Economics Letters 44 (1994) 443–449

0165-1765/94/$07.00

Who should abate carbon emissions?

An international viewpoint

Graciela Chichilnisky

Department of Economics, Columbia University, New York, NY 10027, USA

Geoffrey Heal*,†

101 Uris Hall, Columbia Business School, Columbia University, New York, NY 10027, USA

Received 16 June 1993
Accepted 30 August 1993

Abstract

We review the optimal pattern of carbon emission abatements across countries in a simple multi-country world. We model explicitly (with the model in Chichilnisky, 1993b) the fact that the atmosphere is a public good. Within this framework we establish conditions for it to be necessary for optimality that the marginal cost of abatement be the same in all countries. These conditions are quite restrictive, and amount to either ignoring distributional issues between countries or operating within a framework within which lump-sum transfers can be made between countries. These results have implications for the use of tradeable emission permits, which as normally advocated will lead to the equalization of marginal abatement costs across countries. The observation that the atmosphere is a public good implies that we may need to look at a Lindahl equilibrium rather than a Walrasian equilibrium in tradeable permits.

JEL classification: Q20, H40

1. Who should abate?

The 1992 Rio Convention acknowledged the need for international co-operation in responding to the threat of climate change posed by the rapidly increasing concentration of CO_2 in the atmosphere. There are however substantial differences of opinion both about the main issues and about the framework for resolving them. Industrial countries typically focus on the potential problems posed by the growth of population in developing countries, and on the environmental pressure from carbon emissions that this could create over the next half century. Abatement efforts, they feel, should be initiated in the developing countries. On the other hand, developing countries view the carbon emission problem as one that originates historically and currently in the industrial countries, and one that requires their immediate action. Indeed, the large majority of all

* Corresponding author.
† Research support from NSF Grants 91-10460 and 92-16028, and from the Fondazione Mattei is gratefully acknowledged, as are valuable comments from K. Arrow, B. Kristrom, J-P. Benassy, P. Dasgupta, J. Oliveira Martins and P. Sturm.

SSDI 0165-1765(93)00346-P

carbon emissions, about 73%, originate currently and historically in the OECD countries and in the ex-Soviet Union; the developing countries have almost four-fifths of the world's population yet contribute at most 30% of all carbon emissions.[1]

CO_2 emissions are a by-product of animal life, and of economic activity which involves burning fossil fuels. The rapid increase in the concentration of CO_2 in the atmosphere which has occurred since the Second World War has become a matter of great concern, as it could lead to major and irreversible climate changes. This concentration affects us all equally, because CO_2 mixes uniformly throughout the planet's atmosphere.

From the economic viewpoint, therefore, the abatement of carbon emissions increases our consumption of a *public good*, a 'better' atmosphere. However, this differs from the classic public good in that it is not produced in a centralized fashion. Its production is decentralized: each consumer of the atmosphere is also a producer. Each country uses the atmosphere as a 'sink' for the carbon emissions which are a by-product of its economic activities. We have therefore a public good which is independently *produced* as well as *consumed* by all, a case which is closer to that of an economy with externalities, e.g. Baumol and Oates (1988) and Heal (1990). The classic questions of optimality in the provision of the public good now become questions about the optimal abatement levels of the different countries. Who shall abate, and by how much? And how are the optimality conditions for abatement related to the countries' levels of income, their marginal costs of abatement, and the efficiency of their abatement technologies?

We find some answers to these questions in a simple model (introduced in Chichilnisky, 1993b) of the world economy consisting of a finite number of countries.[2] Each country has a utility function which depends on the consumption of a public good and of a private good, such as income. The production of private good emits carbon dioxide as a by-product, and in each country the private good can be transformed into the public good through an abatement technology.

We show that Pareto efficiency dictates that the marginal cost of abatement in each country must be inversely related to that country's marginal valuation for the private good (Proposition 1). In particular, it is not generally true that Pareto optimality requires that marginal abatement costs be equated across countries: this is true only if marginal utilities of income are equated across countries, either by assumption or by lump-sum transfers across countries. If richer countries have a lower marginal valuation of the private good, then at a Pareto-efficient allocation, they should have a larger marginal cost of abatement than the lower income countries. With diminishing returns to abatement, this implies that they should push abatement further.

There is a presumption in the literature that efficiency requires equalization of marginal abatement costs: this presumption underlies proposals for the use of uniform carbon taxes and tradeable carbon emission permits [Coppel (1993), Weyant (1993)]. However, in view of the public-good nature of the atmosphere and the fact that carbon emissions are produced in a decentralized fashion, without lump-sum transfers, efficiency will not in general require the equalization of marginal costs of abatement across countries.

In a two-country example we show that, at an efficient allocation, the quantity of income allocated by a country to abatement is inversely proportional to the level of income – or consumption – of that country, with the constant of proportionality increasing with the efficiency of the country's abatement technology (Proposition 2).

The equalization of marginal costs would be necessary for Pareto efficiency if the goods under consideration were private goods. But in our case we are dealing with a *public* good, i.e. one which, by definition, is consumed by all in the same quantity: the atmospheric CO_2 concentration.

[1] There is more detail in Chichilnisky (1992, 1993a,b), and Chichilnisky and Heal (1993).

[2] It is, in fact consistent with that of Baumol and Oates (1988, ch. 4).

This public good is 'produced' by the CO_2 emissions (or by the abatement of these emissions) of a finite number of large agents, namely the countries. In this sense, it differs from the classical treatments of Lindahl and Bowen, which were extended subsequently by Samuelson; see Atkinson and Stiglitz (1980, p. 489, footnote 3). In those cases the public good is produced by a single agent, as is the case for law and order or defence.

2. Pareto-efficient abatement strategies

Consider a world economy with N countries, $N \geq 2$, indexed by $n = 1 \ldots N$. Each country has a utility function u_n which depends on its consumption of private goods, c_n, and on the quality of the world's atmosphere, a, which is a public good. Formally, $u_n(c_n, a)$ measures welfare, where $u_n : R^2 \to R$ is a continuous, concave function and $\partial u_n / \partial c_n > 0$, $\partial u_n / \partial a > 0$. The quality of the atmosphere, a, is measured by, for example, the reciprocal or the negative of its concentration of CO_2. The concentration of CO_2 is 'produced' by emissions of carbon, which are positively associated with the levels of consumption of private goods, c_n, i.e.

$$a = \sum_{n=1}^{N} a_n , \quad \text{where } a_n = \Phi_n(c_n) \text{ for each country } n = 1 \ldots N,\ \Phi_n' < 0 . \tag{1}$$

Here a is a measure of atmospheric quality overall, and a_n is an index of the abatement carried out by country n. The 'production functions' Φ_n are continuous, and show the level of abatement or quality of the atmosphere decreasing with the output of consumption. As a very particular example, consider the case where each country has a level of income Y_n which can be consumed or devoted to abatement and the constraint Φ_n is given by

$$c_n + a_n = Y_n, \text{i.e. } \Phi_n(c_n) = Y_n - c_n . \tag{2}$$

This formulation is an example only: the results obtain more generally, an allocation of consumption and abatement across all countries is a vector

$$(c_1, a_1, \ldots, c_N, a_N) \in R^{2N} .$$

An allocation is called *feasible* if it satisfies the constraint (1). A feasible allocation $(c_1^*, a_1^*, \ldots, c_N^*, a_N^*)$ is *Pareto-efficient* if there is no other feasible solution at which every country's utility is at least as high, and one's utility is strictly higher, than at $(c_1^*, a_1^*, \ldots, c_N^*, a_N^*)$.

A Pareto-efficient allocation must maximize a weighted sum of utility functions

$$W(c_1 \ldots c_n, a) = \sum_{n=1}^{N} \lambda_n u_n(c_n, a)$$

with $\Sigma_n \lambda_n = 1$ subject to feasibility constraints. Varying the λ_n's, one traces out all possible Pareto-efficient allocations. The λ_n's are of course exogenously given welfare weights, and a standard set of weights is $\lambda_n = 1/N$ for all n. We are assuming in this formulation that utilities are comparable across countries. This means that we cannot change the units of measurement of utility in any country without making similar changes in other countries. Each country n faces a constraint in terms of allocating total endowments into either consumption c_n or atmospheric quality, a_n, represented by the function Φ_n. Then a Pareto-efficient allocation is described by a solution to the problem:

$$\max W(c_1 \ldots c_n, a) = \sum_{n=1}^{N} \lambda_n u_n(c_n, a) , \tag{3}$$

$$\text{subject to } a_n = \Phi_n(c_n),\ n = 1 \ldots N \text{ and } a = \sum_{n=1}^{N} a_n . \tag{4}$$

Note that, by definition, the marginal cost of abatement is the inverse of the marginal productivity of the function Φ_n:

$$MC_n(a_n) = -1/\Phi_n'(c_n) \tag{5}$$

A Pareto-efficient solution solves problem (3).

Proposition 1. At a Pareto-efficient allocation $(c_1^*, a_1^*, \ldots, c_N^*, a_N^*)$, *the marginal cost of abatement in each country,* $MC_n(a_n^*)$, *is inversely proportional to the marginal valuation of the private good* c_n, $\lambda_n\, \partial u_n/\partial c_n$. *In particular, the marginal costs will be equal across countries if and only if the marginal valuations of the private good are equal, i.e.* $\lambda_n\, \partial u_n/\partial c_n$ *is independent of n.*

Proof. The solution to the maximization problem (3) must satisfy the first-order conditions:

$$\lambda_j\, \partial u_j/\partial c_j = -\Big(\sum_{n=1}^{N} \lambda_n\, \partial u_n/\partial a\Big)\Phi_j'$$

for each country $j = 1 \ldots N$. Since at a Pareto-efficient allocation the expression $(\Sigma_{n=1}^{N} \lambda_n \partial u_n/\partial a)$ is the same constant for all countries, denoted K, and since, as noted in (5),

$$MC_n(a_n^*) = -1/\Phi_n'(c_n) ,$$

we have that a Pareto-efficient allocation is characterized by

$$MC_j(a_j^*) = \frac{K}{\lambda_j\, \partial u_j/\partial c_j}$$

and the proposition follows. □

Proposition 1 shows that the product of the marginal valuation of private consumption and the marginal cost of abatement in terms of consumption, is equal across countries. Writing this product $\lambda_j\, \partial u_j/\partial c_j . \partial c_j/\partial a$, we see that it can be interpreted as the marginal cost of abatement in country j measured in utility terms, i.e. in terms of its contribution to the social maxim and $\Sigma_n \lambda_n u_n(c_n, a)$. An immediate implication is that in countries that place a high marginal valuation on consumption of the private good, typically low income countries, the marginal cost of abatement at an efficient allocation will be lower than in other countries. If we assume an increasing marginal cost of abatement (diminishing returns to abatement), then this of course implies lower levels of abatements in poor countries than in rich countries.

Under what conditions can we recover the 'conventional wisdom' that marginal abatement costs should be equalized across countries? We need to equate the terms $\lambda_n\, \partial u_n/\partial c_n$ across countries. This could be done *by assumption*: we can just decide as a value judgment that is an input to the planning problem that consumption will be valued equally on the margin in all countries. Given the enormous discrepancies between the income levels in OECD countries and countries such as India and China, and the need for all of them to be involved in an abatement program, such a value judgment seems most unattractive. It is however implicitly done in simulation models which seek to maximize world GNP or similar measures.

There is an alternative possibility. Modify the original problem to allow unrestricted transfers of private goods between countries

$$\max W(c_1, c_2, c_n, \ldots a) = \Sigma_n \lambda_n u_n(c_n, a)$$

$$\text{subject to } a_n = \Phi_n(y_n) \text{ and } a = \Sigma a_n \text{ and } \Sigma y_n = \Sigma c_n . \tag{6}$$

This is the same as before except that we now distinguish between the consumption of the private good by country n, denoted c_n, and the production of the private good by country n, denoted y_n. These need not be equal. In addition we now require the sum of the consumptions across countries to equal the sum of the productions, $\Sigma y_n = \Sigma c_n$, instead of having these equal on a country-by-country basis. By this modification we are allowing the transfer of goods between countries, i.e. we are allowing lump-sum transfers. Note that this is not a model of international trade, which would require the imposition of balance of trade constraints. Clearly the first-order conditions now are just

$$\lambda_n \frac{\partial u_n}{\partial c_n} = v , \quad \forall_n \tag{7}$$

$$\Phi_n' \sum \lambda_j \frac{\partial u_j}{\partial a} = -v , \quad \forall n . \tag{8}$$

Set $K = \Sigma \frac{\partial u_j}{\partial a}$. Hence from (7) and (8) we get

$$\lambda_n \frac{\partial u_n}{\partial c_n} = -\Phi_n' K \tag{9}$$

as before. However, we how have an extra condition (7) – namely $\lambda_n \frac{\partial u_n}{\partial c_n} = v \; \forall n$. Substituting this into (9) gives

$$v = -\Phi_n' K ,$$

which of course implies that physical marginal cost is the same across all countries, as v and K are common to all countries. So if we solve an optimization problem that allows unrestricted transfers between countries, and we make the transfers that are needed to solve this problem, it will then be efficient to equate marginal abatement costs.

Consider now the case of two countries, each with a Cobb–Douglas utility function,

$$u_n(c_n, a) = c_n^{\alpha}(a)^{1-\alpha} = c_n^{\alpha}(a_1 + a_2)^{1-\alpha} ,$$

where the abatement production function Φ_n is

$$a_n = \Phi_n(c_n) = k_n(Y_n - c_n)^{1/2} , \quad k_n > 0 , \quad \text{for } n = 1, 2 ,$$

for example, $k_1 = k$ and $k_2 = 1$. This allows us to accommodate potentially different efficiencies of abatement across countries. For simplicity, the two countries are assumed to have the same utility function. In this case:

Proposition 2. At a Pareto-efficient allocation, the fraction of income which each country allocates *to carbon emission abatement must be proportional to that country's income level, and the constant of proportionality increases with the efficiency of the country's abatement technology.*

Proof. Our problem (3) can now be written as

$$\max_{c_1,c_2} W(c_1, c_2) = \max\{c_1^{\alpha}[k(Y_1 - c_1)^{1/2} + (Y_2 - c_2)^{1/2}]^{1-\alpha} + c_2^{\alpha}[k(Y_1 - c_1)^{1/2} + (Y_2 - c_2)^{1/2}]^{1-\alpha}\} .$$

Let

$$A = [k(Y_1 - c_1)^{1/2} + (Y_2 - c_2)^{1/2}] .$$

The first-order conditions for a maximum are then:

$$\alpha c_1^{\alpha-1} A^{1-\alpha} - 1/2(Y_1 - c_1)^{-1/2} k\{c_1^{\alpha} A^{-\alpha}(1-\alpha) + c_2^{\alpha}(1-\alpha)A^{-\alpha}\} = 0$$

and

$$\alpha c_2^{\alpha-1} A^{1-\alpha} - 1/2(Y_2 - c_2)^{-1/2}\{c_1^{\alpha} A^{-\alpha}(1-\alpha) + c_2^{\alpha}(1-\alpha)A^{-\alpha}\} = 0 ,$$

which simplify to

$$\left(\frac{c_1}{c_2}\right)^{\alpha-1} = k\left(\frac{Y_1 - c_1}{Y_2 - c_2}\right)^{-1/2} .$$

Since $\alpha < 1$ this implies that for Pareto efficiency, the income allocated to abatement by each country ($a_n = Y_n - c_n$, $n = 1, 2$) must be proportional to the income level, or the level of consumption, of the country (c_n). Furthermore the larger is the abatement productivity of a country ($k = k_1$), the larger is its abatement allocation as a proportion of income. □

3. Abatement costs, taxes and emission permits

While the atmosphere is a classic public good in terms of consumption, it is produced in a decentralized way, and the first-order conditions for efficient allocation and provision of this 'good' are different from the classical ones and closer to those characteristic of a general externality, as modeled in Heal (1990).

Once the optimal consumption/abatement levels in each country are found, then *quotas* on emissions could be assigned to each country on the basis of these levels, and *permits* could be issued and freely traded as financial instruments across countries on the basis of these quotas. A system of permits for carbon emissions has of course been contemplated for some time, but as far as we know, the country-by-country quotas for these permits have not been connected to the optimality conditions for the allocation of public goods produced in a decentralized way. It would be desirable to ascertain what form of market organization for the permit market would be required in order to reach efficiency. For example, would it involve uniform pricing as in a competitive market, or rather personalized prices as in a Lindahl equilibrium? This should be a subject for further research.

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