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Transboundary environmental problems with a mobile population: Is there a need for central policy?

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By
Michael Hoel and Perry Shapiro

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by

Michael Hoel* and Perry Shapiro**

Abstract

It is a widely held view that efficient environmental policies regulating transboundary pollution will be adopted only if there is interjurisdictional coordination. Efficient policies can be adopted as a result of interstate treaties or mandated by a central authority. However, if the policies of states are chosen to maximize the same function of own-citizen welfare, and if individuals migrate freely between states, constrained-efficient environmental regulatory policies are a non-cooperative equilibrium. The policies are constrained-efficient in equilibrium, the policy choices are the same as those found by maximizing the social welfare function subject to a policy feasibility constraint.

Keywords: Transboundary pollution, Population mobility, Federalism.

JEL classification: D6, H7, Q20, R23

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1 Introduction

Transboundary environmental problems are characterized by the environment in a region being affected directly by actions taken in one or more other regions¹. Transboundary environmental problems have received a large attention in the literature; early contributions include OECD (1976) and d'Arge (1975). The most obvious type of transboundary environmental problem is emissions of some physical substance from one region having a negative impact on the environment in other regions. However, transboundary environmental problems may also be of a non-physical kind, such as e.g. a concern about worldwide biodiversity, see Barrett (1992). In this paper we shall interpret our variables as physical emissions causing environmental damage, but our results are equally valid for non-physical environmental problems.

We use the term “region” as a geographical area that is a jurisdiction with some degree of political autonomy. The typical example of this type of region is a country. However, the regions could also be e.g. states, provinces or counties within a country. The important thing is that the region has some autonomy over policy instruments affecting the emissions in the region.

A standard result from the literature is that without any type of environmental policy coordination or other forms of environmental agreements between regions, the outcome will be socially inefficient. The reason for this is that when a region designs its environmental policy, it takes into account the effect of its emissions only on its own environment. In a socially efficient outcome, the effect of emissions in one region on all regions will be taken into consideration. This result is based on models in which it is assumed that the population in each region is exogenously given. For regions that are geographically and culturally close to each other, such as e.g. the states in USA or the provinces of Canada, this clearly is an unrealistic assumption. In this paper we therefore explore the consequences of an alternative assumption of the populations in the regions. We consider the case of perfect population mobility across regions, implying that the same types of people get the same utility in all regions. Our main finding is that with perfectly mobile populations, we may get an efficient outcome even if there is no policy coordination or environmental agreement between the regions.

A result similar to ours was first shown by Wellisch (1994), who analyzed the provision of a public good that generates interregional benefit spillovers. He showed that with perfect population mobility, the non-cooperative equilibrium would be socially efficient if each region in addition to deciding its level of the public good could set a head tax for

¹ The term “directly affected” excludes any indirect effects via prices, incomes etc. making actions in one region affect the environment in other regions.

the residents in the region and also give non-negative transfers to the residents of other regions. A similar result is shown by Silva (1997), where the public good is pollution abatement, and where the level of pollution also is affected by the choices made by consumers in each region. Silva only considers the special case of a unidirectional spillover, i.e. in his 2 region model region 2 is affected by the consumption choices and the level of abatement in region 1, but not vice versa. He shows that in this case the efficiency property derived by Wellish is valid (in a second best sense) also if interregional transfers are ruled out. This result is valid for the 2-region case with a unidirectional transboundary spillover also if there is no population mobility between regions, see e.g. Hoel (1999).

Our contribution differs from the above-mentioned articles partly in the way we model the environmental externality. In our model this externality is explicitly linked to the production process. More importantly, we derive the efficiency result for very general types of spillovers and for very general assumptions about what policy instruments are available to the regions. The results of Wellisch and Silva follow as special cases of the general result we derive. In addition to the generality with regard to policy instruments, we also generalize previous literature by allowing for heterogeneous populations in each region. Finally, we give an explicit treatment of land and produced capital in the production functions that are not addressed in the previous literature.

The paper is organized as follows. A simple model of a transboundary environmental problem is introduced in Section 2, where we also derive the conditions for efficiency. Section 3 demonstrates that if interregional transfers are ruled out, the non-cooperative outcome is efficient. This result is generalized and discussed in Sections 4 through 7. Section 8 discusses the role played by region specific land and mobile produced capital in models of these types.

2 A simple model of transboundary pollution.

To formalize the analysis of a transboundary environmental problem, consider J regions with emissions (e_1, \dots, e_J) . For each region j there is a variable z_j which measures environmental quality. This variable depends on emissions from all the J regions, and is defined so that it is declining in all e_i . Denoting $e=(e_1, \dots, e_J)$ as the vector of emissions from all regions, we thus have $z_j=z_j(e)$ where all partial derivatives z_{ji} are non-positive. The general description includes several special cases. One such special case is the case of only local environmental damage. For this case all the partial derivatives z_{ji} are zero for $i \neq j$. Another special case is the one of a purely unidirectional environmental problem, like Silva (1996) assumes. An example of such a problem could be a river running through several regions which all pollute the river (for a recent discussion, see e.g. Rogers (1997)). Clearly, a country that is further downstream cannot pollute an upstream country. For this case, the partial derivatives z_{ji} are zero for $i < j$ if we number countries so

that the region index is higher the further downstream the region is. Finally, climate change and depletion of the ozone layer are examples of environmental problems for which it is only the sum of emissions from all countries that matters for the environment². For this special case it is thus only the sum $\sum_i e_i$ that enters as an argument in the functions $z_j(e)$. Notice that even if the physical measure $\sum_i e_i$ of total emissions is the same for all regions, the countries may differ in the way these physical emissions affect the regions. A change in climate caused by an increase in total emissions of greenhouse gases could e.g. affect different regions differently.

Production in region j is higher the population is, as it is assumed that labor input is proportional to (or at least increasing with) population in the region, denoted by n_j . It is also increasing in the emission level e_j for the interesting sizes of emission levels. Production is denoted by $f_j(n_j, e_j)$, and we assume that per capita production f_j/n_j is strictly declining in n_j for any e_j (this assumption is discussed further in Section 7).

In the simplest version there is a homogeneous population: everyone is equally productive and all share the same preferences. In this case it is natural to assume that income and consumption is divided equally among all residents of region j . Moreover, everyone is assumed to have the same utility function u depending on their consumption and on the environmental quality of the region they live in. (These two assumptions are discussed further in Sections 6 and 8.) Denoting the per capita consumption in region j by c_j , we thus have

$$U_j = u(c_j, z_j(e)) \quad (1)$$

While the level of welfare U_j may be specific, the population homogeneity implies homogeneous preferences. Thus, there is no regional subscript for the function $u(\cdot)$. In most analyses of transboundary pollution, the distribution of the population is assumed exogenous, i.e. all n_j are assumed exogenous. With this assumption an efficient allocation of emissions is found by maximizing a function

$$W = \sum_j a_j U_j \quad (2)$$

subject to (1) and the constraint

$$\sum_i n_i c_i \leq \sum_i f_i(n_i, e_i) \quad (3)$$

² These examples are examples of global environmental problems. Obviously, our model is not suitable for such problems, since we assume perfect population mobility between all regions involved.

An allocation of emissions solving this maximization problem for an arbitrary vector of positive α_j 's is a Pareto optimal allocation. It is well known, and straightforward to show that all Pareto optimal allocations must satisfy³

$$f_{je}(n_j, e_j) = \sum_{i=1}^n n_i \frac{u_z(c_i, z_i)}{u_c(c_i, z_i)} (-z_{ij}(e)) \quad (4)$$

If there is population mobility, we obviously cannot assume that the allocation of the population is exogenous. Instead, assume that all n_j 's are choice variables in the maximization problem above, and solve the maximization problem under the additional constraint

$$\sum_i n_i = N \quad (5)$$

where N is the total population in the regions (assumed given). The Pareto optimal outcomes must also in this case satisfy (4). In addition, all Pareto optimal allocations of the population must satisfy

$$f_{1n}(n_1, e_1) - c_1 = \dots = f_{jn}(n_j, e_j) - c_j \quad (6)$$

This is a well-known condition for the optimality of population distribution. It says that the marginal surplus gained by an individual moving into a state (the difference between his contribution at the margin -- his marginal product -- and what he consumes) should be equalized across all states.

Generally, there is a continuum of Pareto optimal outcomes, i.e. outcomes satisfying (3)-(6). These outcomes differ in the distribution of utility levels across regions. However, in this paper we assume that there is perfect population mobility, and that migration therefore eliminates any potential differences in utility levels between regions. We thus have the following condition:

$$U_1 = U_2 = \dots = U_j \quad (7)$$

Together with (3) – (6), this condition selects a particular Pareto optimal outcome. We call this outcome the first-best socially efficient outcome.

³ See e.g. Markusen, (1975) or Hoel (1999).

The first-best optimum given by (3) – (7) gives a particular distribution of consumption per capita across regions. Generally, this distribution will differ from the distribution of per capita incomes (equal to $f_j(n_j, e_j)/n_j$). In other words, interregional transfers will generally be necessary in order to achieve the first-best optimum.

If for some reason interregional transfers are ruled out, it is generally not possible to achieve first-best efficiency. In this case the second-best constrained efficient allocation of emissions is found by maximizing the common utility subject to (1), (5), (7) and, instead of (3), the constraint

$$n_i c_i \leq f_i(n_i, e_i) \quad \text{for all } i \quad (8)$$

To see what the second-best efficiency condition for the allocation of emissions, consider the choice of the emission level e_j , i.e. emissions from region j . Clearly, at the optimum the derivative of U_j with respect to e_j must be equal to zero. Inserting (8) into (1) and differentiating gives

$$\frac{dU_j}{de_j} = u_c(c_j, e_j) \left(\frac{\partial(f_j/n_j)}{\partial n_j} \frac{\partial n_j}{\partial e_j} + \frac{1}{n_j} \frac{\partial f_j}{\partial e_j} \right) + u_z(c_j, e_j) \frac{\partial z_j}{\partial e_j} \quad (9)$$

where the term $\partial n_j/\partial e_j$, together with $\partial n_i/\partial e_j$ for all other i , is determined by (5) and (7).

Setting the derivative in (9) equal to zero and rearranging gives us

$$\frac{1}{n_j} f_{je}(n_j, e_j) = \frac{u_z(c_j, z_j)}{u_c(c_j, z_j)} (-z_{jj}(e)) - \frac{\partial(f_j/n_j)}{\partial n_j} \frac{\partial n_j}{\partial e_j} \quad (10)$$

Together with the equations (1), (5), (7) and (8), this equation gives us the allocation of emissions that is socially efficient given the constraint that interregional transfers are ruled out.

3. The non-cooperative equilibrium

When there is no cooperation among regions, each region chooses its policies in order to maximize the utility level of its own residents, taking the policies of other regions as given. Consider region j . Assume for a moment that population in this region is given, as is usually assumed in the literature of interregional environmental problems. Assume also that transfers between regions are ruled out. Inserting (8) into (1) and maximizing with

respect to e_j gives the optimal emission level in region j . It is straightforward to see that the optimality condition in this case is

$$\frac{1}{n_j} f_{je}(n_j, e_j) = \frac{u_z(c_j, z_j)}{u_c(c_j, z_j)} (-z_{jj}(e)) \quad (11)$$

Comparing this with the condition (4) for first-best efficiency, we see that the conditions do not coincide. While each region only takes the effect of its emissions on its own residents into consideration when designing its optimal policy, the socially efficient allocation of emissions takes into consideration the effect of each region's emissions also on the residents of all other regions. This difference is what makes some kind of cooperation across regions necessary.

When populations are mobile across regions, the optimal emission levels from each region's point of view are no longer given by (11). To find its optimal emission level, region j must take into consideration how its emission level affects the size of its population, and thereby the average consumption in the region. The same maximization as above, but taking account of this effect on population size, gives us equation (10) which was the condition for a constrained social optimum. The term $\partial n_j / \partial e_j$ is determined just as it was in the condition for the constrained social optimum, i.e. by (5) and (7).

It follows from the discussion above that if transfers between regions are ruled out, there is no reason to have an interregional environmental agreement or other type of coordination of environmental policies. With perfect population mobility, the non-cooperative equilibrium is (constrained) socially efficient. This result is contrary to the traditional result in the theory of transboundary environmental problems, where populations are assumed to be exogenously given. As mentioned in the Introduction, Silva (1996) has shown this result for the special case of a unidirectional pollution spillover. However, for this case the non-cooperative equilibrium is efficient also without population mobility, see e.g. Hoel (1999).

In the next sections we show that this important result is quite general, as long as there is perfect population mobility across the regions involved in the transboundary environmental problem we are considering.

4. The efficiency of the non-cooperative equilibrium: a generalization

It is convenient to consider the transboundary problem more formally as a game played between policy-autonomous regions. The strategies of the game are the regional environmental policies, and the payoffs are the utilities of the regional residents. It is

important to recognize, with respect to the previous model with free interstate migration, that market equilibrium imposes an important constraint on the payoffs. Namely the welfare of citizens in every region must be the same.

The game is described in the following way. The players are the regional governments, of which there are J ($j = 1 \dots J$). The feasible strategies are the policy choices of the regional governments. In the model above, the most obvious example would be local contribution to environmental degradation (e_j) as well as the local taxes and transfers to other regions. However, the reasoning of our analysis is applicable to larger, and more complex, sets of potential policies or strategies. Whatever the feasible strategies are, the payoffs are the utilities of the regional citizens U_j . Market equilibrium restricts the inter-regional distribution of welfare to be such that the utilities are the same in all regions.

Formally, let $S = S_1 \times S_2 \times \dots \times S_J$ be the set of feasible strategies with S_j being the set of strategies for region j . The regional payoffs depend on the number of residents and the locally chosen policies. To illustrate, consider the case in which the policy vector s_j of region j consists of the choice of emissions e_j , a head tax τ_j and a vector of transfers to other countries per person in region j , $\tau_{j1}, \dots, \tau_{jJ}$ (it is convenient, but not necessary to assume $\tau_{jj}=0$). A reasonable requirement of feasibility is that $e_j \geq 0$, all $\tau_{ji} \geq 0$ (region j cannot tax residents in other countries) and $\sum_i \tau_{ji} = \tau_j$ (budget constraint). With these strategies, consumption of a person living in region j will be

$$c_j = \frac{f_j(n_j, e_j) + \sum_i n_i \tau_{ij}}{n_j} - \tau_j \quad (12)$$

Together with the migration equilibrium condition (7), the condition (12) for all j determines all population and consumption levels once the policy instruments are given. Given the strategy choices of all regional governments, utility levels thus follow from the preference function (1).

More generally, we have

$$U_j = V_j(s) \quad (13)$$

From the migration equilibrium condition (7) we know that we must equal utility in all regions, whatever the strategy vector s is. This means that the payoff functions $V_j(s)$ must be the same for all regions, i.e.

$$V_j(s) = V(s) \tag{14}$$

Setting-up the transboundary pollution problem in this way yields a surprising conclusion: namely, central governmental mandate is unnecessary to induce the optimal policies:

Theorem: *Let $s^* \in S$ be the vector of policy choices (e.g. environmental policy and tax/transfers) that maximizes $V(s)$ subject to feasibility constraints $s_j \in S_j$; then s^* is the Nash Equilibrium of the policy game described above.*

Proof: Suppose all regions but j make the socially optimal choice, s_{-j}^* . Since the payoff to j , V_j , is identical to $V(s)$, region j makes V_j as large as possible by choosing s_j^* .

While the theorem focuses on the first best optima, for the transboundary pollution problem stated, the first best depends not only on the selection of the correct environmental policy, it also depends on the “correct” distribution of the population. In order to achieve that, the regions must be able to tax themselves and transfer to other regions. Both policy instruments might not be available. There may be laws in state prohibiting direct international monetary transfers, for instance. In other words, the set of policy instruments (feasible strategies) may be limited. The theorem is very hopeful in this regard. What it says, with respect to the limited feasible set of strategies, is that the “best” among the available constitute a Nash Equilibrium of the interregional game. In other words a “second-best” optimum is achievable non-cooperatively.

5. Multiple Nash equilibria

It is tempting to conclude from the previous section that if one has perfectly mobile populations, it is not necessary to coordinate environmental policies across regions, even when pollution is transboundary. Such a conclusion is however somewhat premature. The result in the previous section only states that the social optimum (unconstrained or constrained) is a Nash equilibrium of the policy game between regions. However, it is not obvious that this Nash equilibrium will be the outcome of the non-cooperative game. This is particularly true if there also exist other Nash equilibria of the game. If such other Nash equilibria are not socially optimal, it must be true that they are Pareto dominated by the social optimum. Although it is often assumed that among Pareto ranked Nash equilibria, the players will select the best one; it is not obvious that this will be the case.

In the present model there may exist several Nash equilibria. One possibility of such a case is illustrated in Figure 1. Generally, we know nothing about the concavity properties of the functions giving population distributions as functions of policies. Therefore, the function $V(s)$ need not be concave in s . There may therefore be several local maxima of this function.

Figures 1 and 2 represent possible configurations of level surfaces for which there are multiple equilibria. The closed lines are the combinations of strategies for players 1 and 2 that result in the same level of equal interregional utility (those that satisfy the migration equilibrium condition). Figure 1 is an example of a case in which there are two local maxima, each of which are equilibrium. Only one (s_1^*, s_2^*) is efficient.

Figure 2 represents a more complicated case in which there is an infinity of Pareto dominated equilibria. All (s_1, s_2) pairs along the ridgeline L are equilibria: For any (s_1, s_2) pair along the ridgeline, region 1's strategy options are confined to those that are directly east or west of $(\tilde{s}_1, \tilde{s}_2)$. All feasible changes represent a lower utility for 1 (and 2 as well) than at $(\tilde{s}_1, \tilde{s}_2)$. Similarly, region 2 can make choices only that are directly north or south of $(\tilde{s}_1, \tilde{s}_2)$. Again the feasible choices all yield lower utility than does $(\tilde{s}_1, \tilde{s}_2)$. Therefore $(\tilde{s}_1, \tilde{s}_2)$ is a local Nash Equilibrium. However, this equilibrium is Pareto dominated by the efficient equilibrium (s_1^*, s_2^*) .

6. The possibility of zero population in some regions

When there is perfect population mobility, migration eliminates any potential differences in utility levels between regions. In (7), this is formalized as the utility levels being equal in all regions. This formalization implicitly assumes that some people live in each region. Although this certainly is what one expects in practice, models of the type we are using may give zero population in some regions if there is perfect population mobility. This is easiest to see by using a very simple example: There are two regions, and both have the same production function, which is homogeneous of degree one in labor and emissions. We thus have $f_j = n_j g(\varepsilon_j)$ where $\varepsilon_j = e_j/n_j$ is emissions per capita in region j.

Let the only instrument available to the authorities of each region be an emission tax that is reimbursed as a lump-sum transfer to the residents of the region. In this case emissions will be endogenously determined along with populations. Denoting the emission tax and wage rate in region j by θ_j and w_j , profit maximization (i.e. cost minimization combined with zero profit) implies

$$g_j'(\mathbf{e}_j) = \mathbf{q}_j \quad (15)$$

and

$$g_j(\mathbf{e}_j) - \mathbf{e}_j g_j'(\mathbf{e}_j) = w_j \quad (16)$$

Given the emission tax θ_j , the emissions per capita ε_j and the wage rate w_j thus follow.

Assume that the environmental quality in each country only depends on the sum of emissions e_1+e_2 , and that $z_1(e_1+e_2)>z_2(e_1+e_2)$. In other words, for the same level of private consumption, country 1 is a better country to live in than country 2 is, whatever the sum of emissions are.

Our migration equilibrium condition (7) may now be written as

$$u(g_1(\mathbf{e}_1), z_1(n_1\mathbf{e}_1 + n_2\mathbf{e}_2)) = u(g_2(\mathbf{e}_2), z_2(n_1\mathbf{e}_1 + n_2\mathbf{e}_2)) \quad (17)$$

Consider a pair of emission taxes giving a combination of ε_1 and ε_2 such that $\varepsilon_1 < \varepsilon_2$

$$U_1 = u(g_1(\mathbf{e}_1), z_1(N\mathbf{e}_1)) > u(g_2(\mathbf{e}_2), z_2(N\mathbf{e}_1)) = U_2 \quad (18)$$

as illustrated in Figure 3⁴. An increase in n_2 from $n_2=0$ (and a corresponding reduction in n_1) will make both U_1 and U_2 decline, since $\varepsilon_2 > \varepsilon_1$. Without more information about the functions, u , z_1 and z_2 , we do not know which of the functions will decline most. It may be the case that $U_1>U_2$ for all n_2 , or the curves giving the values of U_1 and U_2 may intersect one or more times, as in Figure 3. In any case, it is clear that $n_2=0$ is an equilibrium for the given values ε_1 and ε_2 that follow from the given emission taxes.

In Figure 3, there is also an equilibrium with positive populations in both regions, given by n_2^* in the Figure. This is a stable equilibrium in the usual (and somewhat casual) meaning of stability: If e.g. $n_2>n_2^*$, we would have $U_1>U_2$, and people would migrate from region 2 to region 1. This would continue until utility levels were equalized, i.e. until we had $n_2=n_2^*$.

The curves for U_1 and U_2 in Figure 3 were drawn for arbitrary emission taxes. However, with the assumptions of the example above, the social optimum must imply that everyone lives in region 1, and that the optimal emission tax in this region is the tax corresponding to the ε_1 -value that maximizes $u(g(\varepsilon_1), z_1(N\varepsilon_1))$. To see that this must be true, denote this maximized u -value V^* . Since $z_2<z_1$ whatever the sum of emissions are, $u(g(\varepsilon_2), z_2(N\varepsilon_2))<V^*$ whatever value ε_2 has. In other words, if everyone lives in one

⁴ The fact that $\varepsilon_1<\varepsilon_2$ makes output per capita highest in country 2. However, provided the difference between ε_1 and ε_2 is not too large, this effect will be outweighed by the fact that $z_1>z_2$, implying $U_1>U_2$.

region, it is best to live in region 1. If people live in both regions, (17) must hold. For (17) to hold, we must have $\varepsilon_2 > \varepsilon_1$. But this implies that as long as n_2 is positive, a reduction in n_2 (and a corresponding increase in n_1) will make the common utility level in (17) increase. The social optimum, and Nash equilibrium, must therefore be a tax combination giving the ε_1 -value that maximizes $u(g(\varepsilon_1), z_1(N\varepsilon_1))$ and a ε_2 -value that is sufficiently small that $U_2 < U_1$ for all population distributions. With these taxes, the optimal outcome with everyone living in region 1 will be achieved.

7. Non-homogeneous populations

The conclusion that no policy coordination is needed for a transboundary environmental problem when there is perfect population mobility is surprising, but its application is somewhat limited. It requires an equality of welfare among all regions. This is achieved in the example with one type of individual and completely free mobility. Not surprisingly, there is a limit to how far the result can be generalized. It is not perfectly general, for it is easy to construct examples in which the result does not hold, for instance some cases in which location preferences differ among people, or some cases where there are locationally fixed factors. However, it is possible to generalize the model to encompass the possibility of multiple types.

Begin by considering a partition of the population into T distinct types or classes. Membership in a class, labeled $t = 1 \dots T$, requires the same preferences and productivity as every other member of that class. In other words, there is homogeneity within a particular type. The welfare of an individual of class t in jurisdiction j is U_j^t . As before, we assume that the utility of any given type depends on consumption and environmental quality, i.e.

$$U_j^t = u^t(c_j^t, z_j(e)) \quad (19)$$

In the present case, perfect population mobility means that for any type, utility must be the same wherever a person of this type chooses to live. In other words for each type t we have the migration equilibrium condition

$$U_1^t = \dots = U_j^t \quad (20)$$

For any given policy vector s , the common utility level of each type is given, i.e. we have

$$U_j^t = \Psi^t(s_j, s_{-j}) \quad (21)$$

Suppose, further, that each region has the same social welfare function, and that this social welfare function depends on the utility level of each type, and not on how many people of each type that are living in the region. Formally we have

$$V_j = \Phi(U_j^1, U_j^2, \dots, U_j^T) = \Phi(\Psi^1(s), \Psi^2(s), \dots, \Psi^T(s)) = V(s)^5. \quad (22)$$

The realism of the assumptions underlying (22) can of course be questioned. In particular, it would seem strange to include the welfare level of a particular type in the welfare function of a region in which none of this type lives. We therefore restrict ourselves to cases in which the equilibrium has a positive number of persons of each type living in each region.

Applying the same logic as in Section 4, we have the following theorem:

Theorem: *If, in equilibrium, at least one of each population class resides in every region, the socially optimal policies are equilibrium strategies of the policy game played by the regions..*

There is a general principle at work in these examples. The common welfare is naturally defined to be social welfare. If social, as well as regional, welfare, are mappings from set of feasible strategies to the reals

$$W : S \rightarrow \mathbb{R} \quad \text{and} \quad V_j : S \rightarrow \mathbb{R},$$

and, if

$$V_j(s) > V_j(s') \Leftrightarrow W(s) > W(s') \quad \forall s, s' \in S,^6$$

then s^* is a Nash Equilibrium (where $s^* \in S$ as before is the vector of policy choices that maximizes $W(s)$ subject to feasibility constraints $s_j \in S_j$).

A consequence of this is that if the policy instruments available to the regions are insufficient to produce a first best optimum, the non-cooperative equilibrium will be a second best. In other words, the non-cooperative equilibrium strategies are ones that

⁵ For instance, if the regional social welfare function is of the Bergson-Samuelson type, then the weights are the same in every region: $V_j = \sum_{t=1}^T \alpha^t U_j^t$

⁶ Monderer and Shapley (1996) would label $W(\cdot)$ a 'potential function' and the resulting game a 'potential game'. In Shapiro and Petchey (1999) this condition implies that there is a "coincidence of collective and individual interests".

maximize social welfare constrained by what are feasible strategies. An example of this is given previously. In order to produce a first best outcome, one that induces not only an optimal environmental policy, but also an efficient distribution of labor, regions must be able to tax themselves and make transfers to other regions in addition to being able to control their own emissions. If this is not a feasible policy alternative, the resulting equilibrium produces the highest social welfare possible without the tax transfer option. It is furthermore true of this that regions may have different feasible policies. One may be able to use command and control regulation while other may be prohibited from using those, but is able to employ pollution based taxes.

8 . Land and capital

To simplify the discussion of the present Section, we return to the case with only one type of persons. However, the discussion in this Section remains valid also for the case of several types discussed in the previous Section.

In the simple models of population mobility without any environmental variables, the only specified production factor is labor (or population), so that output in region j is $f_j(n_j)$. With this specification, one must assume decreasing returns to labor in order to get equilibrium with positive populations in all regions. If there were constant returns to labor, the average productivity f_j/n_j would be independent of n_j , and a socially efficient outcome as well as a non-cooperative equilibrium would have all of the population living in the region(s) with the highest average productivity. If f_j/n_j were equal in some or all regions, the allocation of the population across these regions would not be determined.

If labor is the only specified factor and there are decreasing returns to labor, we have implicitly assumed that there is a fixed factor in the background. It is natural to think of this factor as region specific land. In the simple models of population mobility without environmental variables, the mobility condition (7) implies that consumption per capita should be equalized across regions. It is not obvious how this should be interpreted when per capita income (before taxes and transfers) consists of wage income and rent from land ownership. With perfect mobility it is reasonable to assume after tax wages per person to be equalized across regions. However, there is no reason why land rents per capita should be equalized. This income component is after all an income one gets from the region in which one *owns* land, independent of the region in which one *lives*. The simplest way out of this problem is to assume that land rents in each region are taxed at a rate of 100 percent by the authorities of the region, and that the tax revenues are distributed as equal lump sum transfers to all residents in the region. (This is one way of interpreting Wellisch (1994), who assumes that “land in region I is owned only by residents of that region on

an equal per capita basis”. Silva (1996) is not clear about how he treats income from land, although land is explicitly used in his production functions.)

In our model with environmental variables, there is no need to have a fixed factor (“land”) in the production functions. Even if the production functions $f_j(n_j, e_j)$ are homogenous of degree 1 and differ across regions, we may have an outcome satisfying (7) with positive populations in all regions.⁷ This is most obvious if the only policy instrument in each country is its emission level. In this case all e_j 's are fixed once the authorities have chosen their policies, implying that average productivities $f_j(n_j, e_j)/n_j$ are declining in n_j . If emission levels are determined through direct regulation, there is a residual or rent in the firms equal to $f_j(n_j, e_j) - f_j'(n_j, e_j)n_j$. As in the case with land rents, we must assume that this residual is claimed by the authorities, who reimburse it to the residents in the region. An obvious interpretation is that the chosen emission level of the region is allocated to individual firms in the region through quotas that the firms buy from the regulator at their equilibrium price.

Instead of choosing a fixed level of emissions and allocating it to firms through direct regulation or auctioned quotas, the authorities of the regions could set emission taxes. In this case emissions would be endogenously determined along with populations. Moreover, there will be no residual or rent left in the firms in this case (when constant returns are assumed).

Even if factors such as land and capital are not necessary for the logic of the model, these factors are important in the real world. In the rest of this Section we therefore show how they can be incorporated in our model.

Denote output in region j by x_j . Instead of the simple production function presented in Section 2, let us now assume that

$$x_j = f_j(n_j^1, \dots, n_j^T, k_j, L_j, e_j) \quad (23)$$

where n_j^t is labor (or population) of type t employed in region j , k_j is capital used in region j , L_j is region specific land, and e_j represents emissions in region j . This production function is assumed to be homogeneous of degree one.

Land is exogenously given in each region. The sum of capital in all regions is given, but capital is assumed to be completely mobile across regions. The marginal productivity of

⁷ The simplest example of this is the example used in Section 6, modified so that the environmental quality in each country depends more strongly on own emissions than on emissions in the other country.

capital is therefore equalized across regions, and we denote this common return on capital by q . We also denote the rent per unit of land in region j by r_j , and wages of type t labor by w_j^t .

There are T types of persons in the world. The total number of people of type t is N^t . These types may differ in their labor productivity, implying different wages. They also may differ in their ownership of land and capital. We assume that a person of type t owns $\sigma_j^t L_j$ of the land in region j , and $\sigma_K^t K$ of the total capital stock (since the rate of return on capital is the same in all regions, it makes no difference where the capital owned by a particular person is used). These ownership parameters must satisfy

$$\sum_t \mathbf{s}_j^t N^t = 1 \quad (24)$$

$$\sum_t \mathbf{s}_K^t N^t = 1 \quad (25)$$

A person of type t choosing to live and work in region j will have the following consumption:

$$c_j^t = w_j^t + \sum_i \mathbf{s}_i^t r_i L_i + \mathbf{s}^t q K + Y_j^t \quad (26)$$

where Y_j^t are the net transfers this person receives (positive or negative). The utility index of this person is as usual given by

$$U_j^t = u^t(c_j^t, z_j(e)) \quad (27)$$

But this is the same specification as we gave in Section 7, see (19). The results from Section 7 are therefore valid for the model presented above, where incomes from capital and land go to the owners of this capital and land, independently of in which region they live.

Conclusion

We have shown that the efficient regulation of transboundary pollution is possible without explicit cooperative agreements or central mandates. What is required is that the policy options available to each state are adequate; that states choose policies to maximize the same function of own-citizen welfare and that individuals are fully mobile

between states. These conditions are unlikely to be met in general, but, even if the restrictions are unrealistic, the model does point to an important aspect of policy making.

The conditions set up an interrelationship between autonomous states that, in itself, can induce states to make policy choice consistent with overall welfare maximization while pursuing their own self-interested objectives. The migration equilibrium (equal utility) condition generates a coincidence of interests between the states. In equilibrium the welfare of one state is tied to the welfare of all others: the well being of one state cannot be improved unless the welfare of all states improve. It is not necessary for states to individually recognize this coincidence; they need only know the migration responses to their own environmental policy choice.

An interesting aspect of the analysis is that equilibrium policy choices may not be globally efficient. They may, instead, be second best efficient in the sense that the chosen policies are the best, given the limited set of policy options open to states. This suggests that central intervention might take the form of expanding the policy choices open to individual states rather than direct regulatory control. The results, however, do not fully mitigate the desirability of more active central intervention.

Central government may have an important role beyond simply expanding the feasible set of state policies. Although efficient policies are an equilibrium, the equilibrium may not be unique. Some form of central coordination can be a mechanism for insuring the best equilibrium is, in fact, the one achieved.

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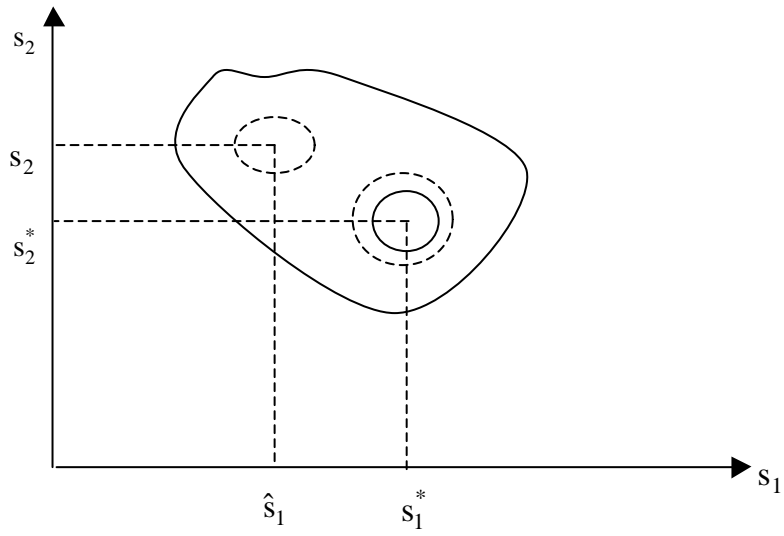


Figure 1

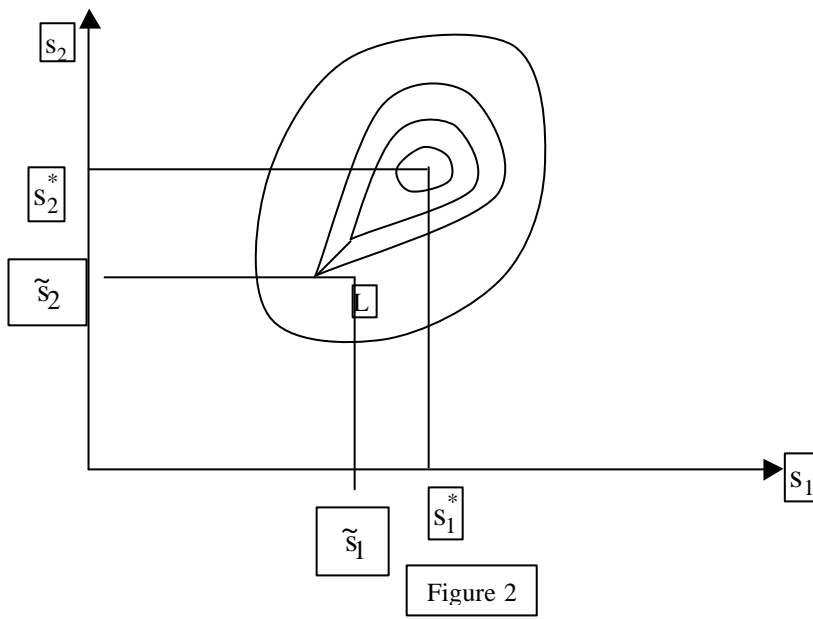


Figure 2

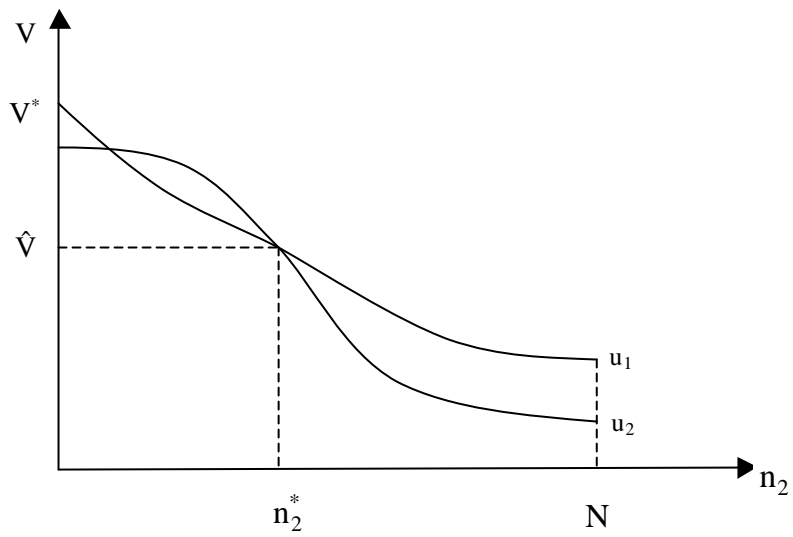


Figure 3