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Free Emission Permits
and Public Revenue

by

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Free emission permits and public revenue

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Abstract

In the presence of preexisting distortionary taxes, it is often argued that auctioned emission permits are preferable to non-auctioned permits, because the former generate revenues that may be used to reduce other taxes. This paper shows that when capital is internationally mobile, it may be optimal to use a combination of non-auctioned and auctioned emission permits, for both environmental and fiscal reasons. By letting the number of non-auctioned permits be a positive function of the amount of capital used domestically, they will attract capital to the home country. This may create environmental benefits in terms of reduced transboundary pollution and may lead to increased public revenue because the price of emission permits may increase. It is also shown that the optimal number of non-auctioned permits may increase as the marginal costs of public funds increase.

JEL classification: D62, F21, Q28.

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1 Introduction

In the wake of the climate negotiations and the Kyoto Protocol, we have witnessed an increasing interest in many countries for tradable emission permits as an instrument for environmental policy making. Since the national commitments in the Kyoto Protocol are specified in terms of emission quotas, it will easier to ensure compliance if emission permits are used rather than emission taxes. Moreover, the "flexibility mechanisms" built into the Protocol ensure that emission quotas are tradable among nations. By using a system of tradable emission permits within each of the participating countries, the national systems will be easy to integrate with the international quota market.

Along with the focus on tradable emission permits has naturally come a discussion about how the permits should be allocated. A central question is whether the permits should be auctioned or not. In an economy with preexisting tax distortions, it is often argued that auctioned emission permits are preferable to non-auctioned permits, provided the revenues generated are used to cut in marginal tax rates. This *revenue-recycling effect* has been discussed by Oates and Schwab (1988) and Poterba (1993), among others. More recently, it has been demonstrated that due to interaction effects with preexisting taxes, environmental policies that do not exploit the benefits of revenue-recycling may produce significantly lower welfare levels than policies that do (Goulder *et al.* (1997), Parry and Williams III (1999), Goulder *et al.* (1999)).

Concerns about revenue-recycling is not the only reason to care about the allocation of emission permits, though. In some countries, it has been suggested that polluting firms that are exposed to international competition should receive emission permits free of charge in order to prevent firm closure and/or relocation to other countries. Such closure/relocation may be a serious problem in the case of transboundary environmental problems, in particular when some countries are unwilling to cooperate in order to solve the problem. The climate problem is a case in point. The climate problem is a global environmental problem. But since only some industrialised countries are willing to commit themselves to binding emission targets, there is a possibility that reduced emissions in these countries will lead to higher emissions elsewhere. There are several potential sources of such leakage effects. One of them is that mobile capital may escape strict regulations in the home country and move to other regions where polluting activities can be continued.[1] In

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[1] Leakage may also occur through the product markets, when foreign producers capture market shares from domestic producers due to unilateral environmental policies (see below).

designing climate policies, the question about granting free emission quotas to certain industries therefore often plays a central role, as was the case, e.g., in the reports form the Canadian Tradable Permits Working Group and the Norwegian "Quota Commission".

The use of free emission permits in order to reduce leakage effects is not without support in the theoretical literature. It has been shown that since increased emission of climate gases in non-cooperating countries imposes a cost on the cooperating ones, it will be efficient to implement policies that reduce the incentives of mobile capital, employed in polluting firms, to move to other regions. Hoel (1996) finds that a uniform carbon tax in the cooperating countries should be combined with an export tax on "polluting" capital. The problem with such a policy is that it is impossible in practice to discriminate between polluting and non-polluting capital, since it is not possible to trace the use of the capital once it has moved abroad. One alternative to such export taxes is to subsidise the use of polluting capital in the cooperating countries (Rauscher (1997), Mæstad (2001)). Such subsidies should be used in combination with a uniform emission tax or a system with tradable emission permits. One way of implementing the subsidy would be to give firms free emission permits proportional to the amount of capital employed within the cooperating countries (Mæstad, 2001). Note that the number of free permits must here be a function of a real variable. Unconditional allocation of free emission quotas will have no efficiency effects at all (cf. the Coase Theorem). We are thus not talking of grandfathering based on historic emissions, but rather of targeted use of free emission quotas in order to obtain efficiency gains. This is a key difference between the environmental economics literature on this topic and the public finance literature.

A problem with previous studies of this issue within the environmental economics literature is that they ignore preexisting distortionary taxes. Consequently, they do not take into account the potential advantage of revenue collecting environmental instruments over policies that do not collect revenue, such as free emission quotas. In this paper, we ask how the presence of preexisting taxes will affect the desirability of targeted free emission permits. The paper thus attempts to bridge the gap between the public economics literature of non-auctioned emission permits, where the emphasis is on the loss of public revenues, and the environmental economics literature, where free emission quotas may play a constructive role as a means to reducing leakage effects.

The paper shows that if capital is internationally mobile, it may be optimal to use both non-auctioned and auctioned emission permits, even if there are preexisting distortionary taxes. Moreover, the optimal number of non-auctioned permits may increase as the marginal costs of public funds increase. It is crucial for the results that the number of non-auctioned emission permits is positively related to the amount of capital used domestically. Non-auctioned permits will then attract more capital to the home country, increase the demand for emission permits, and drive up the permit price, provided there is complementarity between capital and emissions in the production function. If the number of non-auctioned permits is not too large, this may lead to increased public revenues. Hence, considerations about loss in public revenue is not necessarily an argument against (selective) use of non-auctioned emission permits in environmental policy.

The paper is organised as follows. Section 2 presents the model. The economic consequences of giving free emission quotas are discussed in Section 3. In Section 4, the optimal number of free emission quotas is characterised under the assumption that the emission limit also is optimally chosen. A richer set of policy instruments are introduced in Section 5 in order to see whether the results carry over to the case of prior tax policies. Section 6 concludes.

2 Model

We construct a simple, partial equilibrium model with two regions, named the home country (h) and the foreign country (f). There is only one production sector in each country[2]. Output in sector i (y^i) is produced by two factors - capital (k) and a fossil fuel (e). Technology is defined by the production functions

$$y^i = F^i(k^i, e^i) \qquad i = h, f \tag{1}$$

with the properties $F_j > 0$, $F_{jj} < 0$, $F_{kk}F_{ee} - F_{ke}^2 \geq 0$, i.e., marginal products are positive and decreasing, and there is non-positive returns to scale.

The use of fossil fuels causes emissions of greenhouse gases. For simplicity, we normalise the emission factor to 1. Hence, total emissions are $e^h + e^f$.

The government of the home country defines an upper limit $\bar{E}$ on the domestic emission level

$$e^h \leq \bar{E}. \tag{2}$$

If the emission limit $\bar{E}$ is binding, emission permits will have a positive market value p in the home country.

The government may also decide that a certain share of the total emission quota shall be allocated free of charge. If there are free emission quotas, they are allocated to domestic producers in proportion to the amount of capital

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[2] See Mæstad (2000) for a discussion of the use of free emission quotas with more than one production sector in each country.

employed in the home country. This policy design reflects the results in Hoel (1996), Rauscher (1997) and Mæstad (2001) that leakage through capital markets should be alleviated through capital market interventions. Let q be the number of free emission quotas per unit of capital employed in the home country.

In general, regulations of the pollution level in the home country will affect both product prices and factor prices. Previous studies have shown that if product market prices are affected by environmental policies, leakage may occur through competition effects in product markets. Similarly, changes in energy prices imply that there will be potential leakage through the energy market. As shown by Mæstad (1998, 2001) an Hoel (1996), the efficient way of dealing with such leakage effects is through trade policies and not through capital market interventions. Since our focus here is on the optimal use of capital subsidies in the form of free emission quotas to domestic capital, there is no reason for bringing these other potential sources of leakage into the model. Therefore, product prices and the world market price of fossil fuels shall be treated as fixed. Technically, we assume that the price elasticities of product demand and fuel supply are infinite.

Firms take factor prices as given. Let (r^i, w^i) be the factor prices of capital and fossil fuels in country i, let W denote the (fixed) world market price of fossil fuels, and let R be the international rental price of capital. We then have $r^f = R$, $r^h = R - pq$, $w^f = W$, and $w^h = W + p$. Profit maximising behaviour implies that marginal products will be equal to factor prices:

$$F_k^f = R = F_k^h + pq, \tag{3}$$

$$F_e^f = W = F_e^h - p. \tag{4}$$

There is a given total stock of capital $\bar{K}$. Capital is freely mobile internationally. The rental price of capital is determined so that aggregate capital demand equals the capital stock, i.e.,

$$k^h(R - pq) + k^f(R) = \bar{K}. \tag{5}$$

3 The impact of free emission quotas

Consider how the equilibrium of this model is affected by the allocation of free emission permits. Differentiation of Eqs. (3)-(5) with respect to q yields the following system

$$\begin{bmatrix} F^h_{kk} & 0 & 0 & -1 & q \\ 0 & F^f_{kk} & F^f_{ke} & -1 & 0 \\ F^h_{ke} & 0 & 0 & 0 & -1 \\ 0 & F^f_{ke} & F^f_{ee} & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \frac{dk^h}{dq} \\ \frac{dk^f}{dq} \\ \frac{de^f}{dq} \\ \frac{dR}{dq} \\ \frac{dp}{dq} \end{bmatrix} = \begin{bmatrix} -p \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{6}$$

By using Cramer's rule, the effect of free emission quotas can be summarised as follows:

$$\frac{dk^h}{dq} = \frac{1}{|H|} p F^f_{ee}, \tag{7}$$

$$\frac{de^f}{dq} = \frac{1}{|H|} p F^f_{ke}, \tag{8}$$

$$\frac{dR}{dq} = -\frac{1}{|H|} p \theta^f, \tag{9}$$

$$\frac{dp}{dq} = \frac{1}{|H|} p F^h_{ke} F^f_{ee}, \tag{10}$$

where $\theta^i = F^i_{kk} F^i_{ee} - (F^i_{ke})^2$ and $|H| = -\theta^f - F^h_{kk} F^f_{ee} - q F^h_{ke} F^f_{ee}$.

Proposition 1 *If there are not too many free quotas at the outset (q small) and there is a binding emission constraint in the home country (p positive), a larger number of free emission permits per unit of capital will lead to capital inflow in the home country* $(dk^h/dq > 0)$ *and a rise in the international rental price of capital* $(dR/dq > 0)$*. If there is factor complementarity* $(F^i_{ke} > 0)$*, foreign emissions will be reduced* $(de^f/dq < 0)$*, and the price of emission permits will increase* $(dp/dq > 0)$*.*

Given that the price of emission quotas is positive, giving free quotas in proportion to the amount of capital employed in the home country is equivalent to a subsidy on capital use. Capital demand in the home country increases, driving up the international rate of return and leading to capital inflow to the home country. With factor complementarity, less capital in the foreign country reduces the marginal product of fossil fuels in the foreign country and therefore leads to lower foreign emissions. Since there is a binding upper limit on home country emissions, total emissions are reduced as well. As more capital is used in the home country, the demand for fossil fuels will increase. This drives up the price of emission quotas, inducing substitution away from fossil fuels towards capital.

The public sector's income G from sale of emission quotas is given as

$$G = p(\bar{E} - k^h q). \tag{11}$$

Let us investigate how a small increase in the number of free emission permits affect public revenue. Differentiation of (11) with respect to q yields

$$\begin{aligned}
\frac{dG}{dq} &= \frac{dp}{dq}\left(\bar{E} - k^h q\right) - pq\frac{dk^h}{dq} - pk^h \qquad (12)\\
&= \frac{1}{|H|}pF^h_{ke}F^f_{ee}\left(\bar{E} - k^h q\right) - pq\frac{1}{|H|}pF^f_{ee} - pk^h\frac{-\theta^f - F^h_{kk}F^f_{ee} - qF^h_{ke}F^f_{ee}}{|H|}\\
&= \frac{p}{|H|}\left[F^h_{ke}F^f_{ee}\bar{E} - pqF^f_{ee} - k^h\left(-\theta^f - F^h_{kk}F^f_{ee}\right)\right]\\
&= \frac{pF^f_{ee}}{|H|}\left[F^h_{ke}\bar{E} + \left(F^h_{kk} + \frac{\theta^f}{F^f_{ee}}\right)k^h - pq\right].
\end{aligned}$$

To increase the number of free quotas per unit of capital reduces public income both through a direct reduction in the number of auctioned emission permits and through an increase in the capital stock in the home country. Therefore, it is often concluded that non-auctioned emission permits are less attractive than auctioned permits when one pays attention to the presence of preexisting distortionary taxes. As we just showed, however, a larger number of free quotas may increase the price of emission permits. The total effects of free emission quotas on public income is thus ambiguous.

Eq. (12) shows that a necessary condition for having public revenue increase with the number of free emission permits is that capital and emissions are complements (i.e., $F^h_{ke} > 0$). The intuition is a follows: If capital and emission are complements, a higher domestic capital stock will increase the demand for emission permits and thus drive up the quota price. Hence, by attracting more capital to the home country, a capital subsidy has a potential positive impact on public revenue through the quota price. If this effect is stronger than the direct loss in revenue implied by the subsidy, total revenues will increase.

This result suggests that there might be cases in which higher marginal costs of public funds will require a larger number of free emission quotas. However, in the analysis so far, the emission limit has been taken as exogenous. In order to answer our question we have to investigate whether the optimal number of free emission quotas may increase with the marginal costs of public funds also when $\bar{E}$ is chosen optimally.

4 Optimal policies

In this section we characterise the optimal number of free emission permits when the emission limit is optimally chosen. Let home country welfare w be an additively separable function of income and the level of pollution,

$$w = u(I) - v(P), \quad u', v' > 0. \tag{13}$$

Income is the sum of producer surplus (including the value of free emission quotas), government income, and the difference between the return on capital invested abroad less the rent paid to foreign capital invested in the home country[3]. Let α be the share of the capital stock owned by the home country. The net foreign assets of the home country are then $\alpha\bar{K} - k^h$, and the net financial return for the home country is $R(\alpha\bar{K} - k^h)$. We assume that the government has to finance a budget of a given size and that public income is financed by distortionary taxes. Let λ denote the marginal costs of public funds. Hence, one dollar of government income is equivalent to $(1+\lambda)$ dollars of private income. Since our model is of the partial equilibrium type, we treat λ as a constant.

The climate problem is a global environmental problem, and foreign emissions are thus equally damaging as home country emissions. We assume that the emission limit in the home country is binding. Hence, the level of pollution is given by $P = \bar{E} + e^f$.

The welfare of the home country can now be written[4]

$$w = u \left[\begin{array}{c} F^h\left(k^h, e^h\right) - (W+p)e^h + pqk^h + R(\alpha\bar{K} - k^h) \\ +(1+\lambda)p(\bar{E} - k^h q) \end{array} \right] - v\left[\bar{E} + e^f\right]. \tag{14}$$

The government chooses the emission limit $\bar{E}$ and the number of free emission quotas q so as to maximise welfare. The first order conditions for an interior solution are

$$u'\left[-(1+\lambda)pq\frac{dk^h}{dq} - \lambda\left[pk^h - \frac{dp}{dq}\left(\bar{E} - k^h q\right)\right] + \frac{dR}{dq}\left(\alpha\bar{K} - k^h\right)\right] - v'\frac{de^f}{dq} = 0. \tag{15}$$

$$u'\left[-(1+\lambda)pq\frac{\partial k^h}{\partial \bar{E}} + (1+\lambda)p + \lambda\frac{\partial p}{\partial \bar{E}}\left(\bar{E} - k^h q\right) + \frac{\partial R}{\partial \bar{E}}\left(\alpha\bar{K} - k^h\right)\right] - v'\left[1 + \frac{\partial e^f}{\partial \bar{E}}\right] = 0. \tag{16}$$

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[3] There is no consumer surplus since demand is assumed to be infinitely elastic.

[4] Income is measured in terms of income on private hands.

In Eq. (15), the net costs of giving free emission quotas to capital are divided into three components; (1) the costs of inefficient use of capital, (2) the costs due to any losses in public revenue, and (3) gains or losses through changes in the terms of trade in the international capital market. In optimum, these costs should be balanced against the net benefits of reduced pollution from abroad. Eq. (16), showing the marginal cost and the marginal benefits of changing the domestic emission limit, has a similar interpretation.

Eq. (15) can be further simplified by utilising the comparative statics of Eqs. (7)-(10). We obtain

$$q = \frac{1}{p(1+\lambda)} \left[-\frac{v'}{u'} \frac{F^f_{ke}}{F^f_{ee}} - \frac{\theta^f}{F^f_{ee}} \left(\alpha \bar{K} - k^h \right) + \lambda \left(F^h_{ke} \bar{E} + \left(\frac{\theta^f}{F^f_{ee}} + F^h_{kk} \right) k^h \right) \right]. \tag{17}$$

In order to simplify Eq. (16), we need to find the equilibrium effects of changes in the emission limit. Differentiation of the complete model (Eqs. (3)-(5)) with respect to $\bar{E}$ yields

$$\begin{bmatrix} F^h_{kk} & 0 & 0 & -1 & q \\ 0 & F^f_{kk} & F^f_{ke} & -1 & 0 \\ F^h_{ke} & 0 & 0 & 0 & -1 \\ 0 & F^f_{ke} & F^f_{ee} & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \frac{dk^h}{d\bar{E}} \\ \frac{dk^f}{d\bar{E}} \\ \frac{de^f}{d\bar{E}} \\ \frac{dR}{d\bar{E}} \\ \frac{dp}{d\bar{E}} \end{bmatrix} = \begin{bmatrix} -F^h_{ke} \\ 0 \\ -F^h_{ee} \\ 0 \\ 0 \end{bmatrix} \tag{18}$$

By using Cramer's rule, we obtain

$$\frac{dk^h}{d\bar{E}} = \frac{1}{|H|} F^f_{ee} \left(F^h_{ke} + F^h_{ee} q \right), \tag{19}$$

$$\frac{de^f}{d\bar{E}} = \frac{1}{|H|} F^f_{ke} \left(F^h_{ke} + F^h_{ee} q \right), \tag{20}$$

$$\frac{dR}{d\bar{E}} = \frac{-1}{|H|} \theta^f \left(F^h_{ke} + F^h_{ee} q \right), \tag{21}$$

$$\frac{dp}{d\bar{E}} = \frac{-1}{|H|} \left(F^f_{ee} \theta^h + F^h_{ee} \theta^f \right). \tag{22}$$

We now insert these expressions into Eq. (16) and solve Eqs. (16) and (17) simultaneously with respect to p and q. The optimal policies can be characterised as follows

$$p^* = \frac{1}{\mu(1+\lambda)} \frac{v'}{u'}, \tag{23}$$

$$q^* = \mu \left(-\frac{F^f_{ke}}{F^f_{ee}} - \frac{u'}{v'}\frac{\theta^f}{F^f_{ee}}\left(\alpha\bar{K} - k^h\right)\right) + (1-\mu)\left(-\frac{F^h_{ke}\bar{E} + \left(\frac{\theta^f}{F^f_{ee}} + F^h_{kk}\right)k^h}{F^h_{ee}\bar{E} + F^h_{ke}k^h}\right), \tag{24}$$

where $\mu \equiv v'/(v' - u'\lambda(F^h_{ee}\bar{E} + F^h_{ke}k^h))$.

Eq. (24) shows that the optimal number of free emission quotas per unit of capital can be expressed as a weighted sum of two terms. If the marginal costs of public funds are zero ($\lambda = 0$), μ is equal to one. The latter term then disappears. We denote this term the "fiscal" argument for the use of free emission quotas.

The first term has two components. The first one is related to the role of free emission quotas as a means to reducing the level of pollution generated in the foreign country. In order to see this more clearly, totally differentiate the first order condition for optimal use of e^f (see Eq. (4)). After rearranging terms, we obtain

$$\frac{de^f}{dk^f} = -\frac{F^f_{ke}}{F^f_{ee}}. \tag{25}$$

When free emission quotas are used, less capital will be allocated in the foreign country. The expression $-F^f_{ke}/F^f_{ee}$ shows which effect such reallocation of capital has on the foreign emission level. Eq. (24) shows that this term disappears if the marginal cost of pollution is zero ($v' = 0$), reflecting the fact that this term has to do with the environmental reason for using free emission permits.

The second component is related to the terms of trade effect of free emission permits. Since capital subsidies in the home country will increase capital demand and thus tend to drive up the international rate of interest, there will be a terms of trade gain (loss) for capital exporting (importing) countries. This component will disappear if there are constant returns to scale in the foreign country ($\theta^f = 0$), because the international rental rate of capital will then be fixed.

In order to see how the optimal number of free emission quotas varies with the marginal costs of public funds, we need to differentiate Eq. (24) with respect to λ. That is a complex task and is likely to yield unambiguous results, since a change in λ does not only affect the optimal emission limit $\bar{E}$ and the equilibrium capital allocation k^h, but also all F^i_{jk}. We proceed by discussing the terms in Eq. (24) one at a time. We start by singling out the fiscal component, by assuming that there are no environmental problems ($v' = 0$) and that there are constant returns to scale in the foreign country ($\theta^f = 0$). The latter assumption is technically equivalent to the "small open economy" assumption. Thereafter, we study the environmental component, by assuming that the marginal cost of public funds is zero ($\lambda = 0$), while retaining the small open economy framework. Finally, we consider a large economy model with endogenous rental rate of capital.

4.1 Small open economy - no environmental problems

Consider first the case when the home country is a small one, unable to influence the international rental rate of capital. This case can be analysed by replacing the equilibrium condition (5) with a given international interest rate R^*. Alternatively, we can assume that the foreign production technology exhibits constant returns to scale. We follow the latter approach since we then do not need to redo the model; it suffices to replace θ^f by zero. We also do away with the environmental arguments for free emission quotas in order to isolate the arguments related to public finance. By setting $v' = 0$, the optimal policy can be written as

$$\hat{p} = -\frac{\lambda}{1+\lambda}\left(F_{ee}^h \bar{E} + F_{ke}^h k^h\right), \tag{26}$$

$$\hat{q} = -\frac{F_{ke}^h \bar{E} + k^h F_{kk}^h}{F_{ee}^h \bar{E} + F_{ke}^h k^h}. \tag{27}$$

Proposition 2 *In a small open economy without environmental problems, the optimal number of free emission permits per unit of capital may be either negative or positive and may increase with the marginal costs of public funds.*

Proof. As can be seen immediately from Eq. (27), $\hat{q}$ will always be negative when $F_{ke}^h \leq 0$. In order to prove that $\hat{q}$ may be positive and increasing in λ, we need to turn to numerical simulations. Let the production technology take the following form

$$F(k^i, e^i) = \beta_1^i k^i - \beta_2^i (k^i)^2 - \beta_3^i (k^i)^3 + \gamma_1^i e^i - \gamma_2^i (e^i)^2 + \delta^i k^i e^i, \qquad i = h, f, \tag{28}$$

and let the parameter values be as follows

	β_1^i	β_2^i	β_3^i	γ_1^i	γ_2^i	δ^i
$i = h$	5.95	.0015	.1 e-7	500	10	.24
$i = f$	4.375	.0015625	0	500	10	.25

Let $K = 10000$ and $W = 50$. The optimal policies and the equilibrium values of selected variables are shown in the table below

	$\lambda = 0$	$\lambda = .15$	$\lambda = .3$
q	n.a.	.00768	.00787
p	0	51.9	84.4
k^h	5000	4444	4115
E	82.5	73.2	67.7
e^f	85	91.9	96.1
R	10	10	10

This proves that $\hat{q}$ may be positive and increasing in λ. ■

The model without environmental problems and without terms of trade effects in the capital market is indeed a pure model of optimal taxation with internationally mobile capital. Our results can be interpreted to say that the optimal tax rate on capital may be either positive or negative (i.e. a capital subsidy), and that the optimal capital subsidy may increase with the marginal costs of public funds. The reason is that capital subsidies may attract capital from abroad and thus increase the tax base and the government revenue. Of course, as long as capital is subsidised, the direct impact of a larger domestic capital stock will be to reduce government income. But it may have an indirect positive impact on revenues through increased demand for other production factors that are subject to positive tax rates. In order for this to happen, the production factors need to be complements, in the sense that the marginal product of one factor increases with the use of the other factor ($F^h_{ke} > 0$). If factors are non-complements ($F^h_{ke} \leq 0$), these indirect effects are non-positive, and a positive tax rate on capital is then optimal.

In our example, it is optimal to restrict the use of fossil fuels whenever $\lambda > 0$. This is equivalent to imposing a positive tax rate on this factor. In addition, a capital subsidy is implemented in order to reduce the capital flight to the foreign country. Since capital and fossil fuels are complements, a larger capital stock in the home country increases the demand for fossil fuels. In fact, the complementarity is so strong that higher income on quota sale more than outweighs the loss of revenue implied by some quotas being given away free of charge.

Our analysis is related to Razin and Sadka (1992), who show that if foreign income cannot be taxed, it is optimal to introduce capital controls in order to enhance the domestic tax base. By combining such controls (e.g., an export tax on capital) with a positive tax rate on capital in the home country, the first best may be attained. In our model, there is no export tax on capital. We ruled out such instruments by assumption due to our focus on environmental leakage through capital markets, which is associated not with capital movements in general but with capital movements into particular polluting industries in the foreign country. Note, however, that an export tax can be decomposed into a subsidy on domestic use and a tax on domestic supply. Thus, it is not clear, within the framework used by Razin and Sadka, whether or not the optimal *net* tax on domestic capital use is positive or negative. In our model, we show that the net tax may indeed by negative, implying that domestic capital use should be subsidised. The precondition is, however, that a capital subsidy plays a similar role as capital controls in the model of Razin and Sadka (1992), i.e., that it increases the domestic tax base (by increasing the demand for complementary production factors that are subject to positive tax rates).

4.2 Small open economy - with environmental problems

We now introduce transboundary environmental problems into the model. We retain the small open economy framework, implying that the international rental rate of capital is taken as given. The optimal policies are now given as

$$\check{p} = \frac{1}{\mu(1+\lambda)}\frac{v'}{u'} = -\frac{\lambda}{1+\lambda}(F^h_{ee}\bar{E} + F^h_{ke}k^h) + \frac{1}{1+\lambda}\frac{v'}{u'}, \tag{29}$$

$$\check{q} = \mu\left(-\frac{F^f_{ke}}{F^f_{ee}}\right) + (1-\mu)\left(-\frac{F^h_{ke}\bar{E} + k^h F^h_{kk}}{F^h_{ee}\bar{E} + F^h_{ke}k^h}\right), \tag{30}$$

First, we notice that for any $(\bar{E}, k^h)$, the quota price $\check{p}$ will be higher than $\hat{p}$ (see Eq. (26)). This shows that environmental problems always make it desirable to increase the price on polluting factors, even though capital is internationally mobile and pollution is transboundary. The reason is that leakage is more efficiently dealt with by issuing free emission quotas to domestic firms.

The optimal number of free emission quotas per unit of capital is now a weighted sum of the transboundary pollution component and the fiscal component discussed above. For any $(\bar{E}, k^h)$ the optimal number of free emission permits may now be higher or lower than in the preceeding section. The critical factor is whether or not the transboundary pollution terms are greater or smaller than the fiscal term.

We are now able to strengthen the result obtained above.

Proposition 3 *In a small open economy, the optimal number of free emission permits per unit of capital may be either negative or positive and may increase with the marginal costs of public funds.*

Proof. As can be seen immediately from Eq. (30), $\check{q}$ will be negative when $F^h_{ke} \leq 0$ and μ is sufficiently small. In order to prove that $\check{q}$ may be increasing in λ, we first prove that the fiscal term and the transboundary environmental term may be independent constants. As noted earlier, the transboundary environmental term is always a constant when there are constant returns in the foreign country and foreign factor prices are given. In order to prove that the fiscal component may also be a constant, let the production function in the home country take on a quadratic form;

$$y^h = \beta_1 k^h - \beta_2 (k^h)^2 + \gamma_1 e^h - \gamma_2 (e^h)^2 + \delta k^h e^h. \tag{31}$$

We can write marginal products as follows;

$$\begin{aligned} F^h_k &= \beta_1 + F^h_{kk} k^h + F^h_{ke} \bar{E}, & (32) \\ F^h_e &= \gamma_1 + F^h_{ee} \bar{E} + F^h_{ke} k^h. & (33) \end{aligned}$$

By utilising the first order condition for profit maximization, Eqs. (3)-(4), together with Eqs. (32) and (33), we obtain the following implicit expressions for the optimal policy

$$p = \frac{1}{1+\lambda} \frac{v'}{u'} - \frac{\lambda}{1+\lambda} \left(W + p - \gamma_1 \right), \tag{34}$$

$$q = \mu(p) \left(- \frac{F^f_{ke}}{F^f_{ee}} \right) + (1 - \mu(p)) \left(- \frac{R^* - pq - \beta_1}{W + p - \gamma_1} \right), \tag{35}$$

where $\mu(p) = v'/(v' - u'\lambda(W + p - \gamma_1))$. By solving for q and p, we obtain

$$\begin{aligned} \check{p} &= \frac{1}{1+2\lambda} \left[\frac{v'}{u'} + \lambda \left(\gamma_1 - W \right) \right], & (36) \\ \check{q} &= \mu \left(- \frac{F^f_{ke}}{F^f_{ee}} \right) + (1 - \mu) \left(\frac{R^* - \beta_1}{\gamma_1 - W} \right), & (37) \end{aligned}$$

where $\mu = v'/(v' + \lambda u' \left(\gamma_1 - W \right))$. Since R^* is fixed as long as there are constant returns in the foreign country, this shows that the fiscal term is a constant in this case. In order to show that $\check{q}$ may be increasing in λ, note that if v' and u' are constants, μ is monotonically increasing in λ. Hence, $\check{q}$ will be increasing in λ as long as the value of the fiscal term is larger than the value of the transboundary environmental term. ■

This demonstrates that when we introduce environmental problems into the model, the optimal number of free emission quotas per unit of capital may increase for other reasons than in the model with pure fiscal considerations. In the latter case, we showed that $\check{q}$ may increase with λ simply because the fiscal term may increase with λ. That may of course still be the case when environmental problems are introduced. But in addition come two other factors: (1) due to higher weight on the fiscal term as λ increases, $\check{q}$ may increase if the value of the fiscal term is larger than the environmental term, and (2) the environmental term in itself may increase with λ. It is the first of these factors that is utilised in the proof above. The latter one will be discussed more fully in Section 5.

We notice that $\check{p}$ may also increase with λ, implying that the optimal subsidy pq is an increasing function of the marginal costs of public funds. In our example, we have that

$$\frac{d\check{p}}{d\lambda} = \frac{1}{(1+2\lambda)^2}\left[-2\frac{v'}{u'} + (\gamma_1 - W)\right]. \tag{38}$$

Provided that $\gamma_1 - W > 0$, this expression is positive for low levels of v'. The essential point is that if a capital subsidy is called for from a fiscal point of view, a higher marginal cost of public funds will lead to an increase in the optimal quota price. The introduction of transboundary environmental problems into the model will work in the opposite direction in our example, but for low levels of v' this effect is not strong enough to outweigh the fiscal argument for increasing the level of $\check{p}$.

4.3 Large economy - no environmental problems

We now want to investigate how terms of trade effects in the international capital market may affect the optimal number of free emission quotas. In order to focus on one effect at a time, we now ignore the environmental argument for the use of free emission quotas, by assuming that v' is zero. The optimal policy is then defined by the following conditions

$$\tilde{p} = -\frac{\lambda}{1+\lambda}(F^h_{ee}\bar{E} + F^h_{ke}k^h), \tag{39}$$

$$\tilde{q} = \frac{1}{\lambda}\frac{\theta^f}{F^f_{ee}}\frac{\alpha\bar{K} - k^h}{F^h_{ee}\bar{E} + F^h_{ke}k^h} - \frac{F^h_{ke}\bar{E} + \left(\frac{\theta^f}{F^f_{ee}} + F^h_{kk}\right)k^h}{F^h_{ee}\bar{E} + F^h_{ke}k^h}. \tag{40}$$

The formula describing the optimal quota price is the same as in the small economy model without environmental problems. Thus, the large economy assumption does not affect the optimal taxation of the polluting factor. The large economy assumption does, however, affect the optimal number of free emission permits. We recognise the last term in Eq. (40) as the fiscal term, which now has a somewhat different structure than in the small economy models. In order to understand the significance of the additional factor in the nominator, notice that the same term appears in the expression for dp/dq in Eq. (10);

$$\frac{dp}{dq} = \frac{pF^h_{ke}}{-\left(\frac{\theta^f}{F^f_{ee}} + F^h_{kk}\right) - qF^h_{ke}}. \tag{41}$$

The intuition is that when there are decreasing returns in the foreign country, implying that $\theta^f > 0$, free emission quotas will be less powerful in terms of raising the price of emission permits in the home country. It will take a larger capital subsidy to attract a given amount of foreign capital. The result is that the fiscal term will be smaller in a large country model than in a small country model, thus calling for fewer free emission permits per unit of capital.

The large economy assumption also implies that terms of trade effects in the capital market will play a role for optimal policies. Term of trade considerations are reflected in the first term of Eq. (40). As long as the quota price is positive (i.e. $F^h_{ee}\bar{E} + F^h_{ke}k^h < 0$), this term will be positive (negative) when the home country is a capital exporter (importer). This is a standard result; it is desirable for a capital exporting country ($\alpha\bar{K} > k^h$) to make efforts to increase the rental price of capital. In our model, this is achieved by subsidising capital use in the home country (i.e. $pq > 0$). Conversely, a capital importing country ($\alpha\bar{K} < k^h$) will tax domestic capital in order to reduce capital demand and hence reduce the rental price of capital.

How are optimal policies in this model affected by changes in the marginal costs of public funds? Eq. (40) suggests that when λ approaches zero, the terms of trade term may potentially become very large, either positive or negative. This must be understood in connection with the fact that the optimal quota price p is very small under these circumstances. In order to be able to subsidise (or tax) the use of capital at a given rate, the optimal number of free emission permits per unit of capital might then become very large (or strongly negative). Consider the case when α is close to zero, implying that terms of trade considerations call for a capital tax ($q < 0$). Assume also that λ is close to zero. In this case, q^* will be strongly negative. If we now let λ increase, the optimal number of free emission quotas will approach the level of q that is optimal from a pure fiscal perspective. It is quite obvious in this case that the optimal q may increase with the marginal costs of public funds. The opposite will be the case when α is close to one; a very high number of free emission permits will then be called for when λ goes

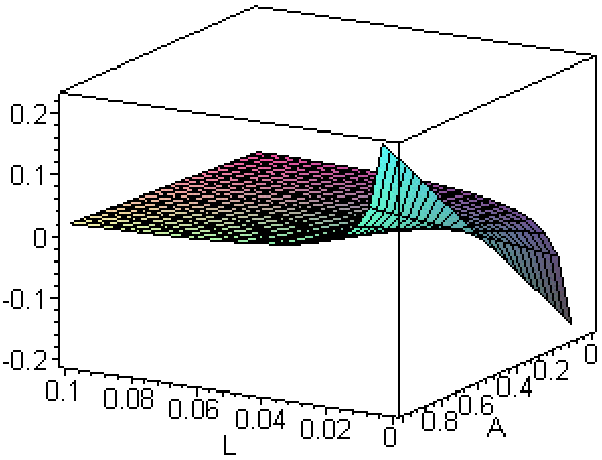

Figure 1: *Optimal number of free emission permits per unit of capital as a function of the ownership of capital (A) and the marginal costs of public funds (L).*

to zero. If λ increases, the optimal number of free emission quotas may well decrease in order to reflect that fiscal considerations call for a more moderate level of free emission quotas.

Proposition 4 *In a large country model with no environmental problems, the optimal number of free emission quotas per unit of capital may increase or decrease with the marginal costs of public funds.*

Proof. The proposition will be formally proved by a numerical example. Let all parameters take on the same values as in the previous numerical example, with two exceptions; let there be a quadratic technology in both countries (i.e. $\beta_3 = 0$), and let the parameters of the foreign production function be identical to the parameters in the home country. The optimal q, as a function of α and λ, is shown in Figure 1.

■

The figure clearly shows that terms of trade effects may make the optimal number of free emission quotas increase or decrease with the marginal costs of public funds, depending on whether the home country is a net capital exporter or net capital importer.

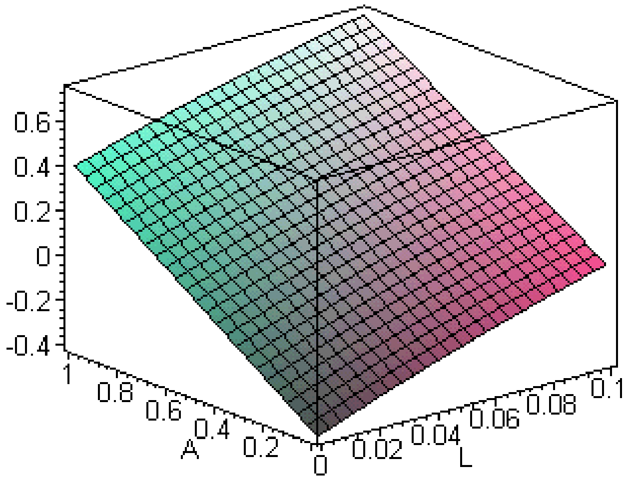

Figure 2: *Optimal capital subsidy as a function of the ownership of capital (A) and the marginal costs of public funds (L)*

It is interesting to note that in our example, even though $\tilde{q}$ decreases with λ at high values of α, the optimal capital subsidy (pq) may still be increasing in λ. Figure 2 depicts the optimal pq as a function of λ and α. This result is however not robust to changes in the parameter values.

To sum up, this section has uncovered several reasons why the optimal number of free emission permits per unit of capital may increase with the marginal costs of public funds. First, there may be pure fiscal arguments for subsidising capital in a world with international capital mobility and factor complementarity. If a capital subsidy is called for at the outset, a higher marginal costs of public funds will typically increase the optimal rate of subsidy. For certain technologies, an increase in q will then be called for. Secondly, we have shown that if environmental considerations call for fewer free emission permits than do the pure fiscal considerations, an increase in the marginal costs of public funds may increase the optimal q simply because a higher value of λ puts greater emphasis on the fiscal argument. Thirdly, we have shown that for a large economy, terms of trade effects will call for very low values of q when the home country is a large capital importer (α low) and the marginal costs of public funds are low (λ low). An increase in λ will then induce a higher level of q provided the fiscal argument calls for a higher value of q than the terms of trade argument in itself. Finally, in all the cases considered, we have demonstrated that not only may the optimal number of free quotas per unit of capital (q) increase with λ; the same may hold for the optimal rate of capital subsidy (pq) as well.

A weakness with the analysis so far is that we have not discussed the possibility that there may be tax instruments in place at the outset which deal with the pure fiscal issues and the terms of trade arguments. Our model is motivated from the environmental side; we ask how an international environmental problem should be dealt with unilaterally by one country (or a group of countries), and we use a partial equilibrium approach in order to focus on how emission permits should be allocated to polluting sectors where capital is internationally mobile. In our model, the optimal allocation of free emission permits reflects considerations (such as the fiscal argument and the terms of trade argument) which are relevant not solely for the polluting sectors but for the economy as a whole. It may be to overload the model to let these considerations enter into the decisions about the optimal allocation of emission permits. In the next section, we therefore assume that there are other tax policies in place at the outset that deal with all issues that are not related to the environmental dimension.

5 Prior tax policies

Consider a model where optimal fiscal policies are in place before environmental problems and environmental policies are introduced. Assume that there is a fiscal tax t_k on capital use and a fiscal tax t_e on the use of fossil fuels. It can be shown that the optimal fiscal tax rates are given as

$$t_e^* = -\frac{\lambda}{1+\lambda}\left(F_{ke}^h k^h + F_{ee}^h e^h\right), \tag{42}$$

$$t_k^* = \frac{1}{1+\lambda}\frac{\theta^f}{F_{ee}^f}\left(\alpha K - k^h\right) - \frac{\lambda}{1+\lambda}\left[F_{ke}^h e^h + \left(F_{kk}^h + \frac{\theta^f}{F_{ee}^f}\right)k^h\right]. \tag{43}$$

The derivation of these expressions is not shown here, since they follow quite straightforwardly from Eqs. (23) and (24). Just realise that a tax on the use of fossil fuels is equivalent to a positive price on emission permits and that a tax on the use of capital is equivalent to a negative subsidy ($-pq$). Then, by setting the marginal cost of pollution equal to zero ($v' = 0$), the tax rates in Eqs. (42) and (43) are readily obtained.

We now introduce transboundary environmental problems into the model and solve for the optimal quota price and the optimal number of free emission quotas under these circumstances. Note that a positive quota price in this case will represent an extra tax on emission beyond any fiscal taxes.

Throughout the analysis we assume that the fiscal taxes t_e and t_k are always set at their optimal levels.

In this case, the optimal environmental policies are as follows

$$p^* = \frac{1}{1+\lambda}\frac{v'}{u'}, \tag{44}$$

$$q^* = -\frac{F^f_{ke}}{F^f_{ee}} \tag{45}$$

Eq. (44) follows directly from Eqs. (23) and (42). Eq. (45) can be obtained by deducting the capital tax t_k^* from the optimal capital tax $(-p^*q^*)$ given by Eqs. (23) and (24) and then dividing by the optimal quota price in Eq. (44).

How will the optimal number of free emission quotas vary with the marginal costs of public funds in this model? As can be seen from Eq. (45), q^* is a constant as long as F^f_{ij} are constants, as will be the case with a quadratic production technology in the foreign country. It turns out that minor perturbations of the quadratic production function will make q^* increase or decrease with the marginal costs of public funds. Typically, p^* will now decline with λ, but for certain technologies the decline in p^* will be smaller than the increase in q^*, implying that the optimal capital subsidy p^*q^* increases with the marginal costs of public funds.

Proposition 5 *When there are separate tax instruments that deal with fiscal consideration and terms of trade effects, the optimal number of free emission permits per unit of capital (q) may increase with the marginal costs of public funds (λ). The optimal capital subsidy (pq) and the optimal total number of free emission quotas (k^hq) may increase as well.*

Proof. The result will be proved by a numerical example. Assume the following production technology, identical for both countries;

$$F^i(k^i, e^i) = 25k^i - .0015(k^i)^2 + 2500e^i - 850(e^i)^2 + 0.1k^i(e^i)^2, \qquad i = h, f. \tag{46}$$

Let $K = 10000$, $W = 50$, $\alpha = .5$, and let $v' = 100$ and $u' = 1$. The optimal policies and the equilibrium values of selected variables are shown in the table below

	$\lambda = 0$	$\lambda = .1$
q	.00100	.00119
p	100	90.91
t_k	.00067	1.43
t_e	0	-52.46
k^h	5000.3	4704
$\bar{E}$	3.36	3.18
e^f	3.50	3.82
R	11.2	10.6

The increase in λ from 0 to .1 causes a 19 per cent increase in q^*, which is a larger increase than the corresponding reduction in p^* and k^{h*}. ■

What explains these results? When the marginal costs of public funds increase, fiscal taxes will be adjusted in order to generate more public revenue. In our example, the optimal tax structure entails a positive capital tax ($t_k > 0$) and a subsidy on the use of fossil fuels ($t_e < 0$).[5] The purpose of this subsidy is to enhance the tax base; a subsidy on fossil fuels will increase the demand for fossil fuels, and more foreign capital will then be attracted to the home country due tot he complementarity between capital and fossil fuels. In our example, the low level of $\bar{E}$ implies that such a subsidy is a relatively inexpensive measure for attracting foreign capital (see Eq. (42)).

When it comes to the issue of transboundary pollution, it is interesting to note that the marginal costs of public funds do not have a direct impact on the optimal number of free emission permits per unit of capital. The level of q is determined by the effectiveness of capital relocations in terms of reducing foreign pollution (i.e., de^f/dk^f). In our example, we have

$$q^* = -\frac{F^f_{ke}}{F^f_{ee}} = \frac{de^f}{dk^f} = -\frac{.2e^f}{-1700 + .2k^f}. \tag{47}$$

An increase in the marginal costs of public funds will increase the foreign capital stock, due to higher capital taxes in the home country. This will also lead to a higher level of foreign emissions. Given our technological assumption, both these effects will increase the value of de^f/dk^f. In other words; the effectiveness of free emission quotas will be enhanced when the marginal costs of public funds increases. Hence, q^* increases.

On the other hand, an increase in the marginal costs of public funds makes it more costly to subsidise capital in order to reduce the leakage effect. This

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[5] Note that t_k also takes care of the terms of trade argument. Since the home country is a capital exporter when $k^h > 5000$, the terms of trade effect implies a slightly positive t_k when $\lambda = 0$ and a negative t_k when $\lambda = .1$.

is reflected in our example by a reduction in p^*, which *ceteris paribus* will reduce the level of the capital subsidy. Of course, the price of those quotas that are auctioned will then also decline, and one might therefore ask why such a policy is desirable when the marginal costs of public funds increases. In order to understand this result, we should bear in mind that since there are other tax instruments in place that deal with the public revenue issue in a cost efficient way, a positive value of p will always imply an efficiency loss (when we ignore the environmental benefits). When the marginal costs of public funds increase, greater emphasis is put on public revenue considerations relative to the transboundary environmental argument. This calls for a movement towards the solution that would be optimal in the absence of environmental problems. Hence, it is optimal to reduce p when λ increases.

In our example, the increase in q^* is larger than the reduction in p^*, implying that the optimal capital subsidy increases as the marginal costs of public funds increase. However, this result clearly depends on parameter values of the model and could easily be reversed for other technological assumptions.

The increase in marginal costs of public funds leads to an additional argument for keeping the capital stock in the home country at a high level, because this will increase the tax base. This argument is handled in our model by the subsidy on the use of fossil fuels in the home country and implies that the decline in the capital stock will not be as large as it otherwise would be. Thus, with a relatively small decline in the capital stock, an increase in the marginal costs of public funds is more likely to increase the total number of free emission permits $k^h q$.

6 Final remarks

This paper sheds light on how the presence of a public sector that imposes distortionary taxes affects the desirability of using free emission quotas as a means to reducing leakage effects when there are transboundary environmental problems.

We find that when the allocation of free emission quotas is implemented in a way that reduces the leakage effect (and not by grandfathering of emission quotas), there is an ambiguous relationship between the marginal costs of public funds and the optimal number of free emission quotas. In our model, where leakage occurs through international capital movements, efficiency requires that free emission quotas are allocated on the basis of the level of capital use in the home country. It is shown that the optimal number of free emission quotas per unit of capital may increase with the marginal costs of public funds for several reasons; (1) because higher capital subsidies may be called for in order to attract more capital and hence increase the use of complementary factors that are subject to a positive tax rate, (2) because fiscal arguments of this kind will become more important relative to environmental arguments, (3) because fiscal arguments of this kind will become more important relative to terms of trade arguments, and (4) because the effectiveness of free emission quoats as an instrument of reducing leakage from abroad may increase in response to changes in the factor usage in the foreign country.

However, only the latter of these mechanisms survive if there are separate tax instruments in place that deal with fiscal issues and terms of trade effects.

In sum, the paper shows that public revenue considerations do not necessarily reduce the attractiveness of using free emission quotas as a means of dealing with environmental leakage effects.

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