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Allocation of tradable emission permits in a global economy

by

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Allocation of tradable emission permits in a global economy

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Abstract:
This paper discusses the question of how a national government should design a system of tradable emission permits when goods or production factors are internationally mobile. Emphasis is on the principles for the allocation of emission permits to firms, and in particular on the role of free emission permits in the design of environmental policies.

It is shown that to allocate emission permits free of charge to certain firms may play a potentially important role in the design of environmental policies. When the allocation criteria are carefully chosen, the use of free emission permits might ensure both higher national welfare and a better environment.

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1. Introduction

National governments often seem to be concerned that their environmental policies will reduce the competitiveness of domestic firms or induce domestic firms to move abroad. This may explain why many governments, which are now working on how to implement their commitments under the Kyoto Protocol, are considering letting domestic firms receive emission permits free of charge, rather than letting them buy the permits at the market price.

While the allocation of emission permits previously was seen primarily as a matter of income distribution, it has to an increasing extent also come to be regarded as a matter of efficiency. One explanation is the strengthened focus on "green tax reforms", i.e., the possibility of using environmental tax revenues to reduce other, distortionary taxes. Another reason is that in a more global economy, where goods and production factors move more freely among countries, increasing attention has been devoted to the role of environmental policy as determinant of the location of production and industries. To allocate emission permits free of charge may seem to be an attractive way of minimising the loss of competitiveness for a given level of environmental protection.

There is a substantial literature on when and how environmental policies can or should be used to affect the location of firms, or more generally, the location of production activities across countries. However, very little has been written on the role of free emission permits in this context. The purpose of this paper is to close this gap. By readdressing previous contributions in this field under the assumption that some emission permits may be allocated free of charge, or more generally, to a price below the market price of emission permits, we will explore the potential impact of this policy instrument.

Our point of departure will be the article by Oates and Schwab (1988). They show that under certain ideal circumstances, it will not be desirable to use environmental policies to attract capital to the home country. These ideal conditions include; no unemployment, perfect competition, non-increasing returns to scale, and only local pollution. The consequences for environmental policies of relaxing the assumptions made by Oates and Schwab have been analysed in a number of contributions. Hoel (1997a) discusses the case of unemployment, and finds that a rigid wage rate may make it optimal to relax environmental standards. Barrett (1994) analyses environmental policies with imperfect competition in product markets and obtains a similar conclusion. Markusen *et al.* (1995), Rauscher (1995) and Hoel (1997b) consider the case of endogenous firm location with increasing returns to scale and conclude that in certain cases it will be optimal to relax environmental standards in order to attract firms, but that the opposite is also a possibility (i.e., the case of *Not In My Back Yard*-policies). Finally, Markusen (1975), Rauscher (1995), Hoel (1996) and Mæstad (1998, 2001) have discussed the impact of transboundary pollution on the design of environmental policies, finding that if domestic environmental taxes or standards are not supplemented by other policy instruments (e.g., taxes/subsidies on international trade and international factor movements), it will be optimal to relax environmental standards in order to avoid relocation of firms.

None of these articles have discussed the possibility of using a system of tradable emission permits where some of the permits may be allocated free of charge. In Sections 3-6 we therefore readdress each of the mentioned issues under the assumption that firms may be able to obtain some emission permits for free. We show that when the allocation rules are carefully chosen, the use of free emission permits will indeed alter many of the conclusions in the previous literature. Free emission permits will in many cases make it desirable to increase environmental standards, thus creating a better environment. National welfare may also improve.

2. Free emission permits

The concept of free emission permits needs to be clarified before proceeding. First, it should be underscored that the essential aspect of free emission permits is not that they are free, but that the emission permits are sold at a price below the going market price. Without loss of generality, we can nevertheless focus exclusively on the case of free permits. It is the *value* of the rebated emission permits that matters to the firms. This value is equal to the number of permits times the margin between the actual price and the market price. If emission permits are not completely free, the (optimal) *number* of rebated permits will simply be increased in order to create the "correct" incentives for firms. Hence, the focus on free permits simply represents an arbitrary choice in the price/quantity space.[1]

Secondly, free emission permits will never be really free, because there will always be one condition or another attached to the permits. The reason why is quite simple to understand. Without any conditions attached to the rebated permits, the value of the rebate would simply add to the equity of the firm. The rebated permits would then not induce any change in firms' behaviour. For instance, if it was profitable for a firm to close down in the absence of free permits, it would be equally profitable to close down after unconditional, free permits are granted; the maximum profit is earned by closing the firm and selling the permits on the market.

Our discussion is therefore only interesting if there are some conditions attached to the "free" emission permits. It may, for instance, be that the rebate is given only if a domestic plant is not closed. Alternatively, the number of free emission permits may be linked to the output level or the level of inputs (e.g., capital or labour). Alternative specifications will be discussed as we go along.

3. Environmental policy in a "perfect", global world

Oates and Schwab (1988) discuss the incentives for local governments to use fiscal and environmental policies to attract capital from abroad. A higher capital stock will be beneficial, because more capital is assumed to increase the marginal product of labour and thus drive up the wage earnings. The model is a standard two-country model with perfectly mobile capital and local pollution. The small country assumption is employed, implying that each country takes the rental rate of capital as exogenously given. Residual profits accrue to labour.

Let us first abstract from environmental issues. It will then not be optimal to subsidise the use of capital in order to attract capital to the home country. As long as firms maximise profits, the subsidy payment will more than outweigh the increase in the wage rate caused by the capital inflow. A profit maximising firm will hire additional capital until the marginal profit is zero. Since all profits are acquired by labour, the firm will choose the level of capital which maximises wage income. A capital subsidy will distort this decision, making the firm employ

[1] Since it may be difficult in practice to let the number of rebated emission permits exceed the total number of emission permits, it may useful to let the rebated emission permits be completely free of charge. That will increase the potential force of this policy instrument.

more than the profit (and net wage) maximising level of capital. Of course, gross wages will increase with a capital subsidy, but this is more than outweighed by an increase in the subsidy payment.

Consider next the issue of environmental protection. In the Oates and Schwab model, there is only local pollution. When the government chooses the environmental standard, it considers both the direct welfare effect and the effect on wages. Lowering the environmental standard will increase the wage earnings, because output will increase and so must the returns to the production factors. Since both emissions and capital have a fixed price, wages are bound to increase.

In the Oates and Schwab model, the marginal product of capital is assumed to increase with the level of emission. Although this effect in isolation lead to an increase in the wage rate, the effect is counteracted by a smaller increase in the wage for a given capital stock, because the returns to capital will then increase and thus reduce the amount available to labour. In fact, the complementarity between capital and emissions is not needed to produce the increase in the wage rate. (But without complementarity, there will be no capital movements in response to changes in the environmental standard, which will make the model less interesting).

The introduction of environmental issues does not fundamentally affect the considerations involved in the determination of the optimal tax on capital use. Hence, the optimal capital tax rate is still zero. With a capital tax rate of zero, there are no effects of environmental policy on tax incomes. Hence the optimal environmental standard is simply to let the marginal rate of substitution between income and environmental quality be equal to the marginal rate of transformation of environmental standards into output. This is the standard Pigouvian rule.

A formal exposition

Let the production function be $y = f(k,l,e)$, with the standard neoclassical properties. Let r denote the exogenous, international rental rate of capital, let s be the capital subsidy, and let p denote the market price of emission permits. The profit-maximising levels of capital and emissions are then given by

$$(1) \qquad \begin{aligned} f_k(k,l,e) &= r - s \\ f_e(k,l,e) &= p \end{aligned}$$

Labour is in fixed supply and earns gross wage earnings W, given by

$$(2) \qquad W = f(k,l,e) - k(r-s) - pe = f(k,l,e) - kf_k - ef_e .$$

Tax income, T, is

$$(3) \qquad T = -sk + pe = -sk + ef_e .$$

Total income, I, is the sum of wage income and tax income:

$$(4) \qquad I = W + T = f(k,l,e) - kf_k - sk .$$

National welfare is given by $u = u(c,e)$, where c is consumption. All income is consumed, i.e., $c = I$. The government maximises welfare by choosing the emission standard e and the capital subsidy s. The first order conditions are

$$(5)\qquad \begin{aligned} &u_c \frac{dc}{de} + u_e = 0 \\ &\frac{dc}{ds} = 0 \end{aligned}$$

In order to proceed, it will be useful to totally differentiate the first order conditions of profit maximisation with respect to e and s. We obtain

$$(6)\qquad \begin{bmatrix} f_{kk} & 0 \\ f_{ke} & -1 \end{bmatrix} \begin{bmatrix} dk \\ dp \end{bmatrix} = \begin{bmatrix} -f_{ke}de - ds \\ -f_{ee}de \end{bmatrix}$$

Using Cramer's rule, we calculate

$$(7)\qquad \begin{aligned} &\frac{dk}{ds} = \frac{-1}{f_{kk}} \\ &\frac{dk}{de} = \frac{-f_{ke}}{f_{kk}} \end{aligned}$$

Consider now how a capital subsidy will affect total income and consumption. The effect on gross wages is ambiguous:

$$(8)\qquad \frac{dW}{ds} = f_k \frac{dk}{ds} - f_k \frac{dk}{ds} - kf_{kk} \frac{dk}{ds} - ef_{ek} \frac{dk}{ds} = k + e\frac{f_{ek}}{f_{kk}}$$

Without environmental policies, a capital subsidy would increase wage income because a higher capital stock would increase output. With environmental policies, a higher capital stock will drive up the price of emission permits, reducing private income.

The effect on tax income is also ambiguous;

$$(9)\qquad \frac{dT}{ds} = -k - s\frac{dk}{ds} + ef_{ek} \frac{dk}{ds} = -k + s\frac{1}{f_{kk}} - e\frac{f_{ek}}{f_{kk}}.$$

While a subsidy reduces tax income, the induced increase in the price of emission permits contributes in the opposite direction.

The effect of a capital subsidy on total income is however clearly negative as long as s is positive

$$(10)\qquad \frac{dI}{ds} = \frac{dc}{ds} = \frac{dW}{ds} + \frac{dT}{ds} = s\frac{1}{f_{kk}} < 0$$

Hence, the optimal capital subsidy is clearly zero ($s = 0$) in this model (see also (5)). The optimal emission level is given by

$$(11) \qquad u_c\left(f_e - kf_{kk}\frac{dk}{de} - kf_{ke} - s\frac{dk}{de}\right) + u_e = 0$$

By utilising (7), this expression can be rewritten as

$$(12) \qquad u_c\left(f_e + s\frac{f_{ke}}{f_{kk}}\right) + u_e = 0\,.$$

By utilising the first order conditions for profit maximisation (1), the optimal policies are thus given by

$$(13) \qquad \begin{aligned} s &= 0 \\ p &= \frac{-u_e}{u_c} \end{aligned}$$

This is to say that the optimal capital subsidy is zero and the price of emission permits (i.e., the marginal costs of abatement) should be equal to the marginal social costs of emissions. In other words, the environmental standard should be at the Pigouvian level.

It is easily seen that this result is fundamentally changed if there for some reason are non-zero taxes/subsidies on capital. Environmental standards will then be used to correct for the distortions in the capital market.

Free emission permits

None of the above results would be affected by introducing free emission permits in the model. Notice that in a model with perfect competition and non-increasing returns to scale, there are no identifiable firms. Hence, we cannot talk about allocating free emission permits to firms. But free emission permits can still be used; they can be distributed based on the level of output or the levels of inputs used in the home country.

Consider first the possibility of allocation of a certain number of free emission permits per unit of capital. We know that this is essentially equivalent to subsidising the use of capital in the home country. But we have shown that there is no role for such subsidies under ideal conditions, i.e., the net capital subsidy should be zero. This implies that if there are no capital taxes or subsidies at the outset, there should be no free emission permits either. On the other hand, if for some reason there is a non-zero tax on capital use at the outset, free emission permits could be used to alleviate this distortion. That would bring the economy towards welfare optimum.

A national government with the ability to freely choose the emission level will in the model of Oates and Schwab be able to attain a first best welfare optimum, because there will be no difference between marginal private and social costs or benefits of an activity. Hence, the introduction of an additional policy instrument, such as free emission permits, is no use, no matter how the permits are allocated.

Policy competition

How are the results obtained above affected by environmental policy in the foreign country? Assume that the foreign country implements a capital subsidy, e.g., through free emission permits allocated per unit of capital in the foreign country. From the perspective of the home country, this means that the international rental rate of capital is higher than at the outset. Capital will then move from the home country to the foreign country. This is a rational response when capital has become more costly in the home country. The use of free emission permits in the foreign country should therefore not lead to similar policies in the home country. The home country should simply adjust its capital stock to a higher rental rate of capital.

Hence, we can conclude that there will be no role for free emission permits in a "perfect" global economy, i.e., an economy with no market imperfections other than a local pollution externality. In the following, we discuss how this conclusion may change as other market imperfections are introduced.

2. Unemployment

A very simple way of modelling unemployment is to assume a fixed wage rate and let employment be determined exogenously. Hoel (1997a) makes such a modification of the Oates and Schwab (1988) model and shows that each country then sets its environmental standard (or environmental tax) below the Pigouvian level. Hoel does not, however, derive the optimal policies. This is what we will do next.

Let w denote the fixed wage rate ($w > 0$). Assume that the firms earn the residual profits. Firms' profits are then

$$\pi = f(k,l,e) - (r-s)k - wl - pe. \tag{14}$$

The first order conditions for profit maximisation are

$$\begin{aligned} f_k(k,l,e) &= r - s \\ f_l(k,l,e) &= w \\ f_e(k,l,e) &= p \end{aligned} \tag{15}$$

Governments maximise the utility $u = u(c,e)$, where the level of consumption is defined by total income (of firms, employees and the government)

$$\begin{aligned} c &= \pi + wl - sk + pe \\ &= f(k,l,e) - rk \end{aligned} \tag{16}$$

The first order conditions are

$$(17)\quad \begin{aligned} & u_c\left[(f_k - r)\frac{dk}{de} + f_l\frac{dl}{de} + f_e\right] + u_e = 0 \\ & (f_k - r)\frac{dk}{ds} + f_l\frac{dl}{ds} = 0 \end{aligned}$$

By utilising the first order conditions for profit maximisation, these conditions can be rewritten as

$$(18)\quad \begin{aligned} & u_c\left[-s\frac{dk}{de} w\frac{dl}{de} + f_e\right] + u_e = 0 \\ & -s\frac{dk}{ds} + w\frac{dl}{ds} = 0 \end{aligned}$$

In order to proceed, we totally differentiate the first order conditions for profit maximisation

$$(19)\quad \begin{bmatrix} f_{kk} & f_{kl} & 0 \\ f_{kl} & f_{ll} & 0 \\ f_{ke} & f_{le} & -1 \end{bmatrix}\begin{bmatrix} dk \\ dl \\ dp \end{bmatrix} = \begin{bmatrix} -f_{ke}de - ds \\ -f_{le}de \\ -f_{ee}de \end{bmatrix}$$

By Cramer's rule, we obtain

$$(20)\quad \begin{aligned} \frac{dk}{de} &= \frac{f_{ke}f_{ll} - f_{le}f_{kl}}{-f_{kk}f_{ll} + f_{kl}^2} \\ \frac{dk}{ds} &= \frac{f_{ll}}{-f_{kk}f_{ll} + f_{kl}^2} \\ \frac{dl}{de} &= \frac{f_{kk}f_{le} - f_{ke}f_{kl}}{-f_{kk}f_{ll} + f_{kl}^2} \\ \frac{dl}{ds} &= \frac{-f_{kl}}{-f_{kk}f_{ll} + f_{kl}^2} \end{aligned}$$

The first order condition for optimal policies can then be written

$$(21)\quad \begin{aligned} & u_c\left[-s\frac{f_{ke}f_{ll} - f_{le}f_{kl}}{-f_{kk}f_{ll} + f_{kl}^2} + w\frac{f_{kk}f_{le} - f_{ke}f_{kl}}{-f_{kk}f_{ll} + f_{kl}^2} + f_e\right] + u_e = 0 \\ & -sf_{ll} - wf_{kl} = 0 \end{aligned}$$

By solving the last equation for s and inserting the optimal s into the first equation, we obtain

$$(22)\quad \begin{aligned} & s = -w\frac{f_{kl}}{f_{ll}} \\ & u_c\left[-w\frac{f_{le}}{f_{ll}} + f_e\right] + u_e = 0 \end{aligned}$$

Rearranging the last equation and using the conditions for profit maximisation (15) yields

$$(23) \qquad p = \frac{-u_e}{u_c} + w\frac{f_{le}}{f_{ll}}$$

Assuming that labour and emissions are complements (i.e., $f_{le} > 0$), this implies that the marginal abatement costs should be lower than the marginal costs of emissions in optimum. Hence, the environmental standard should be lower than what the Pigouvian rule prescribes. This is in order to stimulate labour demand. Higher emissions increase the marginal productivity of labour, and higher emissions therefore alleviate some of the distortion in the labour market.

Similarly, it will be optimal to subsidise the use of capital. This will attract more capital from abroad and will also stimulate labour demand as long as labour and capital are complements ($f_{kl} > 0$).

We therefore conclude that when the level of unemployment is a concern for national governments, it will be optimal both to subsidise capital and to relax environmental standards in order to come to grips with the distortions in the labour market.

Free emission permits

We are interested in whether rebated emission permits might have a role to play in a model of this kind and how their use might affect the results. We assume that free emission permits can be implemented either as a labour subsidy or as a capital subsidy. Let q_L denote the number of free emission permits per unit of labour and let q_K be the number of free emission permits per unit of capital. Since free emission permits allocated to capital are equivalent to a capital subsidy, no other forms of capital subsidies will be specified in this model.

Firms maximise their profit

$$(24) \qquad \pi = f(k,l,e) - (r - pq_K)k - (w - pq_L)l - pe$$

The first order conditions are:

$$(25) \qquad \begin{aligned} f_k(k,l,e) &= r - pq_K \\ f_l(k,l,e) &= w - pq_L \\ f_e(k,l,e) &= p. \end{aligned}$$

The government of the home country maximises utility, $u = u(c,e)$, where consumption is the sum of firms' profit, wage income, and government income[2]

[2] It is implicitly assumed that the home country does not own capital. This assumption does not affect the results as long as the rental rate of capital is taken as given so that there are no terms of trade effects in the capital market.

$$
(26) \qquad \begin{aligned} c &= \pi + wl + p(e - q_K k - q_L l) \\ &= f(k,l,e) - kr. \end{aligned}
$$

Maximisation with respect to the three decision variables e, q_K and q_L yields the following first order conditions

$$
(27) \qquad \begin{aligned} u_c\left[-pq_k\frac{dk}{de}+(w-pq_l)\frac{dl}{de}+p\right]+u_e &= 0, \\ -pq_k\frac{dk}{dq_k}+(w-pq_l)\frac{dl}{dq_k} &= 0 \\ -pq_k\frac{dk}{dq_l}+(w-pq_l)\frac{dl}{dq_l} &= 0 \end{aligned}
$$

It is easily seen that the solution to these equations is given by

$$
(28) \qquad \begin{aligned} p &= \frac{-u_e}{u_c} \\ q_k &= 0 \\ pq_l &= w \end{aligned}
$$

The optimal policy is thus to choose the environmental standard so that the permit price equals the marginal rate of substitution between environmental quality and consumption. This is the Pigouvian rule. Moreover, there is no need to subsidise capital.

These are the same results as Oates and Schwab obtained in their model with fixed labour supply. However, the results differ from those obtained by Hoel (1997a), who finds that endogenous labour supply will call for a less stringent environmental policy standard. The explanation of these seemingly contradictory results is that we have introduced an additional policy variable in our model by making it possible to subsidise the use of labour directly through the allocation of emission permits. The use of free emission permits thus contributes to a better environment as well as to higher national welfare.

In this simple model of endogenous labour supply, increased labour use has no alternative costs from a social point of view. In order for firms to choose the labour use optimally, the wage rate should then be zero. This is obtained by a subsidy corresponding to the wage rate, implemented by allocation of free emission permits in proportion to labour use. More generally, the subsidy on labour use should reflect any difference between the social and the private costs of labour use.

4. Imperfect competition

The Oates and Schwab (1988) model assumes perfect competition in output markets. Their results do not survive however when market power is introduced. With market power, firms will constrain output levels in order to produce pure profits. This in itself is a source of efficiency because the gains for the producers of higher prices and lower output levels will be more than outweighed by consumer losses. Governments may therefore wish to implement policies that stimulate the level of production.

In addition, market power implies that governments may be interested in shifting profits among the firms, e.g., from foreign to domestic firms. Policies that are implemented in order to produce profit shifting are named strategic policies. Hence, the introduction of imperfect competition may lead to the use of environmental policies for strategic purposes. Only this latter issue is related to the international dimension of environmental policies, and we will therefore in the following focus our attention on the strategic use of environmental policies.

Barrett (1994) analyses the case where two firms located in two different countries sell their product to a third market. National governments are concerned by local pollution and by the profits of their local firm. Since all output is sold in third markets, the issue of consumer losses due to imperfect competition does not arise. Barrett argues that in this case, governments will set environmental standards below the Pigouvian level in order to shift profits from the foreign firm to the domestic one. The reason why it is optimal to subsidise local emissions in this way is that the cost reduction of domestic firms will reduce output by the foreign firm. Since the profit of the domestic firm is strictly decreasing in the output level of the foreign firm, this policy will raise domestic incomes (and welfare). By the envelope theorem, a small reduction in environmental quality below the optimal level will have no negative impact on welfare.

This result is closely related to the Brander and Spencer (1985) result about the desirability of export subsidies in the case of a Cournot oligopoly. In the Barrett model, direct subsidies of output or exports are ruled out by assumption. Therefore, the subsidies are implemented more indirectly through a reduction in environmental standards (or taxes).

We are interested in how the result in Barrett (1994) is affected by the introduction of a system of tradable emission permits, where some permits may be allocated free of charge. Let us start by reproducing the essence of the Barrett model.

Let z denote the output price and let $z(y_h + y_f)$ be the inverse demand function, where y_h and y_f are the production quantities of the home country firm and the foreign firm, respectively. Output of the home country firm is given by the production function $y_h = f(k,e)$. The profit of the domestic firm can then be written

(29) $$\pi = z(y_h + y_f)f(k,e) - rk - pe$$

Profit maximisation is achieved when the following conditions are satisfied

(30) $$zf_k - r + \frac{\partial z}{\partial y} y_h f_k = 0$$
$$zf_e - p + \frac{\partial z}{\partial y} y_h f_e = 0$$

Governments choose their environmental policy in order to maximise the utility $u = u(c,e)$ where the level of consumption is the sum of firms' profits and government income;

$$(31)\quad \begin{aligned} c &= \pi + pe \\ &= zf(k,e) - rk \end{aligned}$$

The first order condition for the optimal choice of the emission standard is

$$(32)\quad u_c\left[\frac{\partial z}{\partial y}y_h\left(\frac{dy_h}{de}+\frac{dy_f}{dy_h}\frac{dy_h}{de}\right)+zf_e+(zf_k-r)\frac{dk}{de}\right]+u_e=0$$

By utilising the conditions for profit maximisation, this condition can be rewritten as

$$(33)\quad u_c\left[\frac{\partial z}{\partial y}y_h\left(f_e+f_k\frac{dk}{de}\right)\left(1+\frac{dy_f}{dy_h}\right)+p-\frac{\partial z}{\partial y}y_hf_e-\frac{\partial z}{\partial y}y_hf_k\frac{dk}{de}\right]+u_e=0$$

By simplifying and rearranging terms, we obtain

$$(34)\quad p=\frac{-u_e}{u_c}-\frac{\partial z}{\partial y}y_h\frac{dy_f}{dy_h}\left(f_e+f_k\frac{dk}{de}\right)$$

Under Cournot competition, the output of the foreign firm will decrease with domestic outputs ($dy_f/dy_h<0$). Assuming that capital and emissions are complements implies that $dk/de>0$. Then it follows that the price of emission permits should be lower than the marginal environmental costs (i.e., $p<-u_e/u_c$).

Free emission permits

We now introduce the possibility of free emission permits, q_k, to the firm located in the home country. The profit of the firm is then

$$(35)\quad \pi = z(y_h+y_f)f(k,e)-(r-pq_k)k-pe$$

The optimal emission level is determined by the same condition as above, while the condition for the optimal capital use now takes the following form

$$(36)\quad zf_k-(r-pq_k)+\frac{\partial z}{\partial y}y_hf_k=0$$

The optimal allocation of free emission permits is obtained by differentiating the utility function with respect to q_k (notice that total income is the same here as above because free emission permits to firms reduces government income one by one);

$$(37)\quad \frac{\partial z}{\partial y}y_h\frac{dy_h}{dq_k}\left(1+\frac{dy_f}{dy_h}\right)+(zf_k-r)\frac{dk}{dq_k}=0.$$

By inserting the first order condition for profit maximisation, this expression can be written as

(38) $$\frac{\partial z}{\partial y} y_h f_k \frac{dk}{dq_k}\left(1+\frac{dy_f}{dy_h}\right)+\left(-pq_k-\frac{\partial z}{\partial y} y_h f_k\right)\frac{dk}{dq_k}=0$$

By solving for pq_k, we obtain

(39) $$pq_k=\frac{\partial z}{\partial y} y_h f_k \frac{dy_f}{dy_h}$$

This shows that some emission permits should be allocated free of charge and should be related to the amount of capital use in the home country firm.

Concerning the optimal emission standard, utility maximisation is obtained by fulfilling the same condition as above (see (25)). The solution is not the same, however, because the first order condition for optimal capital use has changed. By using the new profit maximisation condition, the welfare maximising emission level can now be found as the solution to

(40) $$u_c\left[\frac{\partial z}{\partial y} y_h\left(f_e+f_k\frac{dk}{de}\right)\left(1+\frac{dy_f}{dy_h}\right)+p-\frac{\partial z}{\partial y} y_h f_e+\left(-pq_k-\frac{\partial z}{\partial y} y_h f_k\right)\frac{dk}{de}\right]+u_e=0$$

By cancelling terms and inserting the optimal pq_k, we obtain

(41) $$u_c\left[\frac{\partial z}{\partial y} y_h\left(f_e+f_k\frac{dk}{de}\right)\left(\frac{dy_f}{dy_h}\right)+p+\left(-\frac{\partial z}{\partial y} y_h \frac{dy_f}{dy_h} f_k\right)\frac{dk}{de}\right]+u_e=0$$

The optimal price of emission permits is now given by

(42) $$p=\frac{-u_e}{u_c}-\frac{\partial z}{\partial y} y_h \frac{dy_f}{dy_h} f_e .$$

This shows that it is optimal to maintain the price of emissions below the social marginal costs of pollution $(-u_e/u_c)$ also when free emission permits are allocated to capital. We notice that both the capital subsidy and the implicit subsidy on emissions are related to the strategic policy element; it is only when the home country is able to influence the foreign output level $(dy_f/dy_h<0)$ that it is optimal to implement these subsidies. It is also a necessary condition that firms possess market power $(\partial z/\partial y<0)$.

By comparing the optimal price of emission permits before and after free emission permits are introduced, we realise that the price of permits will be higher when free emission permits are used. This is because part of the subsidy element that was previously implemented through low environmental standards is now implemented through capital subsidies. This shows that to implement export subsidies through low environmental standards is not an efficient choice of policy instrument in general.

It is clear that in the model at hand, what the government really should do is to subsidise output (or exports) (cf. Brander and Spencer (1985)). It is a higher level of domestic output that may lead the foreign firm to contract its level of output. Therefore, the output level is the appropriate policy target. Output subsidies can however be replicated by input subsidies. We will now show that the input subsidy that we have derived in the model with free emission permits replicates an output subsidy and therefore is a first best policy choice for the home country.

Let s_y denote an output subsidy and let s_k and s_e denote factor subsidies to capital and emissions, respectively. In order for factor subsidies to replicate an output subsidy, the firms' profits must be the same with an output subsidy as with factor subsidies, i.e.

(43) $$(z+s_y)y - rk - pe = zy - (r-s_k)k - (p-s_e)e$$

or

(44) $$s_y y = s_k k + s_e e$$

Assuming constant returns to scale, this expression can be rewritten as

(45) $$s_y(f_k k + f_e e) = s_k k + s_e e$$

This condition is satisfied if

(46) $$\begin{aligned} s_k &= s_y f_k \\ s_e &= s_y f_e \end{aligned}$$

By comparing these expressions with the optimal capital subsidy and the subsidy element of the emission standard, we realise that the solution that we derived above is equivalent to an output subsidy of

(47) $$s_y = \frac{\partial z}{\partial y} y_h \frac{dy_f}{dy_h}.$$

In other words, the introduction of free emission permits may be used to implement the first best solution provided the emission permits are allocated proportionally with output (or equivalently, with each of the inputs used). The use of free emission permits contributes to a higher level of environmental protection, because the price of emission permits will increase as more of the subsidies are implemented through alternative policy instruments.[3]

5. Imperfect competition and internationally mobile firms

In Barrett's (1994) analysis, the countries compete for market shares, because a high market share implies high domestic incomes. Although production activities can be reallocated

[3] Constant returns to scale were assumed in order to prove this point. With decreasing retuns, there must be an additional factor that earns the residual rent. In that case, the residual factor also needs to be subsidised in order to replicate an output subsidy through factor subsidies.

between countries, there is no international mobility of production factors, or firms. In this section we extend the analysis to the case of internationally mobile firms.

The design of environmental policies in the case of endogenous plant localisation has been discussed by Markusen *et al.* (1995), Hoel (1997b), and Rauscher (1995). In these papers, the only policy variable used to influence plant location as well as environmental quality is an environmental tax. If there are net benefits of having production plants located at home, the Nash equilibrium in environmental taxes will imply that taxes are set lower than marginal environmental costs in order to attract more plants. However, if pollution is local, there will also be costs related to domestic localisation of polluting firms. If pollution costs are high enough, the countries may raise their environmental taxes above the Pigouvian level in order to defer plant locations at home. It is therefore not obvious that endogenous plant locations will reduce the level of environmental taxes.

We want to discuss how the conclusions in this literature are modified if a system of tradable emission permits is used instead of environmental taxes and some of the permits may be allocated free of charge.

We will take a modified version of the model used by Hoel (1997b) as our starting point. In its simplest version, this is a partial equilibrium model with two identical countries and only one firm. Hence, the strategic issues discussed in the previous section do not arise here. There is a negative environmental externality from production of the good under consideration, affecting the country where the firm is located only (i.e., local pollution). There are zero costs of transportation, implying that it will be optimal to serve the market from only one production plant. [4]

The plant will be located in the country where profits are highest. Governments are assumed to be able to credibly commit to a level of emission taxes. The model is thus formulated as a two-stage game, where governments choose emission taxes at the first stage, and the firm chooses its location, its level of output and thus the level of pollution at the second stage.

We will modify this model by assuming (as we did above) that the market served is located in a third country and that the two other countries therefore ignore consumer welfare. The practical implication of this assumption for the optimal policies is that there will be no output subsidy that compensates for the tendency of the monopolist to select an inefficiently low level of output. Assume also that the fixed costs of being located in the third country are higher than in the two other countries, implying that the third country will never be considered as a profitable location.

The profit of the firm is

(48) $\pi = zy - p(e - q)$

where q is the number of free emission permits received by the firm if located in a given country. Note that the firm receives free emission permits only from the country where the firm is actually located. This is a necessary requirement in order for free emission permits to affect location decisions.

[4] Markusen *et al.* (1995) include transport costs in their analysis. This implies that it may be optimal to serve the market from several plants.

The country where the firm is located earns a tax income of $T = p(e-q)$. It also incurs environmental costs from production. Let $u_i(c,e)$ denote the welfare level of country i, and let country 1 be the country where the firm is located and country 0 be the other country.

Let the residents of each of the two first countries own an equal share α of the firm. Residents in the third country may also own a share of the firm. Hence, $\alpha \le 0.5$. Welfare levels may now be defined as

$$
(49) \qquad \begin{aligned} u_1(p,q) &= u(\alpha\pi(p,q) + T(p,q), e(p)) \\ u_0(p,q) &= u(\alpha\pi(p,q), 0) \end{aligned}
$$

Since changes in environmental policy may cause the firm to relocate, the welfare function may be discontinuous in the policy variables. Traditional marginal analysis is therefore not appropriate. However, if both the price of permits, p, and the number of free emission permits q are changed simultaneously so that profits remain unchanged, no relocation will take place and differentiation is therefore possible. Let us therefore start by characterising the optimal price of emission permits under the assumption that no relocation takes place. Technically, this is done by maximising $u_1(p,q)$ with respect to p under the assumption that q is changed so that $d\pi = 0$. Differentiation of the profit function yields (using the first order conditions for profit maximisation)

$$
(50) \qquad d\pi = -(e-q)dp + pdq
$$

Solving this expression under the assumption that $d\pi = 0$ yields

$$
(51) \qquad \frac{dq}{dp} = \frac{e-q}{p}
$$

By using this relationship, we can use differentiation in order to find the maximum welfare given that profit remains unchanged.

$$
(52) \qquad \left.\frac{du_1}{dp}\right|_{d\pi=0} = u_c\left[e-q+p\frac{\partial e}{\partial p} - p\frac{e-q}{p}\right] + u_e\frac{\partial e}{\partial p} = 0
$$

By solving for p, we realise that the optimal emission level is given by the Pigouvian rule

$$
(53) \qquad p = \frac{-u_e}{u_c}
$$

The interpretation is as follows: The two countries participate in a game about the localisation of the firm, where relative profit levels determine location. This result says that for any target value of profits, it will be optimal for the home country to arrange its environmental policy so that the Pigouvian rule applies; the emission level should be chosen so that marginal abatement costs equal marginal environmental costs. In other words, it is more efficient to use free emission permits than to use low environmental standards or low taxes in order to attract firms from abroad.

Hence, when free emission permits are introduced, the location game can be recast as a game with only one variable; the number of free emission permits. Differentiation of the welfare functions with respect to q yields

$$(54)\qquad \begin{aligned} \frac{du_1}{dq} &= u_c(\alpha p - p) < 0 \\ \frac{du_0}{dq} &= u_c \alpha p \geq 0 \end{aligned}$$

In the country where the firm is located, welfare is monotonically declining in the number of free emission permits. Giving more free permits reduces government income. Firms' profits increase correspondingly, but since part of these profits accrue to foreigners, domestic welfare must decline. The country where the firm does not locate will be better off with more emission permits, because the value of its shares in the firm will then increase. The game can be described by the following figure[5]

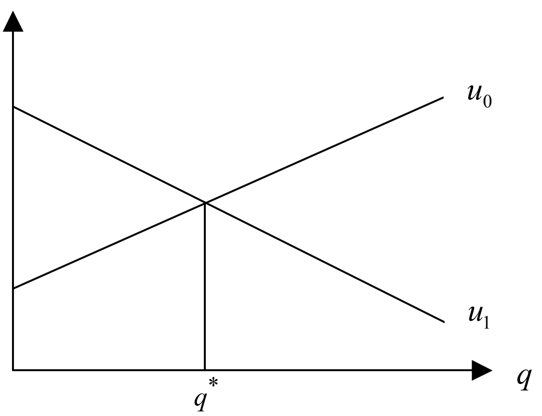

Fig. 1: The equilibrium level of free emission permits

The Nash equilibrium level of free emission permits is q^*. Given that country 0 has chosen q^*, country 1 cannot increase its welfare by reducing the number of free emission permits below the level q^*, because the firm will then move to the other country (provided the environmental standard is not more stringent there). Given that country 1 has chosen q^*, country 0 cannot increase its welfare by increasing the number of free emission permits, because it then will attract the firm, inducing a lower welfare level.

[5] The figure is drawn based on the implicit assumption that $u_1(p,0) > u_0(p,0)$. In the opposite case, which is also possible, the equilibrium number of free emission permits will be negative. Although a negative number of free emission permits may be difficult to implement in practice, there are no conceptual problems with such a solution. It can be implemented by making firms obliged to buy more emission permits than they need for their actual emissions.

We conclude that increasing returns and endogenous firms' location will not influence environmental standards when free emission permits are introduced. Free emission permits make environmental taxes or standards superfluous as means of influencing firm locations. It is more efficient to use free emission permits for this purpose, because such permits affect profits more directly. Note that since the environmental standard without free emission permits may be either more or less stringent than the Pigouvian standard, the impact of free emission permits on environmental quality is ambiguous in this case.

6. Transboundary pollution

The model analysed by Oates and Schwab (1988) considers local pollution only. Many environmental externalities are international in the sense that the pollution damage is imposed also in other countries than where the polluting activities take place. The problem of global warming is a case in point.

Assuming that the home country is not concerned about impacts on foreign welfare, the fact that activities in the home country create polluting spill-over effects on other countries (in addition to the local effects) does not affect optimal environmental policies in the home country. An international externality is per definition external to the home country and does therefore not affect its optimal policies.

However, the fact that the home country may be polluted from abroad matters for the optimal policies, in so far as the home country may affect the amount of pollution that comes from abroad.

There are several ways in which policies in the home country may affect the amount of pollution that it receives from abroad. By increasing the costs of domestic production, environmental taxes and standards may induce increased foreign production and pollution through improved competitiveness of foreign firms. Moreover, domestic policies may cause a relocation of productive resources (e.g., capital or firms) to the foreign country and thus induce more transboundary pollution from abroad.

The design of environmental policies in the case of transboundary pollution has been discussed by Markusen (1975), Rauscher (1995), Hoel (1996), Mæstad (1998,2001), among others. In the articles by Markusen (1975) and Mæstad (1998), there are no movements of productive factors across countries. Domestic policies may still affect the amount of pollution from abroad due to international trade in product markets. In the following, we will concentrate on the cases where environmental policies are used to compete for capital or firms. But before turning to that issue, it is worth noting how environmental policies should be designed when there is no such factor mobility.

Assume that a homogenous good is produced in two countries by a production process that causes transborder externalities. The good may be traded internationally. When one country imposes an emission tax, the costs of domestic producers will increase, causing an upward shift in the "world market" price of the good. Foreign producers will then respond by increasing their level of production. Hence, the domestic reduction of pollution is (partly) offset by increased transboundary pollution from abroad.

As shown by Markusen (1975), Hoel (1996) and Mæstad (1998), the optimal environmental policy in this case consists of a domestic environmental tax at the Pigouvian level combined with an import tax (or export subsidy). The use of trade instruments is cost efficient because it is through international trade that domestic environmental policies cause increased pollution from abroad. If trade measures are not available, it will however be efficient for the home country to relax the domestic emission standard in order to reduce the amount of transboundary pollution.

If trade policies are available, there is no reason to allocate free emission permits to domestic producers in this case. The use of trade policies is however regulated through the WTO, and it is generally not allowed to impose restrictive trade policies on the basis of lax environmental policies abroad. Free emission permits may then be used instead of trade provisions. Notice that an import tax/export subsidy may be replaced by the combination of an output subsidy and a tax on domestic consumption. Hence, trade provisions can be replaced by the combination of free emission permits allocated per unit of output (i.e., an output subsidy) and a domestic consumption tax. In this case, the use of free emission permits contributes to a more restrictive emission standard in the home country.

We now turn to the case of international externalities combined with international factor mobility by introducing internationally mobile capital. We are then essentially back to the Oates and Schwab (1988) model format, except that there are international rather than local externalities. Let e_h denote emissions generated at home and let e_f denote foreign emissions. Pollution damage in the home country is $e = e_h + \gamma e_f$, where γ represents the degree of transboundary pollution.

The government of the home country chooses its environmental policy in order to maximise domestic welfare. The environmental policy takes the form of a domestic emission standard e_h that may or may not be combined with a certain number of free emission permits q_k per unit of capital. Except for the new definition of pollution damage, this model is essentially identical to the model developed in Section 3. The only modification needed is to replace the capital subsidy s in that model with the value of free emission permits per unit of capital pq_k.

We first derive optimal policies in the absence of free emission permits and then study the effect of introducing such permits.

In the absence of free emission permits, the first order condition for welfare maximisation is

$$(55) \qquad u_c \frac{dc}{de_h} + u_e \left(1 + \gamma \frac{de_f}{de_h} \right) = 0$$

In the more general case with free emission permits, consumption is defined as $c = f(k,l,e) - kf_k - pq_k k$. With $q_k = 0$ we then have

$$(56) \qquad \frac{dc}{de_h} = f_e - kf_{kk} \frac{dk}{de_h} - kf_{ke}$$

By using the expression for dk/de_h from (7), we can rewrite the first order condition for welfare maximum as

$$(57)\qquad f_e = \frac{-u_e}{u_c}\left(1+\gamma\frac{de_f}{de_h}\right).$$

Now, let K be the total capital stock available. The stock of capital employed in the foreign country is then $K-k$. By utilising the first order condition for profit maximisation (1), the optimal environmental policy can then be characterised by

$$(58)\qquad \begin{gathered} p = \frac{-u_e}{u_c}\left(1+\gamma\frac{de_f}{d(K-k)}\frac{d(K-k)}{dk}\frac{dk}{de_h}\right) \\ \Updownarrow \\ p = \frac{-u_e}{u_c}\left(1+\gamma\frac{f_{ke}}{f_{kk}}\frac{de_f}{d(K-k)}\right) \end{gathered}$$

If capital and emissions are complements ($f_{ke} > 0$), environmental policy in the home country will induce capital flight to the foreign country. Foreign emissions will then increase. With transboundary pollution ($\gamma > 0$), increased foreign pollution reduces home country welfare. Therefore, the optimal price of emission permits will here be lower than the Pigouvian tax ($p < -u_e/u_c$). Lax environmental standards are used in order to attract capital to the home country.

Consider next how the optimal policies will change when free emission permits may be allocated to capital in the home country. The first order conditions for the government are now

$$(59)\qquad \begin{aligned} & u_c\frac{dc}{de_h} + u_e\left(1+\gamma\frac{de_f}{de_h}\right) = 0 \\ & u_c\frac{dc}{dq_k} + u_e\gamma\frac{de_f}{dq_k} = 0 \end{aligned}$$

The effect on consumption of changes in e_h and q_k is given as

$$(60)\qquad \begin{aligned} & \frac{dc}{de_h} = f_e - (kf_{kk} + pq_k)\frac{dk}{de_h} - kf_{ke} - kq_k\frac{dp}{de_h} \\ & \frac{dc}{dq_k} = -(kf_{kk} + pq_k)\frac{dk}{dq_k} - kq_k\frac{dp}{dq_k} - pk \end{aligned}$$

In order to proceed, we totally differentiate the first order conditions for profit maximisation

$$(61)\qquad \begin{aligned} & f_k = r - pq_k \\ & f_e = p \end{aligned}$$

yielding

$$\begin{bmatrix} f_{kk} & q_k \\ f_{ke} & -1 \end{bmatrix} \begin{bmatrix} dk \\ dp \end{bmatrix} = \begin{bmatrix} -f_{ke}de - pdq_k \\ -f_{ee}de \end{bmatrix} \quad (62)$$

Using Cramer's rule, we obtain

$$\begin{aligned} \frac{dk}{de_h} &= \frac{f_{ke} + f_{ee}q_k}{H} \\ \frac{dp}{de_h} &= \frac{-f_{kk}f_{ee} + f_{ke}^2}{H} \\ \frac{dk}{dp} &= \frac{p}{H} \\ \frac{dk}{dp} &= \frac{pf_{ke}}{H} \end{aligned} \quad (63)$$

where H is the determinant of the Hessian; $H \equiv -f_{kk} - f_{ke}q_k$.

The first order condition for optimal use of free emission permits can now be written as

$$\begin{gathered} u_c\left(-(kf_{kk} + pq_k)\frac{p}{H} - kq_k\frac{pf_{ke}}{H} - pk\right) + u_e\gamma\frac{de_f}{d(K-k)}\frac{d(K-k)}{dk}\frac{p}{H} = 0 \\ \Updownarrow \\ u_c\left(-(kf_{kk} + pq_k) - kq_kf_{ke} - kH\right) - u_e\gamma\frac{de_f}{d(K-k)} = 0 \end{gathered} \quad (64)$$

Further simplification yields the following formula for the optimal use of free emission permits

$$pq_k = \frac{-u_e}{u_c}\gamma\frac{de_f}{d(K-k)} \quad (65)$$

Hence, with transboundary pollution, it is desirable for the home country to allocate some free emission permits based on domestic use of capital in order to prevent capital flight and the resulting increase in pollution from abroad.

The optimal emission limit can now be found as the solution to

(66)

$$u_c\left(f_e-\left(kf_{kk}-\frac{u_e}{u_c}\gamma\frac{de_f}{d(K-k)}\right)\frac{dk}{de_h}-kf_{ke}-kq_k\frac{dp}{de_h}\right)+u_e\left(1+\gamma\frac{de_f}{d(K-k)}\frac{d(K-k)}{dk}\frac{dk}{de_h}\right)=0$$

$$\Updownarrow$$

$$u_c\left(f_e-kf_{kk}\frac{f_{ke}+f_{ee}q_k}{H}-kf_{ke}-kq_k\frac{-f_{kk}f_{ee}+f_{ke}^2}{H}\right)+u_e=0$$

By inserting the expression for H and using the first order conditions for profit maximisation, we obtain

(67) $$p=\frac{-u_e}{u_c}$$

In other words, the use of free emission permits allocated to capital implies that the domestic emission standard can be chosen at the Pigouvian rate, i.e., marginal abatement costs should equal marginal environmental costs. Once again we have then demonstrated that the use of free emission permits, when allocated based on appropriate criteria, will bring environmental taxes and standards back to the Pigouvian level.

Note, however, that the optimal policy for the home country may still be far from efficient from an international point of view. If the government disregards welfare impacts on other countries through transboundary pollution, the domestic emission standard will fall short of the emission standard that would ensure efficiency from a global point of view.

For this reason, international environmental problems cannot be solved without international cooperation, for instance through an international environmental agreement. If such an agreement has been formed, and all countries involved have committed to reduce their emission levels to a certain level, this will significantly affect the results in this section. Most importantly, the foreign emission level will be independent of policies in the home country, i.e., $de_f=0$. This implies that there is no incentive for the home country to relax its environmental standard in order to reduce transboundary pollution from abroad. Nor will it be desirable to allocate free emission permits to capital in order to reduce capital outflows.

These conclusions rest crucially on the assertion that the international agreement encompasses all countries that impose environmental harm upon each other. However, international agreements are sometimes incomplete in the sense that some countries do not participate. In that case, the issue of capital flight will be relevant for the policies implemented vis-à-vis the non-participating countries. In other words, it will be optimal to allocate free emission permits in order to prevent capital from escaping to countries outside the environmental agreement.

7. Conclusions

This paper has discussed the use of rebated emission permits in environmental policy in a world characterised by free movement of goods and/or production factors across national borders. To allocate emission permits free of charge is often criticised because there is a welfare loss, as the government must finance lost revenue through distortionary taxation. This paper shows that there also are potential benefits of free emission permits. Free emission permits may be used to correct for distortions which otherwise might lead politicians to relax their environmental standards. In this way, free emission permits may change environmental policy for the better. National welfare may also improve, as more efficient policy instruments are implemented. If there are no market imperfections (in addition to local pollution externalities), we have found no reason to give any emission permits away for free.

The analysis has also revealed the importance of carefully choosing the criteria for the allocation of free emission permits. The basic lesson is that the allocation criteria should be linked as closely as possible with the source of the underlying market distortion. Hence, when there is unemployment, the number of free permits should be linked with the firms' use of labour. And when international capital mobility causes increased transboundary pollution, the number of free permits should be linked with the domestic use of capital. In other cases, the allocation of free emission permits should be linked with the level of output or be conditioned upon non-closure of plants.

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