Equilibrium with a Market of Permits

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Summary

In this paper we present the main results of three original studies on the equilibrium with a market of tradeable permits in a static framework. In first study, we have considered an international equilibrium of two countries which depend on the quantity of permits to each country. The allocation is efficient if and only if it is proportional to efficient labor. A redistribution in favor of the less developed country implies a redistribution to this country but leads to a dilemma with efficiency. In the second study, we analyze the consequences of the choice between giving free permits to firms and other possibilities. We show that for equalizing incomes of production factors with there marginal productivities, each factor should receive a quantity of free permits proportional to its contribution to production. In the third study, we consider the partial equilibrium of an industry where each firm is characterized by a parameter combining production efficiency and pollution effect. We define a theoretical indicator of environmental efficiency and we analyze its properties.

Keywords: Pollution permits, Capital allocation, International equilibrium, Factor income, Environmental efficiency

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1 General introduction

Since the Kyoto agreement of 1997, the idea of setting up pollution rights as an instrument of environmental policy for the reduction of greenhouse gases has progressed. Tradeable permits were first brought into use in 1975 by the US Environmental Protection Agency (EPA) to reduce air pollution. In 1995, an emission trading programme started in the United States to reduce sulphur dioxide (SO_2). In Denmark, an emission trading system for electricity generators was established by the Danish CO_2 *Quota Act* passed by the Danish Parliament in 1999. Other markets of permits have been experimented (tradeable quotas are used to regulate fisheries in New Zealand and in the European Union (EU))(see Noll 1982, Hahn 1989, Kete 1992, Stavins and Hahn (1993), Tietenberg (2003)) . All these experiences use grandfathering to distribute permits to polluters with an exception for the sulphur reduction programme, in which 2.8% of the permits are auctioned each year.

Recently, a study by the Congressional Budget Office (2000) suggests that if grandfathered permits were used to reduce carbone emissions, low-income households might “loose” several hundred dollars per year while wealthily households could be better-off by “gaining” some $1,500 per year. As shown by Parry (2002), “grandfathered permits create windfall gains for shareholders, who are concentrated in high-income groups, because such policies hand out a valuable asset to firms for free. There is no windfall gain to wealthily households under auctioned permits or emissions taxes ; instead, the government obtains revenues that can be recycled in tax reductions that benefit everyone or disproportionately favor the poor”.

One of the most interesting developments in environmental policy in recent years has been the emergence of global environment as a North-South issue. The close link between global environment and development calls for new insights. In a world of global externalities, national policies have important international repercussions through trade and factor mobility. To be sure that the full impact of environmental policies can be analyzed through to its ultimate effects on factor markets, income and pollution, a general equilibrium approach is needed.

Since Dales (1968), the literature (see for example Baumol and Oates 1998, Pearce and Turner (1990), Cropper and Oates 1992, Tietenberg (1999), Pezzey (2002), Schneider and Wager (2003)) on pollution permits system underline several questions on distribution scheme, on the definition of an international allocation rule for the initial distribution of permits, on the efficiency in the international context, *i.e.* How much does the point of acquittal matter? Do free permits distort competition by creating barriers to entry? Are free permits assigned to sectors or firms? Initial allocation should be based on per capita emission, relative historical responsibility, Size of population,...? What should be the interaction between international and domestic policies?...

Among theses questions, we consider in this paper the three following: Which are the consequences of different allocation rules of permits? Which are the redistribution effects on income distribution of the policy choice of the initial allocation of permits; grandfathering *versus* auctioneering? Does the efficiency of a permit market allow to define the environmental efficiency of different technologies?

In this paper, we refer to three studies on equilibrium with permit market (Jouvet, Michel, and Rotillon (JMR) (2002, 2003 a, 2003 b). Theses papers analyze important consequences of the attribution of permits to firms, studying capital movements, income distributions and technologies efficiency. We present here the main conclusions of these papers and make a special section of political application. Capital movement and income distributions are studied in a model of international equilibrium. The efficiency is analyzed in a partial equilibrium framework considering an industry (given the wage and the demand function).

The paper is set out as follows. Section 2 presents the general framework. Section 3 study the capital allocation at the international equilibrium. In section 4, we analyze the factor income distribution. Section 5 studies the environmental efficiency and section 6 concludes.

2 General framework

Our three studies use the same basic framework,which we present now, for the definition of technologies, the behavior of firms and the equilibrium conditions on the capital market, labor markets and the permits market.

2.1 Production technology

A usual formulation of production with emission of pollutant assumes a neo-classical function homogeneous of degree one with respect to capital, K, labor, L, and emissions, E:

$$Y = G(K, L, E) \tag{1}$$

A typical problem results from the use of a free input when there is no restriction on it. In the literature there are some standard answers (see Turner and Pearce (1990), Baumol and Oates (1998)).

Sometimes one ignore the problem, assuming directly in the economy some quotas or taxes on the free input. In this kind of approach the competitive equilibrium without policy regulation is not defined (see for example Ono (2002)).
Another answer is to impose an upper-bound on emissions, often given exogenously (see for example Jouvet, Michel and Vidal (2000)).
A more technical answer considers a function $G(.)$ non monotonic with respect to emissions (Montgonmery (1972)). [1]

[1] Such a formulation with a negative effect of the stock of pollution on production is often use for dynamics studies (Howarth and Norgaard (1992)).

An interesting way to define a limit on emission is based on the notion of an index of technology used due to Stokey (1998). This index z satisfies $z \leq 1$ and is applied to potential output, $F(K, L)$. F is a standard neo-classical production function homogeneous of degree one with respect to capital, K, and labor, L. Production is

$$Y = zF(K, L) \tag{2}$$

The ratio of emissions on output is an increasing continuous function φ of z

$$\frac{E}{Y} = \varphi(z) \tag{3}$$

or equivalently

$$\frac{E}{F(K, L)} = \psi(z) \tag{4}$$

where $\psi(z) = z\varphi(z)$ is also increasing. Without lost of generality, we assume that $\psi()$ is defined and inversible on $\mathbf{R}^+$. Eliminating z between (2) and (4) allows to define the following production function homogeneous of degree one:

$$\Phi(K, L, E) = \psi^{-1}(\frac{E}{F(K, L)})F(K, L) \tag{5}$$

Production is equal to this function if and only if the index is lower than 1, $z \leq 1$, *i.e.* $Y \leq F(K, L)$. Thus, the three factors production function corresponding to the formulation with an index of technology used is,

$$Y = G(K, L, E) = min\{F(K, L), \Phi(K, L, E)\} \tag{6}$$

This gives production as a function homogeneous of degree one of capital, labor and emissions. This function is not differentiable at the points such that the two terms $F(.)$ and $\Phi(.)$ are equal. In the papers [1] and [3], we use the following Cobb-Douglas formulation:

$$F(K, L) = AK^{\alpha}L^{1-\alpha} \tag{7}$$

and

$$\phi(z) = bz^{\beta} \tag{8}$$

with $A > 0$, $\alpha \in]0, 1[$, $b > 0$ and $\beta > 0$. Then, $\Phi(.)$ is also a Cobb-Douglas function,

$$\Phi(K, L, E) = A^{\frac{\beta}{1+\beta}} b^{\frac{-1}{1+\beta}} K^{\frac{\alpha\beta}{1+\beta}} L^{\frac{(1-\alpha)\beta}{1+\beta}} E^{\frac{1}{1+\beta}} \tag{9}$$

2.2 Firms'behavior

Firms are perfectly competitive and produce an homogeneous good which is taken as numeraire. The competitive firm has a stock of installed capital K and a stock of permits $\overline{E}$. At given q, the price of permits and w, the wage rate, a firm chooses the index of technology, z, labor, L and emissions, E, in order to maximize its net revenue $zF(K, L) - wL - q(E - \overline{E})$ subject to emissions condition $E = \psi(z)F(K, L)$.
The optimal value of z is

$$z = min\{1, \psi^{'-1}(1/q)\} \tag{10}$$

the solution of $\max_{0 \leq z \leq 1} z - q\psi(z) \equiv m(q)$. The optimal choice of labor satisfies,

$$w = m(q)F_L^{'}(K, L) \tag{11}$$

and the corresponding net revenue is,

$$\pi = m(q)KF_K'(K,L) + q\overline{E} \tag{12}$$

This net revenue is distributed to shareholders, the owners of the capital stock. An important property it that return to capital does depend on the quantity of permits attributed to the firms and this property has an important consequence on the equilibrium.

2.3 Equilibrium conditions

The equilibrium in the labor market and in the permits markets implies the equality of demand and supply. The equality of return to capital in all firms results from the arbitrage property. It implies that the allocation of capital at equilibrium will depend on the attribution of permits to firms. In fact, if free permits are given to firms, at the equilibrium the return to capital is generally not equal to the marginal productivity of capital.

3 The capital allocation at the international equilibrium

JMR (2002) consider two countries producing the same good homogenous with the same Cobb-Douglas production technology of capital and labor, and an index of technology used.
For country i, with capital K_i, efficient labor H_i and index of technology $z_i \leq 1$, the production is defined by

$$Y_i = z_i A K_i^{\alpha} H_i^{1-\alpha} \tag{13}$$

with $A > 0$ and $\alpha \in]0,1[$. The ratio of emissions E_i on production Y_i is

$$\frac{E_i}{Y_i} = bz_i^{\beta} \tag{14}$$

with $b > 0$ and $\beta > 0$.

The efficient labor supply and the quantity of permits $\overline{E}$ are given for each country, $i = 1, 2$. The total world capital stock $\overline{K}$ is given and assuming that there is not international mobility of labor, we study its allocation which equalizes the returns in the two countries in the framework of a general equilibrium with an international market of permits.

3.1 Study of the equilibrium

With the equilibrium price $q \geq 0$ on the market of permits, competitive firms in country i maximize $z_i - qbz_i^{1+\beta}$ subject to $z_i \leq 1$. Thus the index of technology used is the same in both countries:

$$z_i = z(q) \equiv min\{1, (\frac{1}{qb(1+\beta)})^{\frac{1}{\beta}}\} \tag{15}$$

The equilibrium wage in country i is equal to the marginal productivity of labor:

$$w_i = (1-\alpha)m(q)AK_i^{\alpha}H_i^{-\alpha} \tag{16}$$

where $m(q) = z(q) - qbz(q)^{1+\beta}$. And the income net of wage and of cost of additional permits is

$$\pi_i = \alpha m(q)AK_i^{\alpha}H_i^{1-\alpha} + q\overline{E}_i \tag{17}$$

Using $E_i = bz(q)^\beta Y_i$ and $Y_i = z(q)AK_i^\alpha H_i^{1-\alpha}$, we obtain the following relation:

$$\pi_i = \alpha(\frac{1}{bz(q)^\beta} - q)E_i + q\overline{E}_i \tag{18}$$

The equilibrium of the market of permits implies $E_1 + E_2 \leq \overline{E}_1 + \overline{E}_2$ with equality if $q > 0$.
The equilibrium of the market of capital implies $K_1 + K_2 = \overline{K}$ and $\pi_1/K_1 = \pi_2/K_2$.

In a world without permits, the equilibrium values of production, Y_i^0, capital stock, K_i^0, and emissions, E_i^0 are proportional to the efficient labor supplies, H_i. Then, the total production, $Y_1^0 + Y_2^0$, is equal to the potential world output, $\mathcal{Y}$,

$$Y_1^0 + Y_2^0 = A(H_1 + H_2)^{1-\alpha}\overline{K}^\alpha \equiv \mathcal{Y}(\overline{K}) \tag{19}$$

and so the total emissions are

$$E_1^0 + E_2^0 = b\mathcal{Y}(\overline{K}) = \widetilde{E} \tag{20}$$

The same equilibrium occurs in the world with permits if and only if $\overline{E}_1 + \overline{E}_2 \geq \widetilde{E}$) and in this case the equilibrium price of permits,q^0, is equal to zero (region A on figure 1).

When the total number of permits is sufficiently low, there exists an unique world equilibrium with under-use of potential output, *i.e.* $z^* = z(q^*) < 1$. The equilibrium ratio of emissions, $e^* = E_2^*/E_1^*$, is a function of the given values of the two ratios: $\mu = H_2/H_1$ of efficient labors and

$\overline{e} = \overline{E}_1/\overline{E}_2$ of initial allocations of permits. Only if the two ratios are equal, $\overline{e} = \mu$, the equilibrium ratios of capital stock, productions and emissions are equal and proportional to the ratio of efficient labors, and then there is no inefficiency.

If the two ratios of efficient labors and of allocations of permits are different, say for example $\mu < \overline{e}$, then the equilibrium ratio e^* satisfies: $\mu < e^* < \overline{e}$. Then, the capital allocation satisfies

$$(K_2^*/K_1^*)^\alpha = e^* \mu^{\alpha-1} \tag{21}$$

and there is an inefficiency of capital allocation which results from the effects of the permits allocation on the return to capital. The world production can be increased by re-allocating capital and keeping the same total world emission. Thix property leads to a reduction factor, $\gamma^* < 1$, such that the total production is $Y_1^* + Y_2^* = \gamma^* z^* \mathcal{Y}(\overline{K})$, z^* being defined by the corresponding total emissions

$$\gamma^*(z^*)^{1+\beta} b\mathcal{Y}(\overline{K}) = \overline{E}_1 + \overline{E}_2 \tag{22}$$

The larger the gap between the ratio of efficient labors, μ, and the ratio of allocations of permits, $\overline{e}$, the smaller the value of the reduction factor, γ^*. This conclusion corresponds to the region B on figure 1 which is characterized by the condition:

$$\overline{E}_1 + \overline{E}_2 < \gamma^* b\mathcal{Y}(\overline{K}) \tag{23}$$

For the intermediary values of total number of permits (region C on figure 1) which are characterized by

$$\gamma^* b\mathcal{Y}(\overline{K}) \leq \overline{E}_1 + \overline{E}_2 < \widetilde{E} \tag{24}$$

there is full-use of potential output in the two countries with a positive price of permits $q^* > 0$, *i.e.* $z^* = z(q^*) = 1$. This has an inefficiency effect on the capital allocation if $\overline{e} \neq \mu$. Then there is a reduction factor, $\hat{\gamma}$, which has similar properties as in region B and satisfies:

$$\hat{\gamma} b \mathcal{Y}(\overline{K}) = \overline{E}_1 + \overline{E}_2 \tag{25}$$

The three regions A, B, C of the international equilibrium are represented on the following figure with coordinate the quantity of permits attributed to country 1, $\overline{E}_1$ and to country 2, $\overline{E}_2$,

INSERT FIGURE 1

Regions corresponding to different equilibria.

3.2 The economic consequences of attribution rules of permits

We consider rules of attribution of permits based on the equilibrium variables in the world without permits. At this equilibrium production, capital and emissions are proportional to the ratio of the efficient labors.

A grandfathering rule attributes permits proportionally to these variables and thus to efficient labor. Then the equilibrium with an international market of permits is simply a proportional reduction of productions and emissions resulting from the common index z^*. There is no change of capital allocation. Such a rule is efficient since it leads to the maximum of the world production subject to a given total emission of pollutants.

Consider now an attribution rule proportional to population. Defining human capital in a country i as the ratio of efficient labor H_i on population N_i, $h_i = H_i/N_i$, we assume $h_2 < h_1$, and we consider the following population attribution rule,

$$\bar{e} = \frac{\overline{E}_2}{\overline{E}_1} = \frac{N_2}{N_1} > \frac{H_2}{H_1} = \mu \tag{26}$$

We can interpret this world as representing a North-South distinction in which the South (country 2) has a lower human capital level than the North (country 1) (see Copeland and Taylor (1994)). Such an attribution is beneficial for the South since at the international equilibrium with the same total emissions (or permits) as in the grandfathering rule, the South produce more, it is a net seller of permits and receives more capital. But it also pollutes more and the total world production is reduced. There is a dilemma between efficiency and redistribution.

Another rule would be to attribute permits proportionally to the per capita variables of the equilibrium in the world without permits. This rule implies

$$\bar{e} = \frac{Y_2^0/N_2}{Y_1^0/N_1} = \mu\frac{N_1}{N_2} \tag{27}$$

This attribution is in favor of the lowest population country.

4 Market for pollution permits and factor income

In this section, we refer to JMR (2003 a) and we study some consequences on the equilibrium of an international allocation of permits assuming that a fraction, f, of permits, $\overline{E}$, is allocated freely to firms, $\overline{E}^F = f\overline{E}$, while the remainder is auctioned, $\overline{E}^G = (1-f)\overline{E}$. We consider a model with n identical countries. This assumption leads to a symmetric equilibrium with $K_i = \overline{K}/n$, $L_i = \overline{L}/n$ for $i = 1, ..., n$, where $\overline{K}$ is the total capital stock and $\overline{L}$ is the total labor in the economy.
In this framework, we analyze the effect of the market for permits on the equilibrium wage, w and on the income of shareholders, π. The introduction of a market of permits always decreases the wage rate but it may decrease or increase profits. It increases profits if restrictions on emissions are not to strong and the fraction of permits allocated to firms is large enough. We show that there is another allocation which restores the neo-classical equilibrium property of the equality between factor income and marginal productivity.

4.1 Equilibrium

4.1.1 The equilibrium with full-use of potential output

In an equilibrium with full-use of potential output, we have $z^* = 1$ and emissions are equal to potential emissions $\widetilde{E} = \psi(1)F(\overline{K}, \overline{L})$. There are two possibilities.

If $\overline{E} > \widetilde{E}$ (excess supply on the market for permits) the equilibrium price of permits is zero then the net value $m(q^* = m(0)$ is equal to one, and $E^* = \widetilde{E}$. The equilibrium wage and rate of return on capital are equal to their marginal productivities, $w^* = F'_L(\overline{K}, \overline{L})$, $\pi^*/K(\overline{K}, \overline{L})$.

The other possibility arises when $\overline{E} = \widetilde{E}$. Then, any value of q^* between zero and $\overline{q}$ is an equilibrium price for permits. All permits are used but there is no transaction on the market for permits. Nonetheless, the fact that $q^* > 0$ affect factor income. In particular, $w^* = m(q^*)F'_L(\overline{K}, \overline{L})$ is smaller than the marginal productivity of labor because $m(q^*) = 1 - q\psi(1) < 1$.

4.1.2 The equilibrium with under-use of potential output

When $\overline{E} < \widetilde{E}$ we have necessarily $E^* = \overline{E}$ in the symmetric equilibrium and $\psi(z(q^*)) = \frac{E^*}{F(\overline{K},\overline{L})} < \frac{\widetilde{E}}{F(\overline{K},\overline{L})} = \psi(1)$. There exists a unique $\overline{z}$, $0 < \overline{z} < 1$ solution of $\psi(\overline{z}) = \frac{\overline{E}}{F(\overline{K},\overline{L})}$. Therefore, the equilibrium price of permits is given by $q^* > \overline{q}$ solution of $z(q^*) = \overline{z}$

4.2 Effect on factor income

4.2.1 Wage and profit

When the equilibrium price for permits, q^*, is equal to zero, factor incomes are equal to their marginal productivities. When the equilibrium price is positive the equilibrium wage and profit are affected by the permits value,

$$w^* = m(q^*)F'_L(\overline{K}, \overline{L}) = z^*\theta^* F'_L(\overline{K}, \overline{L}), \tag{28}$$

with

$$\theta^* = 1 - \frac{\psi(z^*)}{z^*\psi'(z^*)} < 1.$$

Since $\theta^* < 1$, the equilibrium wage rate is smaller than the marginal productivity of labor $\partial Y/\partial L$. The factor θ^* is equal to $1 - 1/\varepsilon^*_\psi$ where ε^*_ψ is the elasticity of ψ in z^*. This is a consequence of costly pollution permits.

The profits per unit of capital is

$$\frac{\pi^*}{\overline{K}} = m(q^*)F'_K(\overline{K}, \overline{L}) + q^* \frac{\overline{E}^F}{\overline{K}} = \theta^* \frac{\partial Y}{\partial K} + q^* \frac{\overline{E}^F}{\overline{K}}. \tag{29}$$

The factor θ^* applies also to the marginal productivity of capital, but the value of permits given to the firm is added.
In the special case where all permits are auctioned ($f = 0, \overline{E}^F = 0$), the two equilibrium returns of the production factors are proportional to marginal productivities.

$$w^* = \theta^* \frac{\partial Y}{\partial L} \quad \textit{and} \quad \frac{\pi^*}{\overline{K}} = \theta^* \frac{\partial Y}{\partial K}. \tag{30}$$

The same factor θ^* applies to the marginal productivities and it is smaller than one if there is under-use of potential output. We show that the equilibrium with a market for permits coincides with the equilibrium with a tax q^* on emissions, *if and only if* all permits are charged to firms (see JMR (2003 a)).

4.2.2 The possibility of increased profits

When $\overline{E} = \widetilde{E}$, $q^* > 0$, $z^* = 1$ and $\theta^* < 1$. The factor θ^* applies to wages. But there exist a possibility of increased profits. A first condition for profits to increase is that the equilibrium index z^* should be close enough to 1. This means that the restriction on emissions should be not to strong. A second condition requires a positive upper bound on the proportion of auctioned permits, or equivalently a lower bound, which is smaller than one, on the fraction of free of charge permits. With these two conditions in the equilibrium with an active market of permits ($q^* > 0$), profits are larger than in the economy without permits. For example, considering a Cobb-Douglas production technology with $\alpha = 1/3$, $\beta = 2$, and a ratio of emissions on production larger than 0.7, if all permits are free of charge ($f = 1$), and the amount of permits reduces production from less to 30%, profits are increased and all the burden are financed by the reduction of wages.

4.3 A fair and efficient distribution of pollution permits

When some free permits are distributed to firms, the equilibrium does not satisfy the neo-classical properties of equality of factor income with marginal productivity. There exist a distribution of permits which restore this equilibrium property. Moreover, the problem of the use of the auction's revenue by the government can be avoided by allocating in a correct way permits to the firms and to the wage earners. This allocation corresponds to attribute freely all permits to firms, $\overline{E}^F$ and workers $\overline{E}^L$, proportionally to their contribution to production, *i.e.* $\overline{E}^F = \overline{E}(KF'_K/F)$ and $\overline{E}^L = \overline{E}(LF'_L/F)$.

According to neo-classical theory, if there is some external effect linked to production, the additional income or cost should be shared between inputs proportionally to there contributions to production. As we have seen giving permits to firms leads to a bias that benefits shareholders. It is even possible that it increases profits. This pleads in favor of an auction scheme, but does not solve the government's redistributive problem. We show that a fair and efficient solution exists, that consists in allocating free of charge permits to production factors proportionally to their contribution to production. In fact, grandfathered permits do not necessarily create windfall gains for shareholders if their allocation is judiciously made to all production factors.

5 Environmental efficiency

In JMR (2003 b) we study an industry with n firms. These firms produce a same good with Cobb-Douglas technologies which differ by productivity and emission.

Pollution is restricted by a tradable market of permits in the industry. Firm i receives a stock of permits $\overline{E}_i,\ i = 1, ..., n$, which it can buy or sell on a market of permits and decides its level of production and so of emission.

The price of input (wage rate, w) and demand curve to the industry are given: $p(Y)$ is the inverse demand curve with $p^{'}(Y) < 0$.

5.1 The equilibrium

First, we assume that each firm i is endowed by a specific technology characterized by two parameters B_i and b_i, respectively productive efficiency and pollution effect.

Each firm i, $i = 1, ..., n$, produces the same good with labor L_i and the potential output is

$$\widetilde{Y}_i = B_i L_i^{\alpha} \tag{31}$$

with a given stock of capital $B_i = AK_i^{1-\alpha} > 0$ and $0 < \alpha < 1$.

Firms are competitive, considering prices as given: p of the produced good, w of labor and q of permits. Each firm i holds a given stock of permits $\overline{E}_i$ and, like in the two precedent papers, its maximizes its profit (including the net gains on the permits market)

$$pY_i - \ wL_i + q(\overline{E}_i - E_i) \quad (32)$$

This implies

$$\frac{L_i}{Y_i} = \frac{\alpha\beta}{1+\beta}\frac{p}{w} \quad (33)$$

At the equilibrium the ratio of productions is equal to the ratio of environmental efficiency factors. More precisely, we have the following result,

For two firms i and j such that $z_i < 1$ and $z_j < 1$ the ratios of emissions, output and labor are equal to the ratio of environmental efficiency factors,

$$\frac{E_i}{E_j} = \frac{Y_i}{Y_j} = \frac{L_i}{L_j} = \frac{D_i}{D_j}$$

where $D_i = (b_i^{1/\beta} B_i)^{\frac{1}{1-\alpha}}$

This result implies that at equilibrium (with $z_i < 1, \forall i$) labor, production and emissions of any firm i are proportional to there total levels in the industry. The coefficient of proportionality is determined by the environmental efficiency factors, $D - i$

$$\frac{L_i}{L} = \frac{Y_i}{Y} = \frac{E_i}{\overline{E}} = \frac{D_i}{\sum_{j=1}^{n} D_j} \equiv \zeta_i$$

The contribution of firm i to the total output is given by ζ_i which is proportional to $D_i = \left(b_i^{-\frac{1}{\beta}} B_i\right)^{\frac{1}{1-\alpha}}$. The environmental efficiency factor.

We show that the existence of an equilibrium with under-use of potential output by all firms implies that total emission $\overline{E}$ is lower than an upper bound $\overline{E}_0$. For all $\overline{E} < \overline{E}_0$, the equilibrium is unique and does not depend on the allocation of $\overline{E}$ between firms.

5.2 Efficiency of production for given total permits

We propose an extension of the notion of productive efficiency including the environmental aspects. This is obtained with a combination of the two parameters of efficiency, the usual productive efficiency B_i and the pollution effect b_i, emission per unit of production. As we shall see, the following definition is useful in order to select the "best" technology in terms of both production and environmental quality.

Definition 1 *The environmental efficiency factor D_i of firm i combines the production efficiency factor B_i and the coefficient b_i of pollution emission, in the following way*

$$D_i = \left(b_i^{-\frac{1}{\beta}} B_i \right)^{\frac{1}{1-\alpha}} \tag{34}$$

If all firms have the same size, comparison between their environmental efficiency is equivalent to compare their environmental efficiency factors D_i. JMR (2003 b) show that *the larger the environmental efficiency factor, the larger the firm's contribution to total production. In different economies with n firms having the same amount of labor and the same total pollution, the larger the sum of environmental efficiency factors, the larger total production.*

The classical framework of the Data Envelopment Analysis applied to environmental analysis (see Färe *et al.* (1989)) may be illustrated in our theoretical model. With the equilibrium condition $L_i/L = D_i/D$, we obtain the following relation between production and emissions depending on D_i.

$$Y_i = \left(\frac{L}{D} \right)^{\alpha \frac{\beta}{1+\beta}} D_i^{\frac{\beta}{1+\beta}} E_i^{\frac{1}{1+\beta}} \tag{35}$$

On figure 1 the corresponding curves are represented for different values of D_i and the equilibrium points are on the intersection with the line $Y_i/E_i =$

$Y/\overline{E}$. This line is the convex hull of the set of equilibrium pairs of production and emission. Our theoretical study allows to define the "best technology" in terms of environmental efficiency (D_1 in Figure 2).

Insert Figure 2

Note that some standard empirical environmental indicators may lead to a different order of environmental efficiency. Consider for example the ratio of emission on production (Jaggi and Freedman (1992)). In our model, in the equilibrium with a market of permits, this ratio is the same for all firms. The historical value of this ratio (without permits) $E_i/Y_i = b_i$ also does not give the same order as our environmental efficiency factors D_i, except if all B_i are equal.

Until now, we have consider that the production efficiency factors B_i are given. But, these factors can be considered as fixed only in the short run. In fact, there may be a size effect which we now explicit simply as a capital stock.

5.3 Capital stock and environmental efficiency

Assume now that the firm i has a capital stock, K_i and that the efficiency factor of production is

$$B_i = A_i K_i^{1-\alpha} \tag{36}$$

Then the potential output $\widetilde{Y}_i = A_i K_i^{1-\alpha} L_i^{\alpha}$ is homogenous of degree one with respect to the two factors capital and labor.

In the long run, the productive efficiency is now characterized by A_i and the pollution technology is always characterized by b_i. With $B_i = A_i K_i^{1-\alpha}$, the environmental efficiency factor,

$$D_i = (b_i^{-1/\beta} A_i)^{\frac{1}{1-\alpha}} K_i = \Delta_i K_i \tag{37}$$

is proportional to the capital stock. The factor of proportionality is $\Delta_i = (b_i^{-1/\beta} A_i)^{\frac{1}{1-\alpha}}$ which combines the efficiency factor of production, A_i and the factor of emissions, b_i. Δ_i is the environmental efficiency factor per unit of capital. The total production of firms is given by $Y = D^{(1-\alpha)\frac{\beta}{1+\beta}} \overline{E}^{\frac{1}{1+\beta}} L^{\alpha\frac{\beta}{1+\beta}}$ with

$$D = \sum_{i=1}^{n} D_i = \sum_{i=1}^{n} (b_i^{-1/\beta} A_i)^{\frac{1}{1-\alpha}} K_i \tag{38}$$

If capital could be reallocated, the maximum of production would be obtained by reallocating it to the firms having the largest efficiency factor per unit of capital and we obtain the following result,

Given a total stock of emission permits $\overline{E} < \overline{E}_0$ and a total stock of capital in the industry $\overline{K} = \sum_{i=1}^{n} K_i$, total production is maximum when all the capital stock is installed in firms which have the highest environmental efficiency factors per unit of capital.

In the short run, with the capital stocks are installed, the policy of allocation of permits has no effect on the short run equilibrium. Nevertheless, such a policy has an important effect on the profits per unit of capital of the firms and on future capital stocks.

5.4 Consequences of permits' allocation on the profitability of the firms

We also study two kind of allocation: granfathering and an allocation of permits proportional to capital. We first show that the profit per unit of capital depends both on environmental efficiency an, on permits' allocation. More precisely, we have,

The profit per unit of capital of the firm i is the sum of the benefits from the permits allocated to the firm and a net unitary profit which is proportional to the environmental efficiency factor per unit of capital.

Is an allocation policy in favor of the most environmental efficient firm ?

The allocation of permits proportional to capital implies that the most profitable firms are those having the largest environmental efficiency factor per unit of capital.

Indeed, with such an allocation all the ratios $\frac{\overline{E}_i}{K_i}$ are equal and we have $\frac{\pi_i}{K_i} > \frac{\pi_j}{K_j}$ if and only if $\Delta_i > \Delta_j$.

In practice, permits are not given proportionally to capital but allocated by granfathering. If we note E_i^0 the emissions of firm i in the economy without permits, we have

$$\frac{E_i^0}{K_i} = b_i A_i^{\frac{1}{1-\alpha}} \left(\frac{\alpha p^0}{w}\right)^{\frac{\alpha}{1-\alpha}} \equiv G_i \left(\frac{\alpha p^0}{w}\right)^{\frac{\alpha}{1-\alpha}}$$

A granfathering allocation is defined by a reduction factor of emission $\theta, 0 < \theta < 1$, $\overline{E}_i = \theta E_i^0 \ \forall i$.

Clearly, the order resulting from granfathering ($G_i < G_j$) is different from the order of environmental efficiency (per unit of capital), except if the b_i's are equal. More precisely, in the granfathering allocation, the ratio of profits per unit of capital is independent of the reduction factor of emission.

Last, we show that in the simple case where all capital stocks are equal, *granfathering may lead a more environmental efficient firm to have a lower profit per unit of capital.*

6 Conclusion

We have first investigated the economic consequences of different allocation rules of permits on the international equilibrium in a two-country model with capital and permit market. We have studied permit allocation rules proportional to production, emissions, physical capital (in level or *per capita*) and to population. We provide a full description of the international equilibrium for all initial allocations of permits. A permit market does not modify the competitive world equilibrium without permits when the total allocation is large enough. When it is not, there exists a unique equilibrium with under-use of the technology, or with full use of the technology in the two countries.

Given the total capital stock, capital mobility and fixed labor, the maximum of the world production subject to a total emissions constraint is reached at the equilibrium obtained by an allocation rule which is proportional to efficient labor (which include the grandfathering rule). They imply proportional reduction of pollution in all countries and have no effect on international capital allocation, under the assumption of the same technology in all countries.

The population allocation rule benefits for developing country (South) in every respects : production, capital transfert and income from the permit market. Nevertheless, *per capita* income remains lower in the developing country.

Per capita allocation rules have different size effects, depending on the ratio of population in the two countries. With the same level of population, the *per capita* rules lead to the efficiency allocation, and thus performs exactly like the level allocations rules. With a different level of population, the developing country benefits if and only if it has a lower level of population than in the developed country which benefits in the opposite case.

Our results shed some light on the recurrent discussion between countries about the initial distribution of permits in a tradeable market. Regarding efficiency, the level allocation rules seems to be the best. But it does not allow for any evolution of the relative income between countries. This shows that the allocation of permits induces a dilemma between efficiency and development.

Our second paper study some consequences of an international allocation of permits assuming that a fraction of permits is allocated freely to firms, while the remainder is auctionned. We consider a model of international equilibrium with n identical countries. The assumption of countries using the same technology to produce the same good leads to a symmetric equilibrium. We analyze the effect of the market for permits on the equilibrium wage rate and on the income of shareholders. We show that the allocation of permits have some consequences on factor income. Giving permits to firms effectively leads to a bias that benefits to shareholders and the equilibrium does not satisfy the neo-classical properties of equality of factor income with marginal productivity . It is even possible that it increases profits (when restrictions on emissions are not very strong). This pleads in favor of an auction scheme, but does not solve the government's redistributive problem (the so-called "double-dividend" problem). We show that a fair and efficient solution exists, that consists in allocating free of charge permits to production factors proportionally to their contribution to production. This distribution of permits restaure the equality of factor income with marginal productivity.

In order to analyze environmental efficiency in an industry with different technologies, we have studied the equilibrium with a market of permits in the third paper. We show that the equilibrium does not depend on the stock of permits allocated to the firms but on the total stock of permits and for each firm on its technology (including the stock of capital).

We said that, given total emissions, a technology is more efficient than another if it leads to a larger global production. With our model, the analysis of the equilibrium allows to define a theoretical measure of environmental efficiency. Our definition of the "environmental efficiency factor" combines for each firm the two parameters linked to productive efficiency and pollution effects. We show that the larger the environmental efficiency factor, the larger the firm's contribution to total production.

This definition takes into account the other production factors which are fixed. But the long run efficiency factor is defined per unit of capital. A policy of permit's allocation based on the environmental efficiency should take into account the time perspective.

We show that an allocation of permits proportional to capital implies that a firm having a larger environmental efficiency factor than an other has also larger profit per unit of capital. This result does not hold with a grandfathering allocation.

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(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

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