Interregional Competition, Spillovers and Attachment in a Federation*

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Abstract: In this paper, regional governments provide a good which generates interregional spillovers in a federation characterized by decentralized leadership and household attachment to regions. The central government redistributes income after it observes regional policymaking. Imperfectly mobile households choose their region of residence in perfect knowledge of the whole set of federal policies. We show that, irrespective the intensity of household attachment, the federal policies yield an efficient allocation of resources for the federal economy if there exist markets for both private and purely public characteristics of the commodity. This result appears relevant for a federation such as the European Union.

Keywords: Interregional Spillovers, Redistribution, Household Attachment.

JEL classification numbers: D62, D78, H41, H77, Q28.

1. Introduction

According to the conventional wisdom in fiscal federalism, regional public goods that generate interregional spillovers -- that is, goods whose economic jurisdiction exceeds the political jurisdiction of a regional or local government -- should be subjected to a Pigouvian subsidy determined by a higher-level government, namely, the central government (see, for example, Oates (1972)). Local governments should provide local public goods as far as economic and political jurisdictions coincide, but local public goods that generate interregional spillovers should be provided by a supralocal level of government.

Recent studies, however, demonstrate that there are circumstances under which competing regional governments may not only provide public goods that generate transboundary spillovers efficiently, but also implement interregional transfers to each other so that a socially efficient population distribution is obtained. In Wellisch (1994), competing regional governments fully internalize externalities associated with provision of public goods in their regions whenever households are not attached to regions. Caplan, Cornes and Silva (2000) demonstrate that decentralized provision of a pure public good -- a good whose economic benefit is available for an entire federation

-- may be efficient for a game where regional governments are policy leaders and a central government is a policy follower. Regional governments decide how much of the pure public good to provide in anticipation of the redistributive income policy implemented by the center. The efficiency result does not depend on the degree of household attachment.

In this paper, we extend the framework advanced by Caplan, Cornes and Silva (2000) by considering commodities that generate regional-specific benefits as well as federal-like benefit (good) or cost (bad). Consider, for example, provision of energy. Energy generates private consumption benefits as well as a federal-like damage (bad), since its consumption or production typically yields emissions of pollutants in the atmosphere (e.g., carbon dioxide). As in Caplan, Cornes and Silva (2000), we are interested in analyzing the allocation of resources for a federal economy characterized by imperfect labor mobility and decentralized leadership. Our example of such a federal economy coincides with theirs, namely the European Union (EU). The governments of the member nations are endowed with considerable economic and political powers vis-à-vis the center concerning most types of policies, including environmental policies.

Our federal regimes are hierarchical. They are built after the federal structure in the EU. Regional governments are concerned with controlling emissions of carbon dioxide in their own regions. We postulate that such a control is done through setting up quotas of pollution permits that can be sold in a regional or federal market for pollution permits. We start the analysis by considering a situation where in each region – there are only two for simplicity – we find a regional market for pollution permits. Residents of a region are unable to trade permits with residents or power plants of the other region. We also assume that the energy commodity is traded within each region. Later, we analyze the implications of federal markets for both energy and pollution permits. The center is endowed with an instrument to implement transfers and effects these transfers after the regional governments decide how many pollution permits to supply to market participants.

This paper is organized as follows. Section 2 presents the basic model of an impure public bad in a federal economy and derives the social optimum. Section 3 analyzes the decentralized Nash equilibrium in an autarkical economy. It shows that the redistribution policy of the center falls short of providing regional governments with incentives to efficiently curb emissions of carbon dioxide. This result is in contrast with the one obtained by Caplan, Cornes and Silva (2000) because of the impurity of the commodity examined here. Section 4 examines the efficiency properties of federal markets for energy and pollution permits. In this section, we demonstrate that a federal regime mirrored after the EU may yield an efficient allocation of resources for the federal economy. We conclude the paper in Section 5.

2. The Model

The federation consists of two regions indexed by $i, i = 1, 2$. There are N households in the economy. To simplify notation, we let $N = 1$. The population of region i is denoted by n_i. We assume that the utility function of households is heterogeneous only with respect to their attachment to a region as in Mansoorian and Myers (1993) and in Wellisch (1994). Then, each type of household is assumed to be distributed uniformly on the interval $[0,1]$. Households of region i derive utility from consumption of x_i units of the numeraire goods and e_i units of energy. Furthermore, since one unit of energy is assumed to generate one unit of air pollution, all households in the economy consume $E \equiv n_1 e_1 + n_2 e_2$ units of a federal bad. The utility function of a type n household, denoted by $V(n)$, can be characterized as

$$V(n) = \begin{cases} u(x_1, e_1, E) + a(1-n), & \text{if the household lives in region 1,} \\ u(x_2, e_2, E) + an, & \text{if the household lives in region 2.} \end{cases} \tag{1}$$

$u(x_i, e_i, E)$ is a strictly quasi-concave sub-utility function, increasing in the first and second elements and decreasing in the third element. The parameter n measures the non-pecuniary benefit the household derives from living in region 2 and the parameter $(1-n)$ the benefit from living in region 1 and the constant parameter $a \geq 0$ denotes the attachment intensity. For $a = 0$, households are perfectly mobile. As a increases, households become less mobile. All households can choose their region of residence and there is no cost associated with migration. Since the psychic benefit each household derives from a region is idiosyncratic, a migration equilibrium is obtained when

$$u(x_1, e_1, E) + a(1-n_1) = u(x_2, e_2, E) + an_1, \tag{2}$$

where n_1 identifies the marginal household who is indifferent between location in either region. While each household with n less than n_1 resides in region 1, each household with n grater than n_1 resides in region 2. Hence, n_1 is also the number (measure) of households residing in region 1.

Each resident of region i is endowed with one unit of homogeneous labor which is supplied at region i. All workers are employed in the production of the numeraire good. The production function for the numeraire good in region i is assumed to be a strictly concave function $F^i(L_i, n_i) \equiv f^i(n_i)$, where L_i denotes the fixed resource endowment of region i, say land. The production cost of energy, in terms of the numeraire good, in region i is $c^i(E_i)$. This cost function is assumed to be increasing and strictly convex.

The central government is constrained by both free migration of households (2) and the feasibility restriction for the entire federation:

$$n_1x_1 + n_2x_2 + c^1(E_1) + c^2(E_2) = f^1(n_1) + f^2(n_2). \tag{3}$$

The federation's total expenditure in the left-hand side must be covered by entire production (i.e., total income) in the right-hand side. Furthermore, the total demand for energy in the economy must be equal to the aggregate provisions of energy in equilibrium:

$$n_1e_1 + n_2e_2 = E_1 + E_2. \tag{4}$$

For a fixed $\theta \in [0,1]$, an efficient allocation can be obtained as a solution to the following problem:

$$\max_{x_1, x_2, e_1, e_2, E_1, E_2, n_1} \theta u(x_1, e_1, E) + (1-\theta) u(x_2, e_2, E), \tag{5}$$

subject to (2), (3), (4) and the fact that $n_1 + n_2 = 1$. Although (5) ignores locational tastes, this maximization problem can characterize an efficient allocation for a given weight θ. Since neither the central government nor regional governments can affect the psychic benefit each household derives from a particular region, any locational change must be accompanied by a change in either u^1 or u^2.[1]

Let λ_1, λ_2 and λ_3 be the Lagrangian multipliers associated with the migration equilibrium constraint (2), the feasibility constraint (3) and the market clearing condition for energy, respectively. For a fixed $\theta \in [0,1]$, the efficient allocation is characterized by the following first-order conditions, provided the solution is interior:

$$(x_i) \quad \theta_i u_x^i + \lambda_2 n_i = 0 \qquad \text{for } i = 1,2, \text{ and } i \neq j, \tag{6a}$$

$$(e_i) \quad \theta_i \left(u_e^i + n_i u_E^i \right) + \theta_j n_i u_E^j + \lambda_3 n_i = 0 \qquad \text{for } i = 1,2, \text{ and } i \neq j, \tag{6b}$$

$$(E_i) \quad \lambda_2 c_E^i - \lambda_3 = 0 \qquad \text{for } i = 1,2, \text{ and } i \neq j, \tag{6c}$$

[1] Wellisch (1994) explains why a Pareto efficient allocation must maximize $\theta u^1 + (1-\theta) u^2$ using a revealed preference argument: if a change in location did not increase utilities, it would not be made.

$$(n_1)\quad \left(\theta_1 u_E^1 + \theta_2 u_E^2 + \lambda_3\right)\left(e_1 - e_2\right) - 2a\lambda_1 - \lambda_2\left[\left(f_n^1 - x_1\right) - \left(f_n^2 - x_2\right)\right] = 0, \qquad \text{(6d)}$$

where $\theta_1 \equiv \theta + \lambda_1$, $\theta_2 \equiv (1-\theta) - \lambda_1$ and partial derivatives are denoted by the subscripts. Combining equations (6a), (6b) and (6c) yields necessary conditions for the socially efficient level of air pollution:

$$-\left(n_i \frac{u_E^i}{u_x^i} + n_j \frac{u_E^j}{u_x^j}\right) = \frac{u_e^i}{u_x^i} - c_E^i, \qquad \text{for } i = 1,2, \text{ and } i \neq j. \qquad (7)$$

Equations (7) represent the modified Samuelson rule in the case of an impure public bad. The regional sum of the marginal benefits for marginal reduction of emission of air pollution in the left-hand side must be equal to the marginal costs in the right-hand side, that is, the utility cost of giving up one unit of private energy in terms of the numeraire good and the saving in production of it. Equations (6c) imply the equalization of marginal costs of energy provision:

$$c_E^1 = c_E^2. \qquad (8)$$

Equations (7) and (8) tell us that the marginal utility of energy in terms of the numeraire good must also be equalized across regions:

$$\frac{u_e^1}{u_x^1} = \frac{u_e^2}{u_x^2}. \qquad (9)$$

Finally, equations (6), (7), (8) and (9) imply:

$$\left(f_n^1 - x_1 - \frac{u_e^1}{u_x^1} e_1\right) - \left(f_n^2 - x_2 - \frac{u_e^2}{u_x^2} e_2\right) = 2a\left(\frac{(1-\theta)n_1}{u_x^1} - \frac{\theta n_2}{u_x^2}\right). \tag{10}$$

Expression (10) is the well-known efficient population distribution condition in the case of an impure public bad (see, for example, Mansoorian and Myers (1993) and Wellisch (1994)). If households are perfect mobile: $a = 0$, equation (10) can be rewritten as follows:

$$f_n^1 - x_1 - \frac{u_e^1}{u_x^1} e_1 = f_n^2 - x_2 - \frac{u_e^2}{u_x^2} e_2 .$$

The net social benefit of an additional mobile household to a region must be equal across regions in the unique efficient equilibrium. If households are imperfectly mobile: $a > 0$, there is a range of efficient population distributions, which depend on the center's weight parameter $\theta \in [0,1]$.

3. Autarky

Consider now a setting in which each regional government regulates emission of air pollution under an autarkical economy, that is, the regions do not trade with each other. We assume that households who reside in a given region own the fixed factor located in that region on an equal per capita basis. Since each household is identically productive and is employed by competitive firms that produce the numeraire good, each individual's total income in region i is $f^i(n_i)/n_i$. Furthermore, each household in the region is assumed to own equal profit shares of the regional energy companies. Suppose that each regional government sets emission permits $Q_i > 0$ and endows each resident with Q_i/n_i . The energy industries must purchase the emission permits at per unit cost $r_i \geq 0$ for production of energy. Then, each resident of region i faces the following budget constraint:

$$x_i + p_i e_i = w_i \equiv \frac{f^i(n_i) + r_i Q_i + \pi^i + t_i}{n_i} \qquad \text{for } i = 1,2, \text{ and } i \neq j, \qquad (11)$$

where p_i denotes the prevailing price of one unit of energy , π^i corresponds to the energy company's profit and t_i represents the interregional income transfer made by the central government. The central government will be assumed to implement the redistribution policy as it wishes provided that $t_1 + t_2 = 0$.

Each household in region i chooses quantities of private consumption $\{x_i, e_i\}$ to maximize $u(x_i, e_i, E)$ subject to his or her budget constraint (11), taking p_i, w_i, E as given. The solution to the problem satisfies (11) and the following condition:

$$\frac{u_e^i}{u_x^i} = p_i \qquad \text{for } i = 1,2, \text{ and } i \neq j, \qquad (12)$$

provided the solution is interior. Equations (12) show that in each region the resident's marginal rate of substitution between energy and numeraire goods must be equal to the price of energy. We can now use equations (11) and (12) to define the demand functions of the resident in region i: $x_i(p_i, w_i)$ and $e_i(p_i, w_i)$.

The energy market clears at $E_i = n_i e_i(p_i, w_i)$ for $i = 1,2$. These market clearing conditions determine the market prices of energy p_i. The energy companies in region i are assumed to be price takers. Then the aggregated profit of energy industry in region i is $\pi^i(E_i) \equiv p_i E_i - c^i(E_i) - r_i E_i$. The profit maximization condition determines E_i as a function of $\rho_i \equiv p_i - r_i$. The market in region i for pollution permits is in equilibrium when all regional emission permits are bought by regional industries: $E_i(\rho_i) = Q_i$. We can use these equilibrium conditions to implicitly define $\rho_i = \rho_i(Q_i)$. Hence, per capita income w_i can be rewritten as follows:

$$w_i(n_i, t_i, Q_i) = \frac{f^i(n_i) + p_i E_i(\rho_i(Q_i)) - c^i(E_i(\rho_i(Q_i))) + t_i}{n_i}. \tag{13}$$

In our federation, regional governments are Stackelberg leaders and a central government is a Stackelberg follower. This seems to accord well with the institutional setup of the European Union. The regulator in region i regulates the supply of energy E_i so as to maximize the utility of a resident $u(x_i, e_i, E)$ subject to (13).

Furthermore, we assume that each region takes the other regional choice as given. Both regional governments determine their emission permits in anticipation of the interregional redistribution policy implemented by the center and the location choices of households. More precisely, the timing for the game is as follows:

1st stage: Region i determines Q_i to maximize $u(x_i, e_i, E)$ subject to

$t_1 = \tau(Q_1, Q_2)$ and $n_1 = m(t_1, Q_1, Q_2)$.

2nd stage: The central government observes Q_1, Q_2 and determines t_1 to maximize $\theta u(x_1, e_1, E) + (1-\theta) u(x_2, e_2, E)$ subject to $n_1 = m(t_1, Q_1, Q_2)$.

3rd stage: After observing the choices made by regional governments and the central government, each household decides a region to reside.

As it is usually done, we start at the last stage of the game. We can now rewrite the migration equilibrium (2) as follows:

$$v(p_1, w_1, E) + a(1-n_1) = v(p_2, w_2, E) + an_1, \tag{14}$$

where $v(p_i, w_i, E) \equiv u(x_i(p_i, w_i), e_i(p_i, w_i), E)$ is indirect utility functions for a representative resident in i and $E = E_1 + E_2$. This equation determines n_1 as an implicit function of the policy variables:

$$n_1 = m\left(t_1, Q_1, Q_2\right). \tag{15}$$

A straightforward exercise in comparative statics yields the following migration responses:

$$\frac{\partial n_1}{\partial t_1} = -\frac{\frac{u_x^1}{n_1} + \frac{u_x^2}{n_2}}{D}, \tag{16a}$$

$$\frac{\partial n_1}{\partial Q_i} = \frac{\left(-1\right)^i \frac{u_x^i}{n_i}\left(p_i - c_E^i\right) - \left(u_E^1 - u_E^2\right)}{D} \qquad \text{for } i = 1,2, \text{ and } i \neq j. \tag{16b}$$

provided that the derivative of equation (15) with respect to n_1:

$$D \equiv \frac{u_x^1}{n_1}\left(f_n^1 - w_1\right) + \frac{u_x^2}{n_2}\left(f_n^2 - w_2\right) - 2a \tag{17}$$

is negative, since we focus our attention on situations at which the migration equilibrium is stable (see Stiglitz (1977) and Boadway (1982)).

Let us now examine the resource allocation in the second stage of the game. Assuming an interior solution for t_1, we obtain the following first-order condition in the central government's maximization problem:

$$\frac{\theta u_x^1}{n_1}\left[\left(f_n^1 - w_1\right)\frac{\partial n_1}{\partial t_1} + 1\right] - \frac{\left(1-\theta\right)u_x^2}{n_2}\left[\left(f_n^2 - w_2\right)\frac{\partial n_1}{\partial t_1} + 1\right] = 0. \tag{18}$$

Combining equations (11), (12), (16a) and (18) yields the efficient population distribution condition (10). The equation defines the center's redistribution policy as an implicit function of regional control variables: $t_1 = \tau(Q_1, Q_2)$. Differentiation of the implicit function yields the following partial derivatives:

$$\frac{\partial t_1}{\partial Q_i} = \left\{ \frac{(-1)^{1+i}\left(p_i - c_E^i\right)}{n_i} + 2a\left[(-1)^i \frac{\theta_j^* u_{xx}^i \left(p_i - c_E^i\right)}{\left(u_x^i\right)^2} \left(\frac{\partial x_i}{\partial w_i} + \frac{u_{xe}^i}{u_{xx}^i} \frac{\partial e_i}{\partial w_i} \right) \right. \right.$$

$$\left. \left. - \frac{(1-\theta) n_1 u_{xE}^1}{\left(u_x^1\right)^2} + \frac{\theta n_2 u_{xE}^2}{\left(u_x^2\right)^2} \right] \right\} \Gamma^{-1}, \qquad \text{for } i = 1,2, \text{ and } i \neq j, \tag{19}$$

where the weights of the center: θ_1^* and θ_2^* indicate θ and $1-\theta$ respectively and the derivative with respect to t_1:

$$\Gamma \equiv -\frac{1}{n_1} - \frac{1}{n_2} + 2a\left[\frac{(1-\theta) u_{xx}^1}{\left(u_x^1\right)^2} \left(\frac{\partial x_1}{\partial w_1} + \frac{u_{xe}^1}{u_{xx}^1} \frac{\partial e_1}{\partial w_1} \right) + \frac{\theta u_{xx}^2}{\left(u_x^2\right)^2} \left(\frac{\partial x_2}{\partial w_2} + \frac{u_{xe}^2}{u_{xx}^2} \frac{\partial e_2}{\partial w_2} \right) \right]$$

is negative.

In the first stage of the game, the regions determine their quotas of emission permits taking into account the responses by the center and population. Assuming interior solutions for their choice variables, the Nash equilibrium is characterized by the following first-order conditions:

$$-n_1 \frac{u_E^1}{u_x^1} - \left[\frac{\partial t_1}{\partial Q_1} + \left(f_n^1 - w_1\right)\left(\frac{\partial n_1}{\partial Q_1} + \frac{\partial n_1}{\partial t_1} \frac{\partial t_1}{\partial Q_1} \right) \right] = \frac{u_e^1}{u_x^1} - c_E^1, \tag{20a}$$

$$-n_2 \frac{u_E^2}{u_x^2} - \left[-\frac{\partial t_1}{\partial Q_2} - \left(f_n^2 - w_2\right)\left(\frac{\partial n_1}{\partial Q_2} + \frac{\partial n_1}{\partial t_1} \frac{\partial t_1}{\partial Q_2} \right) \right] = \frac{u_e^2}{u_x^2} - c_E^2. \tag{20b}$$

The modified Samuelson conditions (7) require that the second terms in the left side of these equations to be equal to $n_2 u_E^2 / u_x^2$, $n_1 u_E^1 / u_x^1$, respectively. Combining equations (20) with (16) and (19), we have

Proposition 1. Provided the solutions to the maximization problems are interior, the subgame perfect equilibrium for the game "Autarkical Decentralized Control" is characterized by equations (10), (16), (19) and (20). Since the equilibrium allocation does not satisfy the modified Samuelson conditions, it is Pareto inefficient.

Caplan, Cornes and Silva (2000) demonstrated that for a pure public good, the interregional transfer implemented by the center induces the regions to behave efficiently. For the impure public goods, however, our results above make it clear that the redistribution policy of the center falls short of providing regions with incentives to behave efficiently. This inefficiency is not based on the degree of household mobility since the center can attain the efficient population distribution with the transfer, but it is, in fact, based on the differences of the marginal rate of substitution (12) and the marginal cost of energy provision across regions.

Corollary 1. If regions are identical, the subgame perfect equilibrium characterized by equations (16), (19) and (20) satisfies the modified Samuelson conditions. Then, the equilibrium allocation is Pareto efficient.

Corollary 1 states that decentralized environmental policy can be successful if prices and costs of energy happen to be equal across regions. In general, however, technology and tastes differ across regions. The following section examines the creation of interregional markets for energy and pollution permits and their implications for the allocation of resources in the federation.

4. Interregional Markets

Let us now consider a situation whereby there are two interregional markets in the federation, one for energy and one for pollution permits. The former market clears if there is equalization between demand for and supply of energy in the federation:

$$n_1 e_1\left(p, w_1\right) + n_2 e_2\left(p, w_2\right) = E . \tag{21}$$

The market clearing condition (21) determines the federal price of energy, p. The energy industries must purchase the emission permits at per unit cost $r \geq 0$ for production of energy. Hence, the energy industry in region i chooses E_i to maximize $\pi_i^* \equiv pE_i - c^i\left(E_i\right) - rE_i$ subject to $E_i > 0$, taking p, r and E_j as given.

The first-order conditions for the industries:

$$c_E^i\left(E_i\right) = p - r \equiv \rho \qquad \text{for } i = 1,2, \text{ and } i \neq j, \tag{22}$$

determine E_1 and E_2 as implicit functions of ρ, $E_1^*\left(\rho\right)$ and $E_2^*\left(\rho\right)$, respectively. The market for pollution permits is in equilibrium whenever:

$$E_1^*\left(\rho\right) + E_2^*\left(\rho\right) = Q_1 + Q_2 \equiv Q. \tag{23}$$

Equation (23) enables us to implicitly define ρ as a function of Q: $\rho^*\left(Q\right)$. Given the assumptions above, the budget constraint for a household in region i can be rewritten as follows:

$$x_i + pe_i = w_i^* \qquad \text{for } i = 1,2, \text{ and } i \neq j, \tag{24}$$

where

$$w_i^*\left(n_i, t_i, Q_i, Q\right) = \frac{f^i\left(n_i\right) + r\left(Q_i - E_i^*\left(\rho^*(Q)\right)\right) + pE_i^*\left(\rho^*(Q)\right) - c^i\left(E_i^*\left(\rho^*(Q)\right)\right) + t_i}{n_i}.$$

Each resident in region i maximizes $u\left(x_i, e_i, E\right)$ subject to above budget constraint, taking p, w_i^* and E as given. The solutions to the problem for $i = 1,2$ satisfy (24) and the following condition:

$$\frac{u_e^1}{u_x^1} = \frac{u_e^2}{u_x^2} = p. \tag{25}$$

Equations (25) entail equalization of the marginal rates of substitution between energy and numeraire goods across regions. They yield equation (9).

We are now ready to examine the three-stage policy game. In the third stage, population moves across regions according to the following migration equilibrium:

$$v\left(p, w_1^*, E\right) + a\left(1-n_1\right) = v\left(p, w_2^*, E\right) + an_1 . \tag{26}$$

We can use this equation to implicitly define the function: $n_1 = m^*\left(t_1, Q_1, Q_2\right)$. Differentiation of the function yields the following migration responses:

$$\frac{\partial n_1}{\partial Q_i} = \frac{\left(-1\right)^i \frac{u_x^i}{n_i} r - u_E^1 + u_E^2}{D}, \qquad \text{for } i = 1,2, \text{ and } i \neq j, \tag{27}$$

where the response with respect to t_1 is equivalent to (16a). These responses lead to the following result:

$$\frac{\partial n_1}{\partial Q_1} - \frac{\partial n_1}{\partial Q_2} = \frac{\partial n_1}{\partial t_1} r . \tag{28}$$

Knowing how population will respond to its choice, the central government determines t_1 so as to maximize $\theta u\left(x_1, e_1, E\right) + \left(1-\theta\right) u\left(x_2, e_2, E\right)$ in the second stage of the game. The first-order condition for the problem is characterized by equation (18). Hence, the center's optimal choice implies that the efficient population distribution condition (10) is satisfied. Use this equation to define the implicit function: $t_1 = \tau^*\left(Q_1, Q_2\right)$. A straightforward exercise in comparative statics gives:

$$\frac{\partial t_1}{\partial Q_1}-\frac{\partial t_1}{\partial Q_2}=-r. \tag{29}$$

In the first stage of the game, both regional governments determine their levels of emission permits, taking the response functions: $m^*(t_1,Q_1,Q_2)$ and $\tau^*(Q_1,Q_2)$ into account. Assuming interior solutions, the Nash equilibrium is characterized by the following first-order conditions:

$$\frac{u_x^1}{n_1}\left(r+\frac{\partial t_1}{\partial Q_1}+\left(f_n^1-w_1^*\right)\left(\frac{\partial n_1}{\partial Q_1}+\frac{\partial n_1}{\partial t_1}\frac{\partial t_1}{\partial Q_1}\right)\right)+u_E^1=0, \tag{30a}$$

$$\frac{u_x^2}{n_2}\left(r-\frac{\partial t_1}{\partial Q_2}-\left(f_n^2-w_2^*\right)\left(\frac{\partial n_1}{\partial Q_2}+\frac{\partial n_1}{\partial t_1}\frac{\partial t_1}{\partial Q_2}\right)\right)+u_E^2=0. \tag{30b}$$

We will now examine whether these first-order conditions imply the modified Samuelson conditions (7). From equations (28) and (29), it follows that:

$$\frac{\partial n_1}{\partial Q_1}+\frac{\partial n_1}{\partial t_1}\frac{\partial t_1}{\partial Q_1}=\frac{\partial n_1}{\partial Q_2}+\frac{\partial n_1}{\partial t_1}\frac{\partial t_1}{\partial Q_2}. \tag{31}$$

Subtracting equation (30b) from (30a) and using equations (29) and (31) yields:

$$\frac{u_x^1}{n_1}r+\left(\frac{u_x^1}{n_1}+\frac{u_x^2}{n_2}\right)\frac{\partial t_1}{\partial Q_1}+\left[\frac{u_x^1}{n_1}\left(f_n^1-w_1^*\right)+\frac{u_x^2}{n_2}\left(f_n^2-w_2^*\right)\right]\left(\frac{\partial n_1}{\partial Q_1}+\frac{\partial n_1}{\partial T_1}\frac{\partial t_1}{\partial Q_1}\right)+u_E^1-u_E^2=0.$$

Dividing this equation by D and using equation (28) for $i=1$ gives

$$\frac{2a}{D}\left(\frac{\partial n_1}{\partial Q_1}+\frac{\partial n_1}{\partial t_1}\frac{\partial t_1}{\partial Q_1}\right)=0. \tag{32}$$

It is clear that the expression in parenthesis of equation (32) is zero because $2a/D < 0$. Given equations (31) and (32), the first-order conditions (30a) and (30b) are reduced to:

$$-n_1 \frac{u_E^1}{u_x^1} = r + \frac{\partial t_1}{\partial Q_1}, \tag{30a'}$$

$$-n_2 \frac{u_E^2}{u_x^2} = r - \frac{\partial t_1}{\partial Q_2}. \tag{30b'}$$

Adding these equations and using equations (22), (25) and (29) yields:

$$-\left(n_1 \frac{u_E^1}{u_x^1} + n_2 \frac{u_E^2}{u_x^2} \right) = \frac{u_e^1}{u_x^1} - c_E^1 = \frac{u_e^2}{u_x^2} - c_E^2. \tag{33}$$

Therefore, we have

Proposition 2. If all regional governments supply positive quotas of emission permits in the interregional market for pollution, the subgame perfect equilibrium for the three-stage game just examined yields an efficient allocation of resources in the federal economy.

The result above makes it clear that combining decentralized control of the impure public bad with an interregional transfer mechanism implemented by the center induces the regions to behave efficiently provided there exist federal markets for energy and emission permits. Since both regional governments together provide a socially efficient level of emission permits in equilibrium, each region in fact faces its Lindahl price. Each region is endowed with the correct incentive to control the impure public bad; each region fully internalizes the transboundary externality.

It is now straightforward to show that a subgame perfect equilibrium of the three-stage game, satisfying the assumptions of the model and claim in Proposition 2, is Pareto efficient regardless of the degree of household mobility. All we have to do is to consider the case where $a = 0$. This case, however, is trivial because it would entail equalization of utilities across regions and hence perfect incentive equivalence (see, e.g., Myers (1990) and Wellisch (1994)). Then, we can summarize these findings as follows:

Theorem 1. Provided there exist competitive markets for energy and pollution permits in the federation and both regions choose to supply positive quantities of permits in equilibrium, the subgame perfect equilibrium for the three-stage game examined in this section yields a Pareto efficient allocation of resources for the federal economy despite the intensity of household attachment to regions.

This is good news for federations such as the EU. Our results suggest that the efficiency of a federal market for pollution permits is contingent on the existence of both a competitive federal market for energy and the redistributive mechanism operated by the center (e.g., Structural and Cohesion Funds in the EU).

5. Conclusion

This paper analyses decentralized control of an impure public bad, a commodity that generates both a private, regional-specific, benefit and a federal negative externality in a federation such as the EU characterized by imperfect household mobility. We show that decentralized environmental policy in absence of federal markets for energy and pollution permits is inefficient. We also show that there exists a combination of decentralized policy making and federal policy making that yields an efficient allocation of resources for the federal economy in the presence of a market for pollution permits and a competitive market for energy. Regional governments should control their own quotas of pollution permits and the center should implement redistributive income transfers. The intensity of household attachment is not an obstacle for the efficiency result.

The result derived in this paper may be applied to many situations whereby regional public goods cause interregional spillovers of the form modeled in this paper. Consider, for instance, infrastructure activities, such as public transportation systems, roads and forestry. Roads provide regional-specific benefits as well as federal-like benefits. A central government can induce regions to behave efficiently by implementing redistributive transfers and by setting up federal markets for the relevant commodities. In future work, we wish to extend our analysis to more general settings where the spillovers are not necessarily perfectly substitutable and the market for the private characteristic is not necessarily competitive.

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