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Michael Hoel
Perry Shapiro

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CESifo
Center for Economic Studies & Ifo Institute for Economic Research
Poschingerstr. 5, 81679 Munich, Germany
Tel.: +49 (89) 9224-1410
Fax: +49 (89) 9224-1409
e-mail: office@CESifo.de

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Abstract

A standard result in the literature on environmental economics is 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 interregional treaties or mandated by a central authority. The present paper demonstrates that if there is perfect population mobility between the regions affected by the transboundary pollution, the efficient outcome is a Nash equilibrium of the policy game between regional authorities. This is true independently of what policies are available to the regional authorities. However, there may be more than one Nash equilibrium, so that policy coordination may be necessary in order to achieve the best equilibrium.

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Michael Hoel
University of Oslo
Department of Economics
Box 1095 Blindern
0317 Oslo
Norway
e-mail: mihoel@econ.uio.no

Perry Shapiro
University of Melbourne
Department of Economics
Victoria 3010
Australia
e-mail: pxshap@econ.ucsb.edu

1 Introduction

With transboundary externalities, regional policy choices are the strategies of a policy game played between sovereign regions. It is well known that the equilibrium of the game is inefficient. In this paper we demonstrate that if interregional migration is free and costless, socially optimal policy can be supported as a Nash equilibrium. If the equilibrium is unique, neither interregional cooperation nor centralized regulation improves the non-cooperative outcome. There may be many equilibria, and if so, some form of coordination is necessary to insure efficiency.

Transboundary environmental problems are characterized by the environment in a region being affected directly by actions taken in one or more other regions[1]. 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 and to some extent the regions/provinces of e.g. Australia and 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, 1995 and 2000 [chapter 6]), who analyzed the provision of a public good that generates interregional benefit spillovers. He showed that with perfect population mobility, the non-cooperative equilibrium can be socially efficient if each region in addition to deciding its level of the public good could set a head tax for the residents in the region and also give non-negative transfers to the residents of other regions.[2]

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[1] The term "directly affected" excludes any indirect effects via prices, incomes etc. making actions in one region affect the environment in other regions. Transboundary environmental problems have received a large attention in the literature; early contributions include OECD (1976) and d'Arge (1975). See also Markusen (1975), Dasgupta et al. (1997), and Hoel (1999).

[2] An expansion of this idea is in Chapter 9 of Wellisch (2000) in which the land market induces goverments to pursue efficient policies when intergenerational spillovers are involoved.

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.

The most important difference between our contribution and the above-mentioned articles is that 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. On the other hand, unlike Wellisch, we only consider the case of perfectly mobile populations. Perfect and costless population mobility is obviously a simplification. The consequences of imperfect population mobility in the form of migration costs[3] or locational preferences that differ among persons[4] has been carefully studied in the literature in the context of models without any environmental spillover between regions. Our simplifying assumption of perfect population mobility makes it possible to analyze transboundary pollution without having to make detailed assumptions about what policy instruments are available to the regions.

The paper is organized as follows. A simple model of a transboundary environmental problem is introduced in Section 2, where we also give the conditions for efficiency and the non-cooperative outcome when there is no population mobility. In Section 3 we introduce perfectly mobile populations. This population mobility implies that utility levels are equalized across regions. The socially optimal emission levels are the emission levels that maximize this common utility level. We show that this social optimum is a Nash equilibrium of the game in which regional governments choose environmental policies without any coordination. In Section 4 we demonstrate that although the social optimum is a Nash equilibrium, there may also be other Nash equilibria that are Pareto inferior to the social optimum. Some concluding comments are given in Section 5.

2 Transboundary pollution without population mobility

To formalize the analysis of a transboundary environmental problem, consider J regions with emissions (e_1, ..., e_J).[5] 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 $\mathbf{e}=(e_1,\ldots,e_J)$ as the vector of emissions from all regions, we thus have $z_j=z_j(\mathbf{e})$ where all partial derivatives z_{ji} are non-positive. The general description includes several special cases. One such is the case of only local environmental damage in which all the partial derivatives z_{ji} are zero for $i \neq j$. Another is the one of a purely unidirectional environmental problem, as in Silva (1997). Finally, climate change and depletion of the ozone layer are

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[3] See e.g. Hercowitz and Pines (1991) and Myers and Papageorgiou (1997).

[4] See e.g. Mansoorian and Myers (1993).

[5] Transboundary environmental problems may also be of a non-physical kind, such as e.g. a concern about worldwide biodiversity, see e.g. Barrett (1992). In this paper we interpret our variables as physical emissions causing environmental damage. However, our results are equally valid for non-physical environmental problems.

examples of environmental problems for which it is only the sum of emissions from all countries that matters for the environment[6]. For this special case it is thus only the sum $\Sigma_i e_i$ that enters as an argument in the functions $z_j(\mathbf{e})$.

Production in region j is higher the larger is its population, as it is assumed that labor input is an increasing function of the population in the region, denoted by n_j. It is also increasing in the emission level e_j. Production is denoted by $F_j(n_j,e_j)$.

We assume that there is a homogeneous population: everyone is equally productive and all share the same preferences.[7] In each region j, income and consumption in the region is assumed to be divided equally among all residents of the region. Moreover, everyone is assumed to have the same utility function u depending on the per capita consumption and the environmental quality in the region they live in. To the extent that a person has a preference for one region to another, everyone shares this preference. There are thus no differences among people in terms of region preferences.[8]

Denoting the per capita consumption in region j by c_j, we thus have

$$U_j = u(c_j, z_j(\mathbf{e})) \qquad j=1,\dots,J \tag{1}$$

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( ).

Total consumption cannot exceed total production, i.e.

$$\sum\nolimits_i n_i c_i \le \sum\nolimits_i F_i(n_i, e_i) \tag{2}$$

A Pareto efficient outcome is an outcome that is on the utility level frontier given the constraint (2). 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 all Pareto efficient allocation of emissions must satisfy[9]

$$F_{je}(n_j, e_j) = \sum_{i=1}^{n} n_i \frac{u_z(c_i, z_i)}{u_c(c_i, z_i)}(-z_{ij}(\mathbf{e})) \qquad j=1,\dots,J \tag{3}$$

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[6] 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.

[7] In an extended version of this paper, Hoel and Shapiro (2000), we have also considered the case in which there are different types of persons.

[8] This assumption is relaxed in Hoel and Shapiro (2000).

[9] See e.g. Markusen (1975) or Hoel (1999).

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. Region j faces the constraint

$$n_j c_j \leq F_j(n_j, e_j) \qquad j=1,\ldots,J \tag{4}$$

Given the constraint (4), region j maximizes (1) with respect to e_j, taking all other emission levels as given. It is straightforward to see that this gives the following first order condition:

$$F_{je}(n_j, e_j) = n_j \frac{u_z(c_j, z_j)}{u_c(c_j, z_j)}(-z_{jj}(\mathbf{e})) \qquad j=1,\ldots,J \tag{5}$$

Comparing this with the condition (3) for Pareto 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. Typically, a non-cooperative equilibrium will have higher emission level than the Pareto optimal emissions levels (see e.g. Hoel (1999) for a further disussion). This difference is what makes some kind of cooperation across regions necessary.

3 Population mobility

Let us now assume that there is perfect population mobility. In equilibrium migration eliminates any potential differences in utility levels between regions.[10] We thus have the following condition:

$$U_1 = U_2 = \ldots = U_J \tag{6}$$

Moreover, the total population in the group of regions is given, i.e.

$$\sum_i n_i = N \tag{7}$$

Consider first the non-cooperative outcome. This is no longer given by equation (5): The reason is that (5) describes a balancing of marginal abatement costs with the marginal benefit of an improved environmental quality, *both for a given population*. But any change in emissions will

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[10] Throughout the paper, we assume that the production and utility functions have properties implying that the population is positive in all countries in all relevant outcomes. See Hoel and Shapiro (2000) for a further discussion of the possibility of corner solutions with zero population in some regions.

generally also affect the allocation of population across regions, and thus give different final effects on per capita consumption and utility than the effects described by (5).[11]

Consider next the social optimum. This is defined as the combination of policies in all regions that maximizes the common utility level given by (6). The policy combination solving this maximization problem obviously depends on what the set of feasible policies is. If this set consists of emission levels in each region and nothing else, we generally will get a different optimum than we would get if transfers from residents in one region to residents in other regions also were permitted.[12] In any case, for all reasonable functions entering our analysis, there will be a solution to the problem of maximizing the common utility level.[13]

The social optimum described above has an important feature: It must also be a Nash equilibrium of the game in which governments in each region choose policies in order to maximize the utility levels of their own citizens. This follows directly from (6): Since utility levels in all regions are equal no matter what policies are chosen, any unilateral deviation from the socially efficient policies by the government of a particular region can never increase the common utility level. Therefore, such a unilateral deviation from the socially optimal policies on behalf of the government in a particular region cannot increase the utility level of the citizens in this region.

We can formalize this important result as follows: We have a game in which the players are the J regional governments. 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 $S = S_1 \times S_2 \times \cdots \times S_J$ 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. Given the vector $\mathbf{s}=(\mathbf{s}_1,\dots\mathbf{s}_J)$ of local policy choices, consumption levels and environmental qualities in all regions follow. From the preference function (1) all utility levels follow, so we have

$$U_j = V_j(\mathbf{s}) \qquad j=1,\dots,J \tag{8}$$

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[11] In Hoel and Shapiro (2000) we derive the equations describing the Nash equilibrium. However, we do not need these for the analysis of the present paper.

[12] It is well known from the literature on federalism that even in a simple model without any environmental variables, a first best social optimum may have transfers from one region to another. Myers (1990) has also demonstrated that a non-cooperative equilibrium may have voluntary transfers from one region to another.

[13] The solution need not be unique. It is easy to construct examples in for which there is a continuum of policy vectors all giving the same maximal value of the common utility level (see footnote 14).

From the migration equilibrium condition (6) we know that utility in all regions must be equal, whatever the strategy vector s is. This means that the payoff functions $V_j(\mathbf{s})$ must be the same for all regions, i.e.

$$V_j(\mathbf{s}) = V(\mathbf{s}) \qquad j=1,\ldots,J \tag{9}$$

Setting-up the transboundary pollution problem in this way gives us the following theorem:

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

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

The interpretation of the theorem is obvious: Since free population mobility makes the utility level in each region equal no matter what policies are chosen at the regional level, all regions share a common interest in maximizing this common utility level.

The theorem is valid no matter what are the feasible policies: if the available policy instruments are insufficient for a first best optimum, the second best (constrained) optimum is nevertheless supportable as Nash Equilibrium.

4 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 does not follow that socially efficient strategies will be the outcome of the non-cooperative game, as there may other Nash equilibria of the game. If such other Nash equilibria are not socially optimal, 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. To see this, is it useful to consider in some more detail the case in which interregional transfers are ruled out. Without any further restrictions on feasible policies, the policies are simply the emission levels in the different regions. In other words, our policy vector **s** is now equivalent to the emission vector **e**.

Since interregional transfers are ruled out, it follows from the utility function (1) and the migration equilibrium (6) that

$$u(\frac{f_1(n_j,e_j)}{n_1},z_1(\mathbf{e}))=...=u(\frac{f_J(n_J,e_J)}{n_J},z_J(\mathbf{e})) \qquad |(10)$$

Together with the balance equation for total population (7), the J-1 equations in (10) determine the population allocation as functions of the emission vector:

$$n_j=n_j(\mathbf{e}) \qquad j=1,\dots,J \qquad (11)$$

Inserting this back into (10) gives the common utility level as a function of the emission vector:

$$V(\mathbf{e})=u(\frac{f_j(n_j(\mathbf{e}),e_j)}{n_j(\mathbf{e})},z_j(\mathbf{e})) \qquad (12)$$

The socially optimal emission vector **e*** maximizes V(**e**), and since V(**e**) is the payoff vector also for each region, **e*** is a Nash equilibrium. However, we cannot rule out the possibility that there exists other emission vectors **e**’ ≠ **e*** with the property that (in obvious notation)

$$V(e_j',\mathbf{e}_{-j}')\geq V(e_j,\mathbf{e}_{-j}') \qquad \textit{for all } e_j\geq 0,\ j=1,\dots,J \qquad (13)$$

If this is the case, the vector **e**’ is a Nash equilibrium.

Whether or not multiple equilibria are “likely” in our very simple model cannot be answered in a meaningful way. The answer depends on properties of the utility and production functions. Notice that even if we have standard regularity conditions such as all functions F_j being concave and u being convex, it is not possible to say much about the properties of the function V(**e**). The possibility of multiple Nash equilibria as described by (13) is not ruled out even if the underlying functions F_j, z_j and u satisfy some general concavity/convexity conditions.

Although we cannot say whether or not multiple equilibria are “likely”, a simple example illustrates the possibility. Consider the simple case of two regions, with identical production functions. Assume that this production function is concave and homogeneous of degree 1, so that

$$F(n_j,e_j)=n_j f(\frac{e_j}{n_j}) \qquad (14)$$

where the function f is increasing and strictly concave in its argument. We also assume that f is twice differentiable.

The utility function is given by

$$u(c_j, z_j(e_1, e_2)) = c_j - D(e_1, e_2) \tag{15}$$

where D is a common convex environmental damage function. Ruling out the possibility of interregional transfers, we thus have

$$U^j = f(\frac{e_j}{n_j}) - D(e_1, e_2) \tag{16}$$

In equilibrium we must have $U_1=U_2$, and from (16) it follows that this implies

$$\frac{e_1}{n_1} = \frac{e_2}{n_2} \tag{17}$$

Normalizing the total population to 1, (17) may be rewritten as

$$\frac{e_j}{n_j} = e_1 + e_2 \tag{18}$$

Inserting this into (16) gives us the following function for the common utility level:

$$V(e_1, e_2) = f(e_1 + e_2) - D(e_1, e_2) \tag{19}$$

If the function D is differentiable, the first order condition for the social optimum (e_1^*, e_2^*) is given by[14]

$$f'(e_1^* + e_2^*) = D_1(e_1^*, e_2^*) = D_2(e_1^*, e_2^*) \tag{20}$$

To see the possibility of Nash equilibria that are not socially optimal, let us specify the example further by assuming that

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[14] As mentioned in footnote 13, the social optimum need not be unique. If e.g. $D=e_1+e_2$, the sum $e_1^*+e_2^*$ would be uniquely determined by $f'(e_1^*+e_2^*)=1$, but the any combination of e_1 and e_2 giving this sum will maximize V. Moreover, all of these combinations of e_1 and e_2 are Nash equilibria of the game between the two regional governments.

$$f\left(\frac{e_j}{n_j}\right)=\left(\frac{e_j}{n_j}\right)^{0,5} \tag{21}$$

and

$$D(e_1, e_2) = \max[e_1, e_2] \tag{22}$$

This environmental damage function corresponds to what Hirshliefer (1983) calls the weakest link damage function. Two regions may share a common barrier to environmental damage, e.g. a dike, and the barrier is only as good as the smallest effort of either region. For the dike maintenance example e_1 and e_2 are the negative of the maintenance efforts.

Inserting (21) and (22) into (19) we get

$$V(e_1, e_2) = (e_1 + e_2)^{0.5} - \max[e_1, e_2] \tag{23}$$

It is straightforward to see that the emission pair that maximizes V is given by

$$(e_1^*, e_2^*) = (0.5\ ,\ 0.5) \tag{24}$$

Consider next the non-cooperative game. Consider region 1. From (24) we find

$$\frac{\partial V}{\partial e_1} = \begin{cases} 0.5(e_1 + e_2)^{-0.5} & for\ e_1 < e_2 \\ 0.5(e_1 + e_2)^{-0.5} - 1 & for\ e_1 > e_2 \end{cases} \tag{25}$$

The best response function for region 1 is the emission level in region 1 that maximizes V, for any given emission level of region 2. It follows from (25) that this best response function is given by

$$e_1 = \min[e_2, 0.25 - e_2] \tag{26}$$

Similarly, the response function of region 2 is given by

$$e_2 = \min[e_1, 0.25 - e_1] \tag{27}$$

It is clear that all emission levels $e_1 = e_2 \geq 0.125$ satisfy both equations (26) and (27), so that they are Nash equilibria of this game. We thus have a continuum of Nash equilibria. All except the one given by (24) are Pareto dominated by the latter.

5 Conclusion

We have shown that the efficient regulation of transboundary pollution may be possible without explicit cooperative agreements or central mandates. What is required is that the policy options available to each region are adequate; that regions choose policies to maximize the same function of own-citizen welfare and that individual are fully mobile between regions. 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 regions that, in itself, can induce regions 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 regions. In equilibrium the welfare of one region is tied to the welfare of all others: the well being of one region cannot be improved unless the welfare of all regions improve. It is not necessary for regions 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 regions. This suggests that central intervention might take the form of expanding the policy choices open to individual regions 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 regional 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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