the optimal target during the first transitional periods. As far as capital accumulation is concerned, the time profile displays symmetrical properties (see figure 2b). During the first periods of the weakly green scenario, capital growth is stimulated while the environmental quality decreases. Even though this policy seems profitable to wealth accumulation, its benefits are not long-lasting because it irreversibly damages the natural capital. This extreme case illustrates the risks which persist when existing policies are inappropriate. It shed lights on the interest of implementing our mechanism of intergenerational transfers of pollution rights.

6 Conclusion

Our framework of analysis was one with institutional failures in environmental policies resulting from the delegation by governments of the exercise of the policy to an agency. Though motivated by the department's expertise, this delegation may conflict with social welfare maximization for many reasons, *e.g.* lobbying pressures, eco-dumping, bureaucratic inertia. In this context, we proposed a policy mechanism designed both to satisfy the delegation principle and to circumvent the sub-optimality of the environmental regulation.

The government is able to rectify the agency's inadequate policy despite the fact that it is not entitled to issue emission rights. Through its transfers of pollution rights, the government fills the discrepancy between the agency's quota and the socially desired level of pollution. We also show that its action has impacts beyond the mere environmental regulation. The government influences individuals' decisions on consumption and savings by recycling the revenue from the sale of emission rights to the young and old generations. These transfers of revenue operate like typical lump-sum transfers in the overlapping generations model *à la* Diamond. Consequently, the whole optimal growth path is decentralized at equilibrium.

We illustrate the dynamic properties of the transfers mechanism with numerical simulations. Depending on the level on the fixed quota, the transfers of pollution rights may go forward or backward on the transition, and they may switch from one regime to the other. In the long run, the government net transfer is equal to zero since the direction and the magnitude of the transfers are replicated identically over time. We also analyse two types of non-optimal policies, which would conventionnally be labelled respectively as weakly and strongly green. We show that these labels are ambiguous. Indeed, because optimal emissions evolve over time, strongly green policies may actually appear too latitudinarian on the transition and weakly green ones too strict. We study the under/over-accumulations of environmental quality and capital per head which occur along non-optimal paths. Especially, in the presence of an overly-generous quota, environmental quality may irreversibly deteriorate within a few periods.

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7 Appendix

7.1 Appendix1

Using the definitions of k_{t+1} and Q_{t+1} in the constraints, the problem is equivalent to the following:

$$\max_{c_t,d_t,P_t} (1-\beta)\log c_t + \beta \log d_t + \delta \log Q_t + \rho\{B\log(k_t^{\alpha_K} P_t^{\alpha_E} - c_t - d_t) +$$
$$+ D\log((Q_t - P_t)^{1-\Gamma}\overline{Q}^{\Gamma}) + G\}$$

The first-order conditions write:

$$\begin{aligned} \frac{1-\beta}{c_t} &= \frac{\rho B}{k_t^{\alpha_K} P_t^{\alpha_E} - c_t - d_t} \\ \frac{\beta}{d_t} &= \frac{\rho B}{k_t^{\alpha_K} P_t^{\alpha_E} - c_t - d_t} \\ \frac{\rho B \alpha_E k_t^{\alpha_K} P_t^{\alpha_E - 1}}{k_t^{\alpha_K} P_t^{\alpha_E} - c_t - d_t} &= \frac{(1-\Gamma)\rho D}{Q_t - P_t} \end{aligned}$$

The first two conditions give us the relation between c_t and d_t:

$$d_t = \frac{\beta}{1-\beta} c_t \tag{26}$$

By substituting (26) in the first equation we get the consumption decision c_t. Hence d_t can be deduced from (26):

$$c_t = \frac{(1-\beta) k_t^{\alpha_K} P_t^{\alpha_E}}{1+\rho B} \tag{27}$$

$$d_t = \frac{\beta k_t^{\alpha_K} P_t^{\alpha_E}}{1+\rho B} \tag{28}$$

Substituting c_t and d_t in the third condition with the last two expressions gives the emissions level:

$$P_t = \frac{\alpha_E (1+\rho B)}{(1+\rho B)\alpha_E + (1-\Gamma)\rho D} Q_t \tag{29}$$

Let us replace these intermediate solutions (27, 28, 29) in the Bellmann equation so as to identify the coefficients B and D:

$$B = \frac{\alpha_K}{1-\rho\alpha_K}$$
$$D = \frac{\alpha_E + \delta(1-\rho\alpha_K)}{(1-\rho\alpha_K)(1-\rho(1-\Gamma))}$$

Hence, we characterize the optimal allocation of the resources between consumption and investment, and the emissions level, by substituting the value of these coefficients in (27, 28, 29).

7.2 Appendix 2

1. *Decentralizing the optimal pollution*

According to (3), the period t equilibrium emissions are given by:

$$P_t = S_t - \Lambda_{t-1} + \Lambda_t$$

i.e. the volume of the quota ($S_t = S + \phi\Lambda_{t-1}$) less the amount transfered to period $t-1$ (Λ_{t-1}) and plus the amount transfered from period $t+1$ to period t (Λ_t). The government determines its policy in order to realize the equality between equilibrium and optimal emissions:

$$P_t^* = P_t = \Lambda_t + S - (1-\phi)\,\Lambda_{t-1} \tag{30}$$

Given the initial transfer Λ_0 and the optimal emissions path P_t^*, the optimal policy of the government is determined by the choice of the sequence of transfers $\{\Lambda_t^*\}$ such that $P_t^* = P_t$. The pollution target is thus achieved by choosing the sequence $\{\Lambda_t^*\}$ which satisfies, at any time t:

$$\Lambda_t^* = P_t^* - S + (1-\phi)\Lambda_{t-1}^* \tag{31}$$

2. Decentralizing consumptions and capital accumulation

By studying the government optimal distribution of the auction proceeds we decentralize the optimal consumptions and capital accumulation. First, using (15) and

(20), the matching between equilibrium and optimal capital accumulation, $k_{t+1} = k^*_{t+1}$, implies:

$$\rho\alpha_K k_t^{\alpha_K} P_t^{\alpha_E} = \frac{\beta\rho\alpha_K(\alpha_L + \alpha_E\mu_t)}{(1-\beta(1-\rho))\alpha_K + (1-\beta)\alpha_E(1-\mu_{t+1})} k_t^{\alpha_K} P_t^{\alpha_E}$$

This yields the following relation between μ_t and μ_{t+1}:

$$\beta(\alpha_L + \alpha_E\mu_t) = (1-\beta(1-\rho))\alpha_K + (1-\beta)\alpha_E(1-\mu_{t+1}) \tag{32}$$

To identify consumption we use (32) in the expression of equilibrium consumption (16), which yields:

$$c_t = \frac{1-\beta}{\beta} k_t^{\alpha_K} P_t^{\alpha_E}(\alpha_K + \alpha_E(1-\mu_{t+1})) \tag{33}$$

and we equate the latter equation with (18):

$$(1-\beta)(1-\rho\alpha_K)k_t^{\alpha_K} P_t^{\alpha_E} = \frac{1-\beta}{\beta}(\alpha_K + \alpha_E(1-\mu_{t+1}))k_t^{\alpha_K} P_t^{\alpha_E}$$

The value of μ_{t+1} which solves this equation is than plugged into (32) in order to obtain the optimal value of the share of the proceeds accruing to the young at any time t:

$$\mu_t^* = \mu_{t+1}^* = \frac{\alpha_K + \alpha_E - \beta(1-\rho\alpha_K)}{\alpha_E} \tag{34}$$

If the government follows, each period, this rule (34) of distribution among young and old households, it simultanously decentralizes consumptions and capital accumulation.

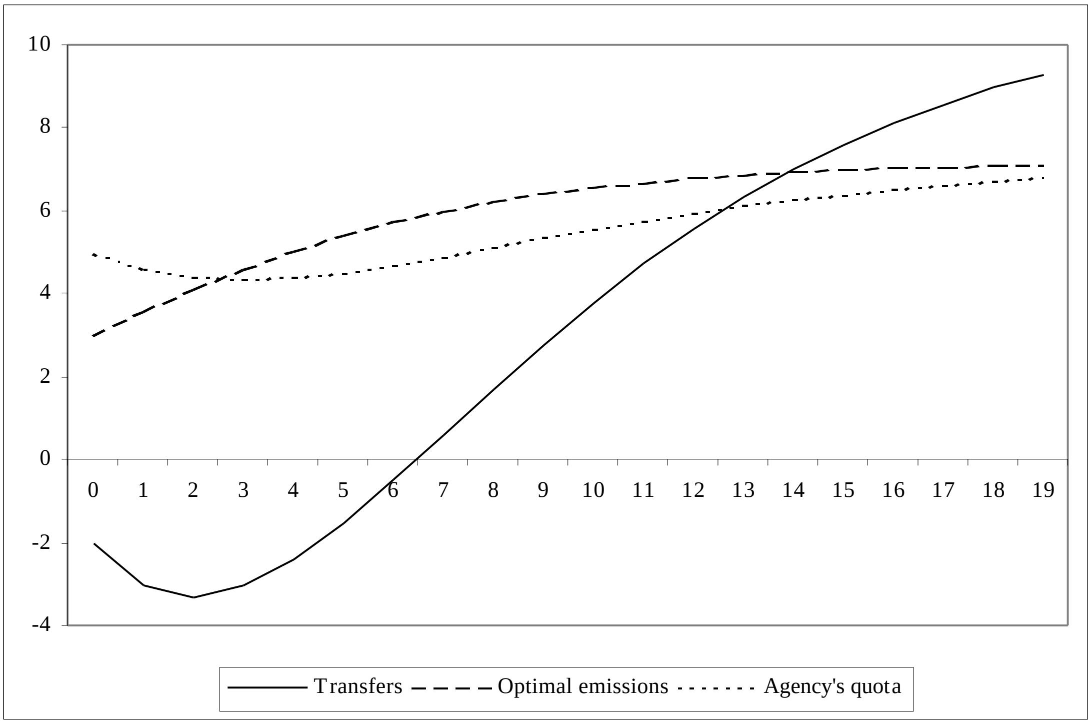

Fig. 1. Time profile of the policy instruments and optimal emissions : an exemple

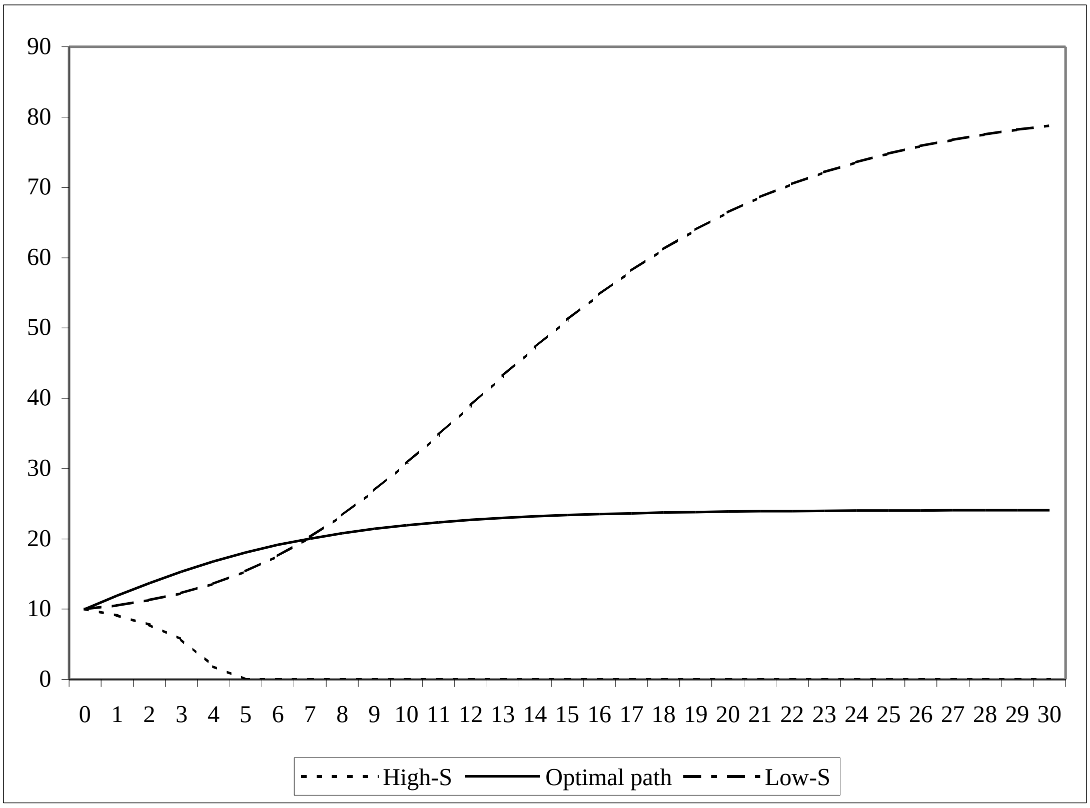

Fig. 2a : Non-optimal policies: the environmental quality

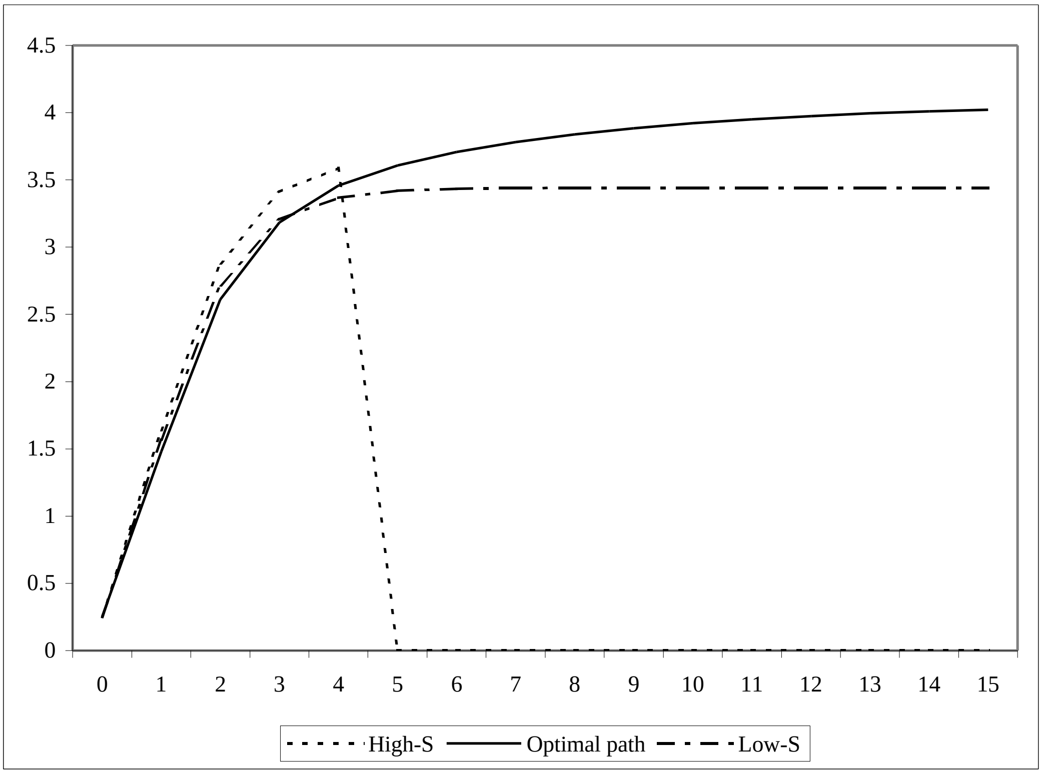

Fig. 2b : Non-optimal policies: the capital stock