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Allocating greenhouse gas emissions among countries with mobile populations

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Allocating greenhouse gas emissions among countries with mobile populations*

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Abstract:

In the negotiations towards an agreement to reduce greenhouse gas emissions, one of the issues negotiated will be the allocation of emissions (or tradable emission permits) between countries. In most analyses and policy discussions, it is usually taken for granted that each country would like their own share of the total permitted emissions to be as large as possible. The paper demonstrates that if there is population mobility between a group of countries, this might not be true. If there is a perfectly homogeneous and mobile population in the countries considered, all these countries have a common interest in a particular allocation of emission quotas. In the more realistic case of population heterogeneity, there will typically be an interest conflict among countries regarding the allocation of emission quotas. However, it need no longer be true that each country is better off the larger its share of the total number of emission quotas.

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1 Introduction

In order to prevent dramatic climate changes the next few hundred years, it is necessary to reduce greenhouse gas emissions from present levels (see e.g. Cline 1991, 1992). To achieve significant reductions in emissions, it will be necessary to have some kind of international agreement on emission reductions.

In the negotiations towards any agreement to reduce greenhouse gas emissions, there will be at least two issues on which countries will have conflicting interests. These are

(a) how much should total emissions be reduced
(b) how should the total emission reduction be allocated among countries

These two issues are closely interrelated: For almost all rules of how to allocate emission reductions, countries will have different opinions about how much the total reduction should be. The reason for this difference in opinions is partly that different economies differ in several ways, so that most rules for sharing the emission reductions (including uniform cuts) will give countries different costs. The benefit from reducing emissions will also differ between countries, as the adverse effect of a given climate change will be different for different countries.[1]

If countries had agreed upon how much the total emission reductions should be, they would nevertheless usually disagree about how the emission reduction should be allocated among countries. In most analyses and policy discussions, it is usually taken for granted that each country would like their own share of the total permitted emissions to be as large as possible (see e.g. Kverndokk (1993, 1995)). As a main rule, this is probably correct. However, in this paper I demonstrate that among countries where there is a large degree of population mobility, each country might not want its own share of total emissions to be as large as possible.

The climate problem is a global problem involving all countries in the world. There is certainly far from full population mobility among all countries. The standard assumption used in most analyses, namely that there is *no* population mobility, might be a fair first approximation. However, between certain groups of countries, there is a considerable degree of population mobility, and there is good reason to expect this to increase in the future. Examples of areas with a large degree of population mobility include USA-Canada, and most countries in the European Union. For these areas, analyses assuming no population mobility are obviously somewhat inaccurate. The opposite extreme assumption, namely perfect population mobility, is probably even more unrealistic. It is nevertheless useful to consider this extreme, since the real world lies somewhere in between the case of no mobility and perfect mobility.

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[1] A recent study by Chao and Peck (2000) gives an explicit discussion of the relationship between the magnitude of the sum of emissions and how these emissions are allocated between countries.

2 Efficient allocations of emissions

We consider a simple model with one good and J countries. Production of this good in country j is given by a concave $f_j(n_j,e_j)$, where n_j is the population in country j. It is assumed that labor input is an increasing function of the population, so that production is higher the higher the population is[2]. The production level is also assumed to be increasing in the greenhouse gas emission level e_j for the interesting sizes of emission levels. The interpretation is that the function $f_j(n_j,e_j)$ is a reduced form function, telling us that production is lower the lower are emissions, i.e. that abatement is costly.

Consumption per capita in country j is denoted by c_j. Total consumption summed over all countries cannot exceed total production, i.e.

$$\sum_i n_i c_i \leq \sum_i f_i(n_i, e_i) \tag{1}$$

Total emissions, denoted by E, are by assumption given, as I in this paper wish to focus on the allocation of emissions among countries:

$$\sum_i e_i \leq E \tag{2}$$

Finally, the total population in the group of countries we are studying is given at the level N, so that

$$\sum_i n_i = N \tag{3}$$

There may be other constraints in addition to (1)-(3). In this paper I discuss what is meant by efficient allocations of emissions under various additional constraints. Table 1 gives an overview over the different cases considered, denoted A-F.

[2] Throughout he paper, the analysis is simplified by assuming that the relationship between population and labor input is exogenous.

Table 1: The six cases A-F studied in sections 3-5

	Exogenous population	Population determined through optimization	Population mobility
No transfers between countries	**A**	**C**	**E**
Inter-country transfers permitted	**B**	**D**	**F**

The cases with given populations in each country (i.e. A and B) have been extensively studied in the literature, and will be briefly treated in Section 3. Sections 4 and 5 treat the cases with endogenous populations (cases C-F).

3 Exogenous population

Consider first case A, i.e. the case in which population is fixed and we disregard the possibility of transfers (i.e. side payments) between countries. In this case *all* allocations of emissions across countries are Pareto efficient[3]: An increase in per capita consumption in one country can in this case only be achieved by increasing the permitted emissions in this country. But this must mean lower emissions in at least one other country, giving reduced per capita consumption there.

Case B is somewhat different. Since inter-country transfers in this case are permitted, an efficient outcome must imply that total consumption is maximized. The condition for this is that

$$f_{1e}(n_1, e_1) = \ldots = f_{Je}(n_J, e_J) \qquad (4)$$

i.e. that the marginal abatement costs are equalized across countries. This condition is often referred to as the condition of cost-effectiveness, as it is the condition for minimizing abatement costs for a given amount of abatement.

In the simple model used here the efficiency condition (4) in combination with the given sum of emissions and the given population levels gives a unique allocation of emissions, and therefore also of production levels, across countries. The distribution of consumption between countries is however not determined by the efficiency condition. Any distribution of consumption is consistent with (4), given the appropriate transfers between countries.

[3] More precisely: All allocations giving a positive marginal productivity of emissions (i.e. a positive marginal abatement cost) in all countries.

An obvious way to introduce inter-country transfers is via a scheme of tradable emission quotas. Under such a scheme each country would be allocated a specific emission quota. However, countries would be free to trade quotas with other countries. In our simple model, the equilibrium competitive price of quotas will be equal to the common marginal abatement cost given by (4). Countries selling quotas will receive a "transfer" equal to the amount of emission quotas they sell multiplied by this price; and vise versa for countries that buy quotas.

Under such a scheme one gets the efficient allocation of emissions no matter how the quotas are initially allocated. The initial allocation of quotas is thus simply the device that picks which of the efficient outcomes we obtain, and is thus a pure distributional issue.

4 Population determined through optimization

In this section it is assumed that the location of people across countries is a policy choice, in the same way as we are considering the allocation of emissions as a policy choice. This scenario is not meant to be a description of a real world case. Nevertheless, it is useful as a hypothetical reference scenario.

When population levels are endogenous, one must take some care in the definition of efficiency. We define efficiency as any outcome that satisfies the constraints of the problem and maximizes some welfare function $W(c_1,\ldots c_J)$ that is increasing in all its arguments.

Consider first case D, i.e. the case with inter-country transfers. In this case (1)-(3) are the only constraints of the problem. Maximizing the function $W(c_1,\ldots c_J)$ subject to these constraints gives us (4) and the condition[4]

$$c_1 - f_{1n}(n_1, e_1) = \ldots = c_J - f_{Jn}(n_J, e_J) \tag{5}$$

Notice that unless all per capita consumption levels are equal in the efficient outcome considered, this condition implies that populations (and thus labor input) are not allocated so that total output is maximized. While this at first thought might seem counterintuitive, given the existence of inter-country transfers, it is in fact a direct consequence of the way we define efficiency. To see this, consider the two-country case. Imagine for a moment that the sum of income in the two countries was given, independent of where people live. Moreover, consider an outcome where per capita consumption is higher in country 1 than in country 2. In this case it would clearly be possible to increase per capita consumption in both countries by moving people from

[4] Throughout the paper, I shall assume that the production functions have properties implying that the population is positive in all countries in all efficient outcomes. The possibility of zero population in some countries is discussed by Hoel and Shapiro (2000).

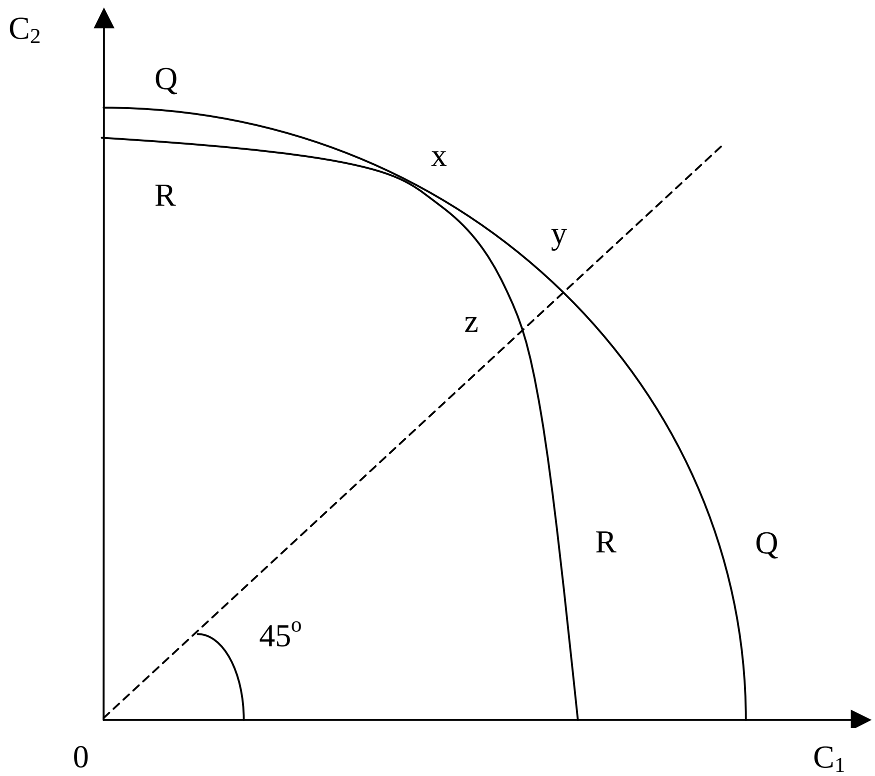

Figure 1

country 1 to country 2[5]. This would remain true even if this migration gave a slight reduction in the sum of income. How much the sum of income could go down without this conclusion being changed depends on the difference between the per capita consumption levels in the two countries. It is precisely this balancing of per capita consumption differences with the difference in marginal productivities that is implied by the efficiency condition (5).

In the two-country case, the efficiency conditions (4) and (5) define a downward sloping curve in the consumption per capita space, illustrated by Q in Figure 1. All points along the frontier Q are efficient. Clearly, the residents of country 1 prefer the points further down and to the right[6]. Which point one reaches on Q depends on the size of the transfers. The more transfers country 1 receives from 2, the further to the right on the line Q will the outcome be. There will be one point along Q that transfers are zero, we have denoted this point by x.

Consider next case C. In addition to the constraints (1)-(3) we now have the additional constraints

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[5] Notice however that although such a change increases the value of *W*, it need not be a Pareto improvement: People moving from country 1 to country 2 may get a reduced consumption level when they move.
[6] Strictly speaking, this need only be true for the persons who are residents in country 1 both before and after the move along the frontier.

$$n_i c_i \leq f_i(n_i, e_i) \quad i = 1,..., J \tag{6}$$

Maximizing $W(c_1,\ldots c_J)$ now gives us

$$\frac{f_{1e}(n_1,e_1)}{c_1 - f_{1n}(n_1,e_1)} = \ldots = \frac{f_{Je}(n_J,e_J)}{c_J - f_{Jn}(n_J,e_J)} \tag{7}$$

In this “second-best” efficient case, the first-best conditions (4) and (5) are generally not satisfied. Since the second-best has more constraints than the first-best, the consumption per capita possibility curve for the former case lies inside Q. The consumption per capita possibility curve for the second-best case is denoted R in Figure 1. The curve R lies inside Q, except at the tangency point x. since there in both cases are no transfers between countries at x.

Case C has an important feature in common with case D: In both cases there is a conflict of interest between the different countries. In the two-country case, the residents of country 1 prefer the points further down and to the right on the curve R, just as they did with the curve Q in case D. There is however an important difference: While greenhouse gas emissions should always satisfy the cost-effectiveness condition (4) in case D, this is not true in case C. The reason is of course that since the possibility of using transfers to distribute consumption is ruled out in case C, the allocation of emissions now has an important distributional role.

Both of the cases C and D are unrealistic in one important way. They both require that the distribution of persons among countries is a policy choice. Although countries to some extent can limit immigration, this is nevertheless a rather strong assumption. In the next section I therefore consider the opposite extreme, where people choose freely were they want to live.

5 Population mobility

In this section I consider the case in which there are no restrictions on where people live. I also make the following strong assumption: People are identical and have no locational preferences. All they care about is their consumption level[7]. Given these strong assumptions, and ignoring corner solutions (see footnote 4), perfect population mobility will give an equilibrium where per capita consumption is the same in all countries, i.e.

$$c_1 = \ldots = c_J \tag{8}$$

This equilibrium condition determines the allocation of populations between countries in our cases E and F.

[7] Since people are identical, it is assumed that all residents of the same country have the same consumption level.

For the two-country case, the points along the 45-degree line in Figure 1 give the equilibrium condition (8). Consider first case E: All points along the 45 degree line between the origin and the point z, and no other points, are feasible outcomes in this case. Clearly, both countries have a common interest in achieving the point z. In this case there is thus no conflict of interest between different countries. They both (or all in the general case of J countries) would like greenhouse gas emissions to be allocated in a particular way, namely in a way that maximizes the common per capita consumption level.

At the point z, there are no transfers between countries. However, generally all countries can gain from inter-country transfers, thus enabling them to increase their per capita consumption levels from z to y in Figure 1. This somewhat counterintuitive result that a donor country may benefit from giving a transfer to another country was first pointed out by Myers (1990).

Notice that since per capita consumption levels are equalized at the point y, it follows from (5) that the marginal productivity of labor is also equalized at this point. Together with (4), this means that total output is maximized at this point.

In case E there are by assumption no transfers between countries. Since international trade of emissions quotas serves as a type of transfers, case E is a case where such trade has been ruled out. In this case the final allocation of emissions will be identical to the initial allocation of emission quotas. Only one particular allocation of quotas will give the desired outcome z; any other allocation will make all countries worse off.

One interpretation of case F is that country j is given an emission quota e_j* and simultaneously a transfer Y_j* (where Y_j* can be positive or negative). Obviously, the sum of transfers over all countries must be equal to zero. Since the allocation of emissions and transfers in case F implies that the cost-effectiveness condition (4) holds, marginal abatement costs are equalized across countries. Denote this common abatement cost by $q*$. If the quotas of country j are distributed among private agents in country j, and domestic emission trading is allowed, the equilibrium quota price will be $q*$. Since this price is the same in all countries, there will be no incentives for inter-country emission trading.

An alternative interpretation of case F is that each county j is given an emission quota equal to $e_j** \equiv e_j* + Y_j*/ q*$, and no transfers. If actual emissions in each country were equal to the country's emission quota, marginal abatement costs would not be equalized across countries. If quotas are distributed among private agents in each country, there will thus be an incentive for inter-country quota trade. With no restriction on such trade, the equilibrium quota price will be $q*$. Country j would in this equilibrium be selling an amount $e_j**- e_j*$ of quotas, and thus receiving an income $q* (e_j**- e_j*)=Y_j*$ from its quota trade. It is therefore clear that this equilibrium is identical to the case in which country j receives an emission quota e_j* and simultaneously a transfer Y_j*.

From the discussion above it follows that the desired outcome in case F (point y in Figure 1) can be achieved whatever the initial allocation of emission quotas is, provided they are accompanied by a suitable set of transfers: Let country j be given an emission quota e_j^0 and a transfer $Y_j^0 = q^* (e_j^{**} - e_j^0)$. When these quotas are distributed to private agents, they will in equilibrium be selling an amount $q^* (e_j^0 - e_j^*)$ of quotas, and thus receiving an income $q^* (e_j^0 - e_j^*) = q^* (e_j^{**} - e_j^*) - Y_j^0 = Y_j^* - Y_j^0$ from their quota trade. The net transfer to country j is thus Y_j^*, and its emissions will be e_j^*, i.e. the desired outcome is achieved.

Of the cases studied, B and F seem the most interesting cases: It is difficult to find good reasons to rule out the possibilities of inter-country transfers. Moreover, although countries can place some restrictions on immigration, population levels in each country are a long way from being policy variables.

Consider the cases B and F, and assume first that the only inter-country transfers are the payments related to inter-country trade of tradable emission quotas by private agents. In this context, cases B and F have very different properties. In B, i.e. the traditional case without population mobility, there is a conflict of interest between countries regarding the appropriate initial allocation of emission quotas between countries. In fact, this allocation is a pure issue of income distribution between countries, as quota trade between private agents will give a Pareto efficient allocation of final emissions no matter how quotas are initially distributed among countries. Case F, i.e. the case with perfect population mobility, is quite different. Here all countries have a common interest in how emission quotas should be allocated. If they for some reason are allocated in a different way than this commonly shared optimum, the governments of the countries would either have to reallocate the emission quotas before distributing them to private agents, or introduce an appropriate set of transfers between countries, cf. the discussion above.

6 Locational preferences

The model used in the discussion above is extremely simple in many respects. One of the simplifying assumptions used is that there are no locational preferences, i.e. people care only about their consumption levels, and not where they live. This is obviously unrealistic. Introducing locational preferences is however a simple modification of the model, as long as these preferences are shared by everyone. To see this let utility of a person living in country j be given by $u_j(c_j)$. Notice that this utility level does not depend on which person we are considering. If e.g. $u_j(c') > u_k(c')$ for an arbitrary consumption level c', this means that everyone prefers to live in country j rather than k. In order for anyone to choose to live in country k instead of j, they would need to be compensated, i.e. the consumption they could get in k would have to be higher than the consumption they could obtain in country j. In an equilibrium with population mobility and people living in all countries we would thus have the equilibrium condition

$$u_1(c_1) = ... = u_J(c_J) \qquad \text{(8b)}$$

instead of (8).

In our discussion of Figure 1, the only change would be that instead of the 45-degree line, we would have an upward sloping line reflecting the locational preferences. If people preferred country 1 to country 2 (for the same consumption level) this line would lie somewhere above the 45 degree line. Apart form this change; all of our results form the previous discussion would remain valid.

Obviously, it is not particularly realistic to assume that everyone has the same locational preferences. In the next section I therefore consider the case of non-homogeneous populations, where differences in locational preferences could be one of the differences between people.

7 Non-homogeneous populations

Assume that there are T distinct types or classes of people. There is homogeneity within a particular type, and the utility level of an individual of type t living in country j is as in the previous section assumed to depend on consumption and the country this person lives in. We denote this utility level by $u_j^t(c_j^t)$.

Consider first the case in which the only difference between people are their locational preferences. In this case the consumption for everyone living in the same country is the same, i.e. $c_j^t = c_j$.

If there is no population mobility, differences in locational preferences are of course irrelevant. The present case is thus identical to the case discussed in Section 3 when there is no population mobility.

Consider next the case of population mobility, i.e. cases E and F in table 1. Population mobility will imply that conditions of the type (8b) will hold for all types. However, we can no longer ignore the possibility of corner solutions, i.e. situations in which some types live only in a subset of all the countries. Formally, let *I(t)* be the set of countries in which persons of type t will live in (in equilibrium). Then instead of condition (8b) we will have

$$\begin{aligned} u_j^t(c_j) &= u^t \; for \, t \in I(t) \\ u_j^t(c_j) &\leq u^t \; for \, t \notin I(t) \end{aligned} \qquad (9)$$

where u^t is the equilibrium value of the utility level of type *t*.

Unless the differences in utility functions across persons are trivial, the equilibrium cannot have the property that all types live in all countries. This follows immediately from (9): If *I(t')* is the set of all J countries for a particular type *t'*, then it follows from (9) that there is a particular equilibrium consumption pattern across all countries. This consumption pattern can only make utility levels for other types be equal across all countries if the utility functions of other types differ from the function $u^{t'}$ in a trivial manner.

There is not much one can say in general about whether or not there will be a conflict of interest between countries regarding the allocation of emission quotas. There are, however, two special cases worth mentioning. First, consider the case in which, for all *t*, *I(t)* consists of only one country. In other words, each type of person lives only in one country. In this case we are, in the neighborhood of the equilibrium, in a situation where there is no population mobility. The standard results of Section 3 apply to this case (at least as long as only small reallocations of emission quotas are considered).

A second special case is the one where *I(t')* is the set of all J countries for a particular type t', i.e. the equilibrium is characterized by people of type *t'* living in all countries. In this case it follows from (9) that any change in the allocation of emission quotas will change the per capita consumption levels of all countries in the same direction. Although most types of persons will be living in separate countries, all types therefore share a common interest in choosing the allocation of emission quotas that makes all consumption levels as high as possible.

Let us finally consider the case in which there may also be other differences among persons than differences in locational preferences. These differences could consist of differences in labor productivity and in ownership of other resources (e.g. capital and land).[8] To give a general discussion of these types of heterogeneity, let us introduce the following formal notation**:** Let $\boldsymbol{e}=(e_1,\ldots e_J)$ denote the vector of emissions from all countries (satisfying (2), i.e. $\Sigma_i e_i \leq E$). Let $\boldsymbol{s_j}$ be a vector describing the policy of country j, including this country's choice of all transfers within the country and (under F) to residents in other countries. The vector $\boldsymbol{s}=(\boldsymbol{s_1},\ldots \boldsymbol{s_J})$ thus gives a complete description of the policy choices in all countries.[9]

Once $(\boldsymbol{e},\boldsymbol{s})$ is given, all other variables follow. In particular, the utility levels of all types and the number of each type living in each country follows.[10] Formally,

$$u^t = u^t(\boldsymbol{e},\boldsymbol{s}) \tag{10}$$

and

$$n_j^t = n_j^t(\boldsymbol{e},\boldsymbol{s}) \tag{11}$$

[8] See Hoel and Shapiro (2000) for a more detailed discussion of how such differences can be explicitly modeled.
[9] As previously, the vector ***e*** denotes actual emissions. If emission quotas are tradable, we thus interpret ***e*** as the final allocation of actual emissions. The vector ***s*** in this case includes payments for traded quotas. The choice of the initial allocation of emission quotas is thus reflected in ***s***.(See also the discussion in the second half of Section 5.)
[10] When types differ also in other respects than in locational preferences, consumption levels may differ across types as well as across countries. It is easily verified that an implication of this is that the equilibrium may be characterized by several or all types living in all countries.

Among all emission and policy vectors ***(e,s)***, the ones giving Pareto efficiency are of special interest. All types share a common interest in eliminating all vectors ***(e,s)*** that do *not* give Pareto efficiency, since everyone can be made better off with appropriate policy changes if the initial vector ***(e,s)*** does not give Pareto efficiency. In an economy resembling the one presented in Section 1 (except for heterogeneity in populations) all types would thus share the common interest in having the emission vector being cost-effective (cf. (4)), provided there are no restrictions on inter-country transfers.

We have already discussed the special case in which locational preferences are the only differences among types, and where there is one type that lives in all countries in equilibrium. For this case there is only one Pareto efficient outcome. Clearly, there is no conflict of interest in this case.

For the more general case there will be several vectors ***(e,s)*** giving Pareto efficiency, and there will thus be pure conflict of interest: Any change in the vector ***(e,s)*** that increases the utility level for one group, will by definition reduce the utility level for another group.

In order to discuss whether or not there is a conflict of interest between *countries* as well as between types we must define what we mean by the welfare level of a country. Let us therefore introduce a welfare function in each country that weighs the interests of the different types. These weights may depend on the number of persons of each type that choose to live in the country. The welfare function for country j must therefore generally depend on the number of persons of each type living in the country as well as on the utility levels persons of each type have. Using (10) and (11) we thus have

$$V_j = \Phi_j(u^1(\boldsymbol{e},\boldsymbol{s}),\cdots,u^T(\boldsymbol{e},\boldsymbol{s}),n_j^1(\boldsymbol{e},\boldsymbol{s}),\cdots,n_j^T(\boldsymbol{e},\boldsymbol{s})) = V_j(\boldsymbol{e},\boldsymbol{s}) \qquad (12)$$

Notice that a special case of this function is where the population and utility levels of each type t enter only as the product $n_j^t\, u_j^t$.

The discussion above on common interests and interest conflicts among types is not affected by the properties of the welfare functions that countries have. No matter what properties these functions have, there will in most cases be a conflict of interests between different types regarding how emission quotas ought to be allocated. Whether or not there also is a conflict of interest between *countries* depends on the welfare functions of the countries. To see this, consider the special case analyzed by Hoel and Shapiro (2000). Here we analyze the case in which each country has the same social welfare function. Moreover, this social welfare function is assumed to depend only on the utility level of each type, and not on how many people of each type that are living in the country. In other words, in this case the welfare function (12) simplifies to

$$V_j = \Phi(u^1(\boldsymbol{e},\boldsymbol{s}),\cdots,u^T(\boldsymbol{e},\boldsymbol{s})) = V(\boldsymbol{e},\boldsymbol{s}) \qquad (13)$$

In this special case all countries have the same welfare level, no matter what the vector ***(e,s)*** is. They thus have a common interest in maximizing this common level. In other words, we get the same situation as we had with homogeneous populations: There is no conflict in interest regarding the allocation of emission quotas across countries. This is true independently of whether or not inter-country transfers are permitted, i.e. it is true both for case E and F.

For the more general welfare function (12), however, there will generally be an interest conflict among countries as well as among types. This follows directly from the fact that there is an interest conflict between types. If different countries weigh different types differently in their welfare functions, this interest conflict carries over to an interest conflict between countries. However, it is not necessarily true that each country would like to have as much as possible of the total emission quotas. Any change in the allocations of emission quotas will typically improve the utility levels of some types, and reduce it for other types. The effect on the welfare levels of countries will depend on the specification of the general welfare function given by (12).

8 Concluding comments

This paper has challenged a common view in the literature discussing international climate agreements. The common view suggests that there is an interest conflict between countries, in the sense that for a given amount of total emissions, each country is better off the larger its share of the total number of emission quotas. This interest conflict is independent of whether or not the emission quotas are tradable.

In the paper I show that if there is a perfectly homogeneous and mobile population in the countries considered, the interest conflict vanishes. In this simple case all countries have a common interest in a particular allocation of emission quotas.

The result is modified if one more realistically allows for population heterogeneity. In this case I show that there typically will be an interest conflict among countries regarding the allocation of emission quotas. However, it need no longer be true that each country is better off the larger its share of the total number of emission quotas.

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