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August 10, 2001

Domestic inefficiencies caused by transboundary pollution problems when there is no international coordination of environmental policies

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Abstract

In most models of transboundary pollution, lack of international cooperation does not cause any inefficiency within each country. The paper shows that this result is only valid in the hypothetical case of no international trade. With international trade, we get a domestic inefficiency in addition to the well-known inefficiencies at the international level. More precisely, when there is no cooperation on how to handle transboundary pollution, it is individually rational for each country to choose a policy that gives it a lower welfare than what is possible given the emission levels of all countries.

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1. Introduction

It is well known from the literature on transboundary pollution problems that without any type of international cooperation, the outcome is inefficient. There are in fact two types of inefficiencies. The first and most important is that total emissions in a non-cooperative outcome typically are too high[2]. A second type of inefficiency is that given the total amount of emissions in the non-cooperative outcome, these emissions are allocated across countries in an inefficient manner.

In most models of international environmental problems, the two inefficiencies above are the only inefficiencies that occur[3]. In particular, in most models the lack of international cooperation does not cause any inefficiency within each country. More precisely, given the emission level a particular country chooses in the non-cooperative outcome, the country's income, or more generally its level of welfare, is maximized given this level of emissions (and given the emission levels of all other countries). In this paper I will argue that this result is only valid in the hypothetical case of no international trade. With international trade, we get a third type of inefficiency when there is no cooperation on how to handle transboundary pollution.

Throughout the paper, I shall formally only consider a transboundary pollution problem for which it is only the sum of emissions from all involved countries that affects the environmental quality in each of the countries. The most important example of such a problem is the climate problem, and I will have this example in mind when interpreting various assumptions and results. Although the formal analysis only deals with this particular type of transboundary pollution, it will be clear that the main points are valid also for more general types of transboundary pollution problems.

[2] More precisely: Emissions in a non-cooperative outcome will typically be higher than total emissions in all of the Pareto efficient outcomes.

[3] If markets are not competitive, there will of course generally be additional inefficiencies in the non-cooperative outcome.

In most of the literature, models of the following simple type are used. There are N countries, and country j has a welfare level given by

(1) $$u_j = F_j(e_j) - D_j(\sum_i e_i)$$

where e_j denotes emissions from country j. In (1), we may interpret F_j as the income of country j. This function is a reduced form function, telling us that income is lower the lower are emissions, i.e. that abatement is costly. The function D_j is a money measure of the environmental costs, which depend on the sum of emissions from all countries. In most of the literature the non-cooperative outcome is defined as a Nash equilibrium of the game in which each country has its own emission level as its strategy variable. This leads to the following conditions for the non-cooperative outcome:

(2) $$F_j'(e_j) = D_j'(\sum_i e_i) \qquad j=1,\ldots,N$$

These N equations determine all emission levels.

The outcome described by 2 is socially inefficient. The conditions for social efficiency depend on whether one assumes that there are any restrictions on transfers between countries or not (see e.g. Hoel (1999) for a further discussion). The simplest case is when there are no such restrictions. Then an efficient outcome must maximize the sum of incomes minus the sum of environmental costs for all countries. This gives (see e.g. Hoel, 1999)

(3) $$F_1'(e_1) = ... = F_N'(e_N) = D_j'(\sum_i e_i)$$

These N equations determine all emission levels. Compared with 2, the sum of emissions is lower in the social optimum[4]. Moreover, the first N-1 equations in (3) imply that the sum of emissions is allocated across countries in a cost-effective manner. This is generally not true in the non-cooperative outcome, as marginal abatement costs (F_j') generally differ across countries, cf. (2).

In the simple model above, it is not possible to have any inefficiency within countries: Given all emission levels, the welfare level of each country follows. This relationship between emission and welfare levels would of course not hold in a more complex model, e.g. with a model with several goods and/or several production sectors. However, as long as the interaction between countries is modeled as a game in which each country has its own total emissions as its strategy variable, there is nothing inherent in the model leading to any inefficiency within countries.

It is far from obvious that games where emission levels of each country are the strategy variables is the best way to model environmental interaction between countries. The problem with this approach is that the sum of emissions in each country is not a decision variable for any agent in the economy. Instead, emissions are the result of several factors, of which various policy instruments play an important role. One could therefore argue that a more correct specification of the game played is that the strategy variables in each country are the policy instruments of the government in the country.

In the simple model sketched above, the simplest possible way to introduce policy instruments would be to let country j have an emission tax s_j as its strategy variable. Households and firms would react to this tax by choosing emissions so that the marginal abatement costs are equal to the emission tax rate, i.e.

(4) $$F_j'(e_j) = s_j$$

In this simple model choosing the tax rate s_j is thus equivalent to choosing total emissions. Modeling the economy as a game where emission levels are strategy

[4] See e.g. Hoel (1997) where it is also shown that the emissions in some countries may be higher in the social optimum than in the non-cooperative outcome.

variables can therefore be regarded as a simplified representation of the more "correct" game where emission taxes are the strategy variables.

In the simple model above it thus makes no difference whether one assumes emission levels or policy instruments as strategy variables. However, as I shall demonstrate in the next section, slight modifications of the model will imply that it is important whether emission levels or policy instruments are regarded as the strategy variables of the game. The basic point is that when the economy is modeled in a realistic way, emissions in a country depend not only on the policies chosen in this country, but also on policies chosen *in other countries*.[5] As we shall see, this small modification of the model will lead to a third type of inefficiency of the non-cooperative outcome: Even for given emission levels in all countries, all countries could be better off with other policies than the ones chosen in the non-cooperative outcome.

2. **Transboundary pollution when there is international trade**

In the simple model presented in the previous section, there was no international trade. In this section I shall demonstrate that when there is international trade, it is no longer true that emissions in a country follow uniquely from the policy choices of that country, as the case was in the model of section 1. In the simple model presented in the present section, there are N countries and L internationally traded goods. Each country has K policy instrument to its disposal for influencing its emissions[6]. We shall use subscripts for countries, and superscripts for goods and policy instruments. The notation is as follows: The policy vector of country j is denoted by $\mathbf{s_j}=(s_j^1,\dots s_j^K)$ and the vector of all policies is $\mathbf{s} = (\mathbf{s_1,\dots,s_N})$. The price vector of the internationally traded goods is $\mathbf{p} = (p^1,\dots,p^L)$. Emissions from country j are denoted by e_j, and the sum of emissions is E $(=\Sigma_j e_j)$. The welfare level of country j is denoted by u_j.

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[5] An exception is when a system of tradable emission quotas is used domestically, and the sum of quotas is given. I return to this case in Section 5.

[6] I will return to a more specific discussion of what type of policy instruments these might be in Sections 4 and 5. For now, simply think of the policy instruments as some given set of continuous variables, such as a specific set of taxes and subsidies.

Our model is summarized by the following equations:

(5) $u_j = u_j(\mathbf{s}_j, \mathbf{p}(\mathbf{s}), E)$

(6) $e_j = e_j(\mathbf{s}_j, \mathbf{p}(\mathbf{s}))$

(7) $E = \sum_i e_i(\mathbf{s}_i, \mathbf{p}(\mathbf{s})) = E(\mathbf{s}, \mathbf{p}(\mathbf{s}))$

Equation (5) is a reduced form equation, expressing that a country's choice of policy has a direct effect on the welfare level of the country, even when all world market prices and the sum of emissions are held constant. Each country's welfare level also depends on the prices of all internationally traded goods, which in turn depend on the policies chosen by all countries. Emissions from each country also depend on the policies chosen in the country and on the price of internationally traded goods, cf. equation (6). Finally, each country's welfare level depends on the environmental quality in the country, and given our assumptions this is captured by the sum of emissions from all countries, cf. equation (7).

Notice that emissions from country j are affected both by this country's choice of policy and by the prices of internationally traded goods. This is a crucial assumption in our model, and I therefore give some justification. I will use the climate problem as an example, but similar arguments can be made for other transboundary pollution problems.

For the climate problem, the most obvious way emissions in a country are affected by international prices is through the prices of fossil fuels. For given policies in a country (e.g. given tax rates and/or various types of regulations such as specifications of fuel efficiency etc), the use of fossil fuels, and thus carbon emissions, will depend on the international prices of fuels. International prices of energy intensive goods are also important: The higher these prices are, the more will a country produce of such goods (cet. par.) for any given domestic policies. Since increased production of energy intensive goods at the expense of production in other goods will increase the country's use of energy, this will increase carbon emissions provided some of the increased energy use is based on fossil fuels.

Mechanisms of this type have been studied extensively in the literature of carbon leakage, see e.g. see e.g. Bohm (1993), Golombek et al. (1994), Hoel (1994, 1996, 2000) and Rauscher (2000). This literature discusses how policies introduced in one country or a in a group of countries with the aim of reducing carbon emissions may increase carbon emissions in other countries thus weakening the effect of the policies. (We will return briefly to this issue in the next Section.)

3 The non-cooperative outcome

As mentioned in the Introduction, we assume that the non-cooperative outcome is given by the Nash equilibrium where the strategy variables of country j are given by its policy vector $\mathbf{s}_j$. Formally, we find the equilibrium by maximizing each u_j with respect to the K policy variables in the policy vector $\mathbf{s}_j$, taking all other policy variables as given. This gives the following NK first order conditions:

$$(8) \qquad \frac{\partial u_j}{\partial s_j^k} + \frac{\partial u_j}{\partial E}\frac{\partial e_j}{\partial s_j^k} + \Omega_j^k = 0 \qquad k=1,\ldots,K; \;\; j=1,\ldots,N$$

where

$$(9) \qquad \Omega_j^k = \sum_l \frac{\partial u_j}{\partial p^l}\frac{\partial p^l}{\partial s_j^k} + \frac{\partial u_j}{\partial E}\sum_l \frac{\partial E}{\partial p^l}\frac{\partial p^l}{\partial s_j^k}$$

The term Ω_j^k thus measures how a change in policy variable k indirectly affects the welfare of country j, via the effect on the prices of internationally traded goods. Notice that the total welfare effect of price change is the sum of the direct effect of the price change and the indirect effect via the effect of the price change on emissions in all countries. We shall assume that all countries are small in the sense that the first of these effects, i.e. the direct effect (given by the first term in (9)), is close to zero. We therefore disregard this term[7], and rewrite (9) as

$$(10)\qquad \Omega_j^k = \frac{\partial u_j}{\partial E}\sum_l \frac{\partial E}{\partial p^l}\frac{\partial p^l}{\partial s_j^k}$$

so that (8) may be written as

$$(11)\qquad \frac{\dfrac{\partial u_j}{\partial s_j^k}}{\dfrac{\partial e_j}{\partial s_j^k}} = -\frac{\partial u_j}{\partial E}(1+\alpha_j^k)$$

where

$$(12)\qquad \alpha_j^k = \frac{\sum_l \dfrac{\partial E}{\partial p^l}\dfrac{\partial p^l}{\partial s_j^k}}{\dfrac{\partial e_j}{\partial s_j^k}}$$

The term α_j^k measures the ratio for country j between the indirect effect of policy k on emissions via the prices of internationally traded goods and the direct effect of policy k on emissions. Typically (but generally not for all policy instruments) these terms will be negative. The discussion in Section 2 of carbon leakage gave examples of how international prices could be affected by the policies chosen by a particular country. If a country reduces its demand for fossil fuels by introducing a carbon tax, international fuel prices will decline. This reduction of fuel prices will lead to an increase in fuel demand other countries, and thus in their CO_2 emissions. A second mechanism of carbon leakage is via the prices of energy intensive tradable goods: if the use of fossil fuels is reduced through a carbon tax in the sectors producing these goods, production of energy

[7] Notice that although we are assuming that the first term in (9) is small in all countries, we cannot set the second term in (9) to zero. The reason is that for a small country, $(\partial u_j/\partial E)(\partial E/\partial p^l)$ will typically be "large" compared to $\partial u_j/\partial p^l$. We return to this in Section 4.

intensive tradable goods will be reduced in the country which introduces a carbon tax, thereby resulting in reduced CO_2 emissions from this country. However, the reduced supply of energy intensive tradable goods in this country will increase the international price of these goods, thus increasing the supply in other countries. Emissions from other countries therefore increase.

Numerical simulations quantifying the importance of carbon leakage include Pezzey (1992) and Kolstad et al. (1999) who conclude that the carbon leakage might be quite strong, while e.g. Olivera-Martins et al. (1992), Felder and Rutherford (1993), Perroni and Rutherford (1993), and Jacoby et al. (1997) give numerical simulations indicating that the effects are modest.

In the absence of international trade the terms α_j^k would be zero, and (12) would correspond to (2), except that we now have one equation for each policy instrument. The l.h.s. of (11) can be interpreted as the marginal abatement costs (measured in utility) when using policy instrument k to reduce emissions. The first term on the r.h.s. of (11) is the marginal environmental cost of emissions (measured in utility). If $\alpha_j^k=0$ for all k for country j, equation (11) tells us that the marginal abatement cost for country j should be equal to the marginal environmental cost for country j for all policy instruments country j uses to reduce emissions.

For any country j, the terms α_j^k will generally differ from zero, and they will generally depend on k, i.e. on the policy instrument considered. This is the source of the third type of inefficiency mentioned in the Introduction: For given emission levels, a cost-effective policy implies that the l.h.s. of (11) should be the same for all policy instruments.

Formally, this third type of inefficiency is demonstrated as follows. Denote the emission vector following from (11) by **e***. Maximizing the welfare function of country j given these emission levels can be formulated as the following optimization problem:

$$(13)\qquad \begin{aligned} &\max \quad u_j(\mathbf{s}_j, \mathbf{p(s)}, e_j^* + \sum_{i \neq j} e_i^*) \\ &\quad s.t. \quad e_j(\mathbf{s}_j, \mathbf{p(s)}) \leq e_j^* \end{aligned}$$

It is straightforward to see that the first order condition of this optimization problem is (when country j is a price taker)

$$(14)\qquad \frac{\dfrac{\partial u_j}{\partial s_j^k}}{\dfrac{\partial e_j}{\partial s_j^k}} = \lambda_j$$

where λ_j is the shadow price of the emission constraint in (13). The l.h.s. of (14) is identical to the l.h.s. of (11). Cost-effectiveness for given emission levels thus implies that the marginal abatement costs should be the same for all policy instruments used to reduce emissions.

4 Emission taxes as policy instruments

So far, we have not discussed in any detail what the policy instruments may be. In order to get sharper results, this section considers a specific example of the general model presented in the previous sections. In this example the policy instruments are assumed to be taxes on emissions, possibly differentiated by production sector.

Assume that the welfare level of country j only depends on the income level y_j of country j in addition to the price vector **p** and total emissions E. Moreover, assume that total income y_j depends on the vector of emission taxes as well as on international prices. The welfare function given by (5) then takes the form of the following indirect utility function:

(15) $u_j = v_j(y_j(\mathbf{s}_j, \mathbf{p}(\mathbf{s})), \mathbf{p}(\mathbf{s}), E)$

Production decisions are made by profit maximizing price-taking firms. Denote the output vector by $\mathbf{x_j} = (x_j^1,\ldots,x_j^L)$. Emissions per unit of output l are ε_j^l. Emission taxes may vary across goods, and are thus given by the vector $\mathbf{s_j}=(s_j^1,\ldots,s_j^L)$, so that producers in country j face the price vector $\mathbf{q_j}=(p^1-\varepsilon_j^1 s_j^1,\ldots, p^L-\varepsilon_j^L s_j^L)$. Producers maximize revenue given a technological constraint on the feasible vectors $\mathbf{x_j}$. This gives a convex revenue function $R_j(\mathbf{q_j})$ with the property

(16) $x_j^l(\mathbf{q}_j) = \dfrac{\partial R_j(\mathbf{q}_j)}{\partial(q_j^l)}$

Total income in the economy is given by the sum of this maximized revenue and the tax revenue collected, i.e.

(17) $y_j = R_j(\mathbf{q}_j) + \sum_l s_j^l \varepsilon_j^l x_j^l(\mathbf{q}_j)$

and total emissions in country j are given by

(18) $e_j = \sum_l \varepsilon_j^l x_j^l(\mathbf{q}_j)$

The demand for each good is given implicitly by the indirect utility functions, and the price vector **p(s)** is determined so that total demand equals total supply of each good.

Given the specification above, it is straightforward to see that the expressions in (11) now are given by

(19) $$\frac{\partial u_j}{\partial s_j^k} = \frac{\partial v_j}{\partial y_j}\left(-\sum_l s_j^l \varepsilon_j^l \frac{\partial x_j^l}{\partial q_j^k}\right)$$

(20) $$\frac{\partial e_j}{\partial s_j^k} = -\sum_l \varepsilon_j^l \frac{\partial x_j^l}{\partial q_j^k}$$

(21) $$\frac{\partial u_j}{\partial E} = \frac{\partial v_j}{\partial E}$$

The first order conditions for a non-cooperative equilibrium, given by (11) for the general case, may thus be written as

(22) $$\frac{\sum_l s_j^l \varepsilon_j^l \frac{\partial x_j^l}{\partial q_j^k}}{\sum_l \varepsilon_j^l \frac{\partial x_j^l}{\partial q_j^k}} = m_j(1+\alpha_j^k)$$

where

(23) $$m_j \equiv -\frac{\frac{\partial v_j}{\partial E}}{\frac{\partial v_j}{\partial y_j}}$$

is the marginal environmental cost of country j, measured in money.

The condition (16) for cost-effectiveness may in the present case be written as

(24) $$\frac{\sum_l s_j^l \varepsilon_j^l \frac{\partial x_j^l}{\partial q_j^k}}{\sum_l \varepsilon_j^l \frac{\partial x_j^l}{\partial q_j^k}} = \frac{\lambda_j}{\frac{\partial v_j}{\partial y_j}}$$

A well-known result follows immediately from (24): If taxes are equalized across sectors in a country, we get a cost-effective outcome.[8]

It follows from (22) that taxes are equalized across sectors in country j if $\alpha_j^1 = \ldots \alpha_j^K$. In particular, if we had no international trade all α_j^k would be zero. In this case it follows immediately from (22) that the optimal solution is

$$(25) \quad s_j^1 = ... = s_j^K = m_j \qquad for \qquad \alpha_j^1 = ... = \alpha_j^K = 0$$

In other words, the non-cooperative equilibrium is in this case characterized by each country choosing a uniform emission tax for all sectors. This implies that we have cost-effectiveness within each country, in the sense that given a country's emission level, its welfare level is maximized. The level of the common tax in each country is equal to the country's own marginal environmental cost. The outcome is thus globally inefficient as discussed in Section 1: A first best cooperative outcome in this economy is characterized by emission taxes being equal across countries, and the common tax level should be equal to the sum of all countries' marginal environmental costs.

When the terms α_j^k differ across goods, it follows from (22) that taxes will differ across sectors, so that we get the type of inefficiency discussed more generally in the previous Section. Even for the simple model of the present section, it is not possible to say much about exactly how taxes differ between sectors. To get some further insight, I therefore make a further simplification of the model.

Let good number 1 be a numeraire good with an international price equal to one. Moreover, there are no emissions from the production of this good. Let the cross

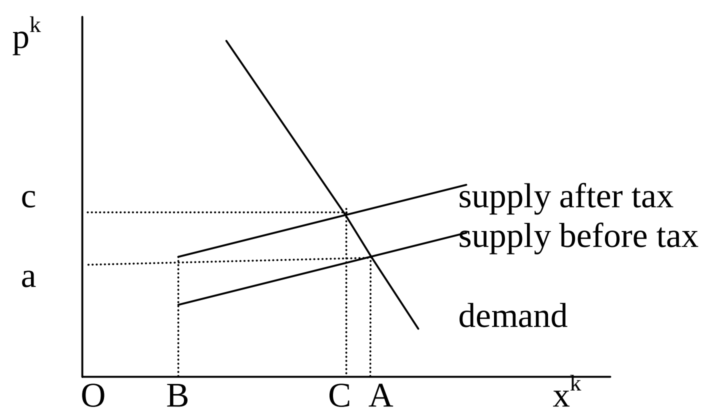
[8] The level of the common tax must be so high that the emission constraint in the optimization problem (15) is satisfied, i.e. equal to the r.h.s. of (24).

derivatives of the revenue function R_j be zero for all other goods.[9] For this case (22) may be rewritten as

(26) $$s_j^k = m_j(1+\alpha_j^k)$$

For this special case there is thus a direct relationship between the optimal carbon tax used in the sector producing good k and the size of the term α_j^k. As mentioned in the previous Section, we expect most α_j^k to be negative, so that in most sectors the optimal carbon tax will be lower than the marginal environmental cost of the country considered. The α_j^k terms will generally differ across sectors. However, as these terms depend in a complex way of demand and supply conditions in all countries, we cannot give any simple rule telling us for which sectors the terms are relatively high or low. A simple partial equilibrium analysis is useful to illustrate this. In Figure 1 we have drawn the aggregate supply and demand curve (for the whole world) for good k.

Figure 1:



[9] The production possibilities could e.g. be given by $x_j^1/w_j+\Sigma_{i>1}n_j^i(x_j^i)\leq N_j$, where w_j and N_j are a given wage rate and a given supply of labour in country j, respectively. All functions $n_j^i(x_j^i)$ are increasing and strictly convex.

Introducing an emission tax on producers of this good in one country will give the supply curve a (small) upward shift. The direct effect of this (i.e. at the original price Oa) is to reduce production from OA to OB. However, the upward shift in the supply curve will also change the equilibrium price from Oa to Oc. This price increase will increase aggregate output of this good from OB to OC. The net reduction of the production of the good will thus only be the magnitude CA. Since emissions by assumption are proportional to output, this partial equilibrium analysis implies that the term α_j^k will be negative with $-\alpha_j^k$ equal to the ratio BC/BA. From Figure 1 it is clear that the size of this term will depend on the relative steepness of the supply and demand curves: The ratio BC/BA is higher the flatter is the supply curve and the steeper is the demand curve. Notice also that the ratio BC/BA is independent of how large the shift in the supply curve is. We have previously assumed that each country is small, so that no matter what it does international prices are only marginally affected. This means that the price increase from Oa to Oc is very small, i.e. the upward shift in the supply curve is very small. It is clear form the discussion related to Figure 1 that the terms α_j^k might be large (in absolute value) also for small countries.

The partial equilibrium analysis above does not give the whole story about the magnitude of the α_j^k terms. When the price of good k increases from Oa to Oc, this generally affects the demand for all goods[10]. This will in turn affect the equilibrium prices of all goods, and thus production and related emissions of all goods. When these secondary effects are added, the size of the terms α_j^k will no longer be given simply by ratios of the type BC/BA in Figure 1. If these secondary effects are small compared to the direct price effects given in Figure 1, it will nevertheless remain true that the steepness of the aggregate supply and demand curves for good k are important predictors for the size of the term α_j^k.

[10] If we made the same seperability assumption on the demand side as on the supply side, a change in the price of good k would only affect the demand of good 1 in addition to good k.

5 Emission taxes versus auctioned quotas

In the previous Section we saw that if emission taxes were the only policy instruments available, it would usually be individually rational for a country to choose a differentiated tax structure. In Hoel (1996) I have shown that if the set of policy instruments is expanded so that import and export tariffs are allowed for, it will be optimal for each country to have a uniform emission tax. This emission tax should be supplemented with import and export tariffs (some negative and some positive) in order to take account of the price induced effects on emissions in other countries. The general result from Section 3, i.e. that the absence of international cooperation leads to domestic inefficiency, is thus valid also for this case.

In the present section I assume that export and import tariffs are not feasible policy instruments. However, let auctioned (and tradable) emission quotas be an alternative policy to emission taxes (uniform or differentiated). It is well known that in the absence of any type of uncertainty, auctioned emission quotas are equivalent to a uniform emission tax. Provided the α_j^k terms differ across sectors for a country, it follows from the analysis in Section 4 that differentiated emission taxes give the country a higher welfare level than auctioned quotas. This is illustrated by the first two columns of Table 1, which gives the welfare level of alternative policies for a particular country.

Table1: Welfare levels for a particular country for alternative policies

	Other countries choose differentiated emission taxes	Other countries choose a uniform emission tax	Other countries choose auctioned quotas
Differentiated emission taxes	u	w	y
Uniform emission tax	v	x	z
Auctioned quotas	v	x	z

In Table 1 it is assumed that

(27) $u>v \quad w>x \quad y<z$

The two first inequalities follow from the results of Section 4: If other countries use emission taxes, the terms α_j^k of the country considered will generally differ across sectors, so that a differentiated tax structure is superior to a uniform emission tax, which in turn is equivalent to a system of auctioned quotas. However, if all other countries use quotas as their environmental policy, emission levels in all these countries will be given. In this case all the terms α_j^k of the country considered will therefore be equal to zero. But when this is the case the best policy for the country is to have a uniform emission tax, or equivalently, use auctioned quotas. We therefore have $y<z$ in the last column of Table 1.

The structure of table 1 is the same for all countries. It is therefore clear that an outcome in which all countries have differentiated emission taxes is a non-cooperative equilibrium, in the sense that no country can gain by unilaterally deviating from this outcome. The outcome in which all countries choose auctioned quotas is also an equilibrium for the same reason. If all other countries use quotas as their policy instrument, no country can do better than to use quotas. However, the latter equilibrium is weak in the sense that each country is equally well of by using a uniform emission tax as by using auctioned quotas. But if some countries choose to use a uniform tax instead of quotas, the quota equilibrium brakes down. Without any cooperation, an equilibrium with differentiated taxes in all countries thus seems to be a more likely outcome than an equilibrium in which all countries choose quotas.

Notice that although there is no domestic inefficiency in the quota equilibrium, it is not obvious that this equilibrium is better than the equilibrium with differentiated taxes, although $z>u$ seems to be the most plausible case.

6 Concluding remarks

It is well known that without any coordination between countries, transboundary pollution will give an inefficient level of emissions in each country. The present analysis has shown that in addition to this inefficiency, there will usually also be domestic inefficiencies, in the sense that given the emission levels in all countries, each country could increase its welfare by changing its policy. The reason for the inefficiency is that each country does not regard emission levels in other countries as given when it decides its own environmental policy.

A typical manifestation of this domestic inefficiency for the climate problem is that countries choose carbon taxes that are differentiated across sectors. It was shown in Section 4 that the optimal tax structure for a single country might be difficult to calculate. Nevertheless, several countries in fact do attempt to differentiate carbon taxes for the reasons given in the present paper. In e.g. my own country (Norway), the most emissions intensive parts of the manufacturing industries are completely exempted from carbon taxes, while most other sectors (including households) pay a carbon tax varying from approx. 10 to approx. 40 Euro per ton CO_2. The exemptions have been justified by the carbon leakage argument discussed more generally in this paper.

The process around the Kyoto agreement has shown how difficult it can be to reach international environmental agreements. One of the reasons for this is the free rider problem: If a country stays outside an agreement between all other countries, it can enjoy (almost) the same benefits of reduced emissions as if it participates in the agreement, while it doesn't bear any of the costs of reducing emissions. This free rider incentive remains even if the agreement is such that all countries are better off with the agreement than without: A country may be better off participating in an agreement than it would be without any agreement. But it will usually be even better off if the other countries cooperate, while it itself stays outside the agreement and pursues its self-interest.[11]

An important result of Section 4 was that although a non-cooperative equilibrium with differentiated emission taxes seems to be the most likely outcome when there is no cooperation, there may also be an equilibrium where all countries use quotas as their environmental policy. It may very well be the case that this equilibrium Pareto dominates the equilibrium with differentiated emission taxes. If this were the case, a good start for international cooperation would be to coordinate on this superior equilibrium. This type of international cooperation would not be undermined by free riding: If other countries choose to use quotas as their environmental policy, then no country can do better than to use quotas itself.

[11] For a further discussion of this issue, see e.g. Carraro (1999) and the references given there.

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