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Interregional Tax Competition and Spillovers: Centralized versus Decentralized Leadership

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We examine the shape of federal policy making hierarchical federal structures. Regional governments engage in tax competition to attract mobile capital and design environmental policies to control correlated transboundary pollutants. Federative hierarchy is modeled as leader-follower games in which the leader is at the top of the hierarchy. Our results indicate that hierarchical federal structures characterized by decentralized leadership prevent a race to the bottom provided that players' utilities are conditionally transferable, the center cares about interregional redistribution and makes interregional transfers accordingly.

Keywords: Correlated transboundary pollutants, interregional tax competition, income redistribution, timing of federal policy making, race to the bottom.

JEL classification numbers: D62, D78, H41, H77

1 Introduction

Most federations care about by enhancing or maintaining equity across regions. In the United States, there are many forms of federal grants that attempt to reduce regional (i.e., state) income disparities. Similarly, in the European Union, interregional redistribution schemes are in place to maintain cohesion and reduce income disparities amongst its objective regions.

Most federations also have policies that attempt to address coordination failures arising from the existence of interregional spillovers. Perhaps, the clearest example of federal policy that attempts to address interregional spillovers is environmental policy making for the control of transboundary air pollutants, such as sulfur dioxide and nitrogen oxides, the main sources of acid rain. This form of federal policy is widely observable in the United States, the European Union and Canada, to cite just a few federal systems.

More recently, the European Union launched the second phase of the European Union Emissions Trading System (EU ETS) in order to account for some damages that are caused by emissions of greenhouse gases from significant European air polluting sources.[1] A similar cap and trade program for the United States was part of President Barack Obama's agenda, but it stalled at the Senate in 2010 after passing in the House. Even though the United States has not yet implemented such an emissions trading scheme for greenhouse gases, it may become a reality in the future if President Obama is reelected.[2]

Another key characteristic of federal systems is harmful tax competition. For example, as a clear demonstration that harmful tax competition has been a major concern in Europe, the European Union adopted in

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December 1 1997 the Code of Conduct for business taxation to induce the member nations to reduce existing tax policies that produced harmful competition as well as to inhibit the implementation of such tax policies in the future.[3] For the United States, Devereux et al. (2007) find evidence of harmful tax competition for cigarettes amongst neighboring states and for gasoline amongst state and federal governments. More recently, however, Chirinko and Wilson (2011) find evidence that, in the United States, the average state, in setting its capital tax policy, reacts negatively rather than positively to changes in capital taxes in neighboring states. This finding apparently runs counter to the "race to the bottom" phenomenon typically associated with tax competition in federal systems.

In this paper, we consider the interplay of regional environmental policy designed to control net emissions of air transboundary pollutants, federal redistributive policy and tax competition between two regions that compete to attract capital. Our main settings are hierarchical federal systems in which two levels of government, federal and regional, have divided responsibility over implementation of socially desirable policies. The federal policy attempts to reduce regional inequality. The motivation for the regional environmental policy is to reduce pollution damages. Tax competition emerges from the facts that capital is mobile and the regional governments are obliged to utilize capital taxes to finance regional provision of air pollution abatement.

Silva and Caplan (1997) considered the potential pitfalls that divided responsibility between federal and regional governments over control of transboundary pollutants may produce in hierarchical federal systems. They demonstrated that a federal system which features decentralized leadership, similar to the prevalent system in the European Union, may be socially superior to a federal system which features centralized leadership, similar to the prevalent system in the United States. Decentralized leadership dominates centralized leadership whenever regional welfare functions are quasi-linear and the center, which cares about equity across regions, promotes interregional transfers. The subsequent paper by Caplan and Silva (1999) made the superiority of decentralized leadership even sharper, since in their setup decentralized leadership was socially efficient even when the center did not care about equity, and thus did not pursue redistribution across region. Decentralized leadership is shown to be superior whenever the regional governments choose pollution taxes and subsequently the center decides on the levels of pollution abatements the regions should produce. Both Silva and Caplan (1997) and Caplan and Silva (1999), however, assume that governments use lump-sum income taxes to finance their expenditures.

The literature on interregional tax competition is vast (see, e.g., Wilson (1986, 1999) and Wildasin (1989)). Wilson (1986) states that "…tax competition exists if and only if a rise in a single region's public service output causes capital to flow out of the region." (p.303). Wilson (1986) also shows that financing the provision of a local public good by levying a capital tax is inefficient. Wildasin provides an intuitive explanation for the inefficiency caused by capital tax competition: "The inefficiency associated with tax competition can be understood as a kind of externality. This externality occurs because an increase in the tax rate in one jurisdiction causes a flow of capital to other jurisdictions that increases their tax revenue." (Wildasin 1989, p.194). Wilson (1999) surveys the large literature on tax competition and focuses on the tension there exists between Oates' (1972) claim that tax competition is wasteful and Tiebout's (1956) theory of local public good provision which calls for decentralization and competition at the local level to improve efficiency.

As illustrated in studies of tax competition, regional governments in many federations adopt distortive taxation to finance the provision of public goods and services. In some papers, the regionally financed public goods may generate interregional consumption benefits. A particularly important example is Cremer and Gahvari (2004). These authors study tax competition in the presence of transboundary pollution. The regional governments control two policy instruments, an output tax and a pollution tax. In the absence of pollution, the regional governments would have incentives to lower their output taxes in order to attract capital, characterizing a race to the bottom. In the presence of pollution and without capital mobility, however, the regional governments may wish to set pollution taxes at levels that equate the marginal regional pollution damages. The authors demonstrate that uncoordinated governments typically set inefficient environmental taxes, leading to too much pollution relative to the first-best level, and choose output taxes that support the "race to the bottom" argument.

In a recent paper, Hadjiyiannis et al. (2009) provides evidence that in most OECD countries over 40% of the costs of providing pollution abatement and control are financed by public expenditures. The authors utilize this fact in conjunction with the facts that transboundary pollution is ubiquitous and capital is internationally mobile to build a general equilibrium model in which regional provision of pollution abatement and tax competition are explicitly considered to analyze the efficiency of environmental policy designed by the governments of two politically independent regions (nations). They show that pollution taxes are efficiently chosen when countries are symmetric, but are inefficient when countries are asymmetric.

To our knowledge, this paper is the first study of tax competition that considers the efficiency properties of hierarchical federal systems in a context in which the center promotes interregional transfers and regional governments engage in tax competition to attract capital (i.e., capital is mobile) and raise tax revenue to finance provision of public abatement (e.g., utilization of desulfurization and carbon capture and storage technologies) to partially mitigate the detrimental effects associated with emissions of correlated air pollutants. Our framework, therefore, deviates from the framework used in Silva and Caplan (1997) and Caplan and Silva (1999) in many respects. First, regional governments are not endowed with lump-sum income taxes. Second, we consider a situation where the regions are afflicted by multiple correlated pollutants. Third, as explained below, we allow individuals' utilities to feature variable (albeit common) marginal utilities of income.

As in Silva and Caplan (1997) and Caplan and Silva (1999), there are two types of federal hierarchies, one featuring centralized leadership and another featuring decentralized leadership. Unlike these papers, we also consider another type of federation, namely, one in which central and regional governments make simultaneous choices. This setting provides a valuable benchmark for comparisons, enabling us to capture the effects of each type of leadership relative to a hypothetical setting in which no leadership is present. It is also empirically relevant if one recognizes that neither level of the federal hierarchy (central or regional) may be capable of perfectly anticipating the policies that will be chosen by the other level of the federal hierarchy.

The paper is organized as follows. Section 2 describes the basic model. Section 3 provides the center's most preferable allocation. A central government chooses regional capital taxes and interregional income transfers to maximize a general Bergson-Samuelson social welfare function. The allocation provides us with a benchmark for comparison. Section 4 examines the three federal policy scenarios, simultaneous policy making, decentralized leadership and centralized leadership. Regional governments choose regional capital taxes to maximize their own regional welfare and the center chooses the interregional transfers to maximize the social welfare. We compare each equilibrium allocation with the center's most preferable allocation, respectively. This section provides the main results of this study. Section 5 concludes the paper.

2 The Federal Economy

Consider a federation consisting of two regions, two autonomous regional governments and one central government. Each region is indexed by j, $j=1,2$. There are n_j identical individuals in each region. Let $N>0$ be the total population of individuals in the federation where $N=\sum_{j=1}^{2} n_j$. For simplicity, we consider a model in which there is production of a single composite (numeraire) good.

In region j, there are n_j units of labor, E_j units of an energy-generating resource (say, coal), and K_j units of capital. For simplicity, we assume that the regional supplies of labor and coal are fixed because labor and energy markets are regional and there is no mobility of either labor or coal across regions. Each individual in region j is endowed with one unit of labor, E_j/n_j units of coal and K_j/n_j units of capital. Each individual supplies his/her labor unit and her coal units inelastically in the region in which he or she resides. Each individual also supplies his or her capital units in the economy-wide capital market. The total amount of capital units supplied in the economy-wide capital market is $K=K_1+K_2$.

The competitive industry in region j rents k_j units of capital and employs n_j units of labor and E_j units of coal to produce $F_j\left(k_j; n_j, E_j\right)\equiv f_j\left(k_j\right)$ units of the numeraire good. We assume that the production function $f_j\left(k_j\right)$ is increasing in its argument, strictly concave, twice continuously differentiable and satisfies the following Inada condition: $\lim_{k_j\to 0} f_j'\left(k_j\right)=\infty$. The production function exhibits decreasing returns to scale due to the regionally fixed labor and coal factors. The Inada condition implies that the capital input is essential in production. For simplicity, we assume that each unit of coal utilized in region j generates one unit of sulfur dioxide and one unit of carbon dioxide, which are emitted in the atmosphere. Letting S_j and C_j denote the units of sulfur dioxide and carbon dioxide emitted in region j, we have $S_j=C_j=E_j, j=1,2$.

The profit of the industry in region j is $\pi_j\equiv f_j\left(k_j\right)-\left(r+t_j\right)k_j-w_j n_j-\nu_j E_j$, where $r>0$ is the economy-wide rental rate, $t_j>0$ is the regional capital tax rate levied by the regional government to finance provision of pollution abatement, and $w_j>0$ and $\nu_j>0$ are the labor wage and coal price in region j. In order to focus on the effects of interregional capital tax competition, we assume that the sole tax instrument that regional governments have at their disposal is the regional capital tax.

Since the technology features decreasing returns to scale, profits are positive in equilibrium. Letting $\rho_j\equiv r+t_j$ denote the rental rate after tax in region j, the first order condition for profit maximization is $f_j'\left(k_j\right)=\rho_j$, from which we derive the factor demand functions,

$k_j\left(\rho_j\right),\ j=1,2.$ Observe that $k_j'\left(\rho_j\right)=1/f_j''\left(k_j\right) < 0$.

The economy-wide capital market clears when $k_1\left(\rho_1\right)+k_2\left(\rho_2\right)=K$. Since $\rho_j \equiv r+t_j,\ \ j=1,2,$ this condition enables us to implicitly define the rental rate as function of the capital tax rates, $r\left(t_1,t_2\right)$. Plugging this function into the market-clearing condition and differentiating with respect to t_j yields

$$\partial r/\partial t_j = -f_m''/\left(f_1''+f_2''\right)\in\left(-1,0\right),\qquad j,m=1,2,\ j\neq m. \quad (1a)$$

Conditions (1a) are standard in the tax competition literature; they are the marginal rental-rate functions (see, e.g., Wildasin (1989)).

Each individual in region j obtains $r\left(t_1,t_2\right) K_j/n_j$ units of rental income from capital, $v_j E_j/n_j$ units of rental income from coal, w_j units of labor income, and π_j/n_j units of profit. Profits are not expatriated. Letting x_j denote the quantity of numeraire good consumed by the representative resident of region j, this individual's budget constraint is $x_j = \tau_j + \left[f_j\left(k_j\left(\rho_j\left(t_1,t_2\right)\right)\right)+r\left(t_1,t_2\right)K_j - \rho_j\left(t_1,t_2\right)k_j\left(\rho_j\left(t_1,t_2\right)\right)\right]/n_j$, whereis τ_j the federal interregional transfer received (if positive) or paid (if negative) and $\rho_j\left(t_1,t_2\right)\equiv r\left(t_1,t_2\right)+t_j,\ \ j=1,2.$ Adding up the individual budget constraints yields region j's resource constraint

$$n_j x_j + t_j k_j\left(\rho_j\left(t_1,t_2\right)\right)=f_j\left(k_j\left(\rho_j\left(t_1,t_2\right)\right)\right) + r\left(t_1,t_2\right)\left(K_j - k_j\left(\rho_j\left(t_1,t_2\right)\right)\right)+n_j\tau_j. \quad (1b)$$

Let g_j denote region j's expenditure in the provision of pollution abatement. Since each regional government must balance its budget, we have

$$g_j = t_j k_j\left(\rho_j\left(t_1,t_2\right)\right),\quad j=1,2. \quad (1c)$$

Equations (1c) enable us to express the regional pollution abatement expenditures as functions of the capital tax rates, $g_j\left(t_1,t_2\right)\equiv t_j k_j\left(\rho_j\left(t_1,t_2\right)\right)$, $j=1,2$. It follows that

$$\partial g_j/\partial t_j = k_j\left(.\right)+t_j k_j'\left(.\right)\left[1+\partial r/\partial t_j\right] \quad (1d)$$

where $t_j k_j'(.)\left[1+\left(\partial r/\partial t_j\right)\right] < 0,\ \ j=1,2.$

$$\partial g_j/\partial t_m = t_j k_j'(.)\left(\partial r/\partial t_m\right) > 0, \quad (1e)$$

$$j,m=1,2,\ \ j\neq m.$$

These conditions demonstrate that any increase in a region's capital tax rate causes an outflow of capital to the other region. Therefore, the regions are tempted to set low capital tax rates in order to increase the total capital supply in the region. These results are standard in the literature (see, e.g., Wilson (1986) and Wildasin (1989)).

We use the budget constraint for the representative resident to define $x_j\left(t_1,t_2,\tau_j\right)\equiv \tau_j + \left[f_j\left(k_j\left(\rho_j\left(t_1,t_2\right)\right)\right)+r\left(t_1,t_2\right)K_j - \rho_j\left(t_1,t_2\right)k_j\left(\rho_j\left(t_1,t_2\right)\right)\right]/n_j,\ \ j,m=1,2,\ \ j\neq m$. It follows that

$$\partial x_j/\partial \tau_j = 1 \text{ and } \partial x_j/\partial \tau_m = 0,\qquad j,m=1,2,\ j\neq m, \quad (1f)$$

$$\partial x_j/\partial t_j = \left[\left(\partial r/\partial t_j\right)\left(K_j - k_j\left(\rho_j\left(t_j,t_m\right)\right)\right) - k_j\left(\rho_j\left(t_j,t_m\right)\right)\right]/n_j,\ j=1,2, \quad (1g)$$

$$\partial x_j/\partial t_m = \left[\left(\partial r/\partial t_m\right)\left(K_j - k_j\left(\rho_j\left(t_j,t_m\right)\right)\right)\right]/n_j,\ j,m=1,2,\ \ j\neq m. \quad (1h)$$

Equations (1f) tell us that the consumption of the numeraire good of the representative resident of region j varies at one-to-one rate with the federal interregional income transfer.

Let us now discuss the interregional spillovers caused by transboundary pollution. Emissions of sulfur dioxide produce acidic rain and emissions of carbon dioxide produce an increase in the global temperature and ocean acidification, among other things.[4)] Acid rain damages depend, among other things, on wind patterns and the (ground) resources (e.g., rivers, fish, fauna, infrastructure) available in a particular region. Climate change damages are solely associated with (health, biodiversity, hurricane, ocean acidification, etc.) damages caused by higher levels of carbon dioxide in the atmosphere.

The regional governments may use a coarse abatement technology to simultaneously abate emissions of the two types of air pollutants. The technology produces g_j units of pollution abatement utilizing the numeraire good as an input. Note that we assume that it takes one unit of the numeraire good to produce one unit of pollution abatement, since g_j is the total pollution abatement expenditure in region j.

In the absence of pollution abatement, the ground-level environmental quality in region j is $L_j = Z_j - \alpha_{jj} S_j - \alpha_{mj} S_m$, where $Z_j > 0$ is the ground-level environmental quality that nature provides to residents of the region in the absence of acidic deposition and $\alpha_{jj} S_j + \alpha_{mj} S_m$ is the total amount of acidic deposition in the region, for $\alpha_{jj} \in (0,1)$ and $\alpha_{mj} \in (0,1)$, $j, m = 1, 2$, $j \neq m$. Thus, region j suffers from acidic deposition, which is in part caused by its own sulfur dioxide emission (i.e., the domestic component) and in part caused by the other region's sulfur dioxide emission (i.e., the transboundary or imported component). Note that $\alpha_{11} + \alpha_{12} = 1$ and $\alpha_{22} + \alpha_{21} = 1$ that we allow for asymmetric transboundary sulfur dioxide depositions because we do not impose the restriction that $\alpha_{12} = \alpha_{21}$. In the absence of pollution abatement, the domestic and imported components of the acidic deposition in a region depend on regional sulfur emission levels and on exogenous wind patterns. The latter determine α_{11} and α_{22}.

By employing the coarse abatement technology and producing g_j units of pollution abatement, regional government j can reduce its sulfur emission by $\phi(g_j)$ units, where we assume that $\phi(0) = 0$, $\phi' > 0$ and $\phi'' < 0$ for all $g_j > 0$ and $\lim_{g_j \to 0} \phi'(g_j) = \infty$.[5] Hence, $L_j(g_j, g_m) = Z_j - \alpha_{jj}[S_j - \phi(g_j)] - \alpha_{mj}[S_m - \phi(g_m)]$ is region j's ground-level quality when region j provides g_j units of pollution abatement.

Let $Y > 0$ denote the climate quality level in the absence of carbon dioxide emissions and $C \equiv C_1 + C_2$ denote the total amount of carbon dioxide emitted in the federation. The climate quality in the presence of carbon emissions is $Q(G) = Y + G - C$, where $G \equiv g_1 + g_2$ denotes the total quantity of carbon dioxide abatement in the economy.

The utility of an individual who resides in region j is $U_j(x_j, g_j, g_m) \equiv \Phi(x_j, L_j(.), Q(.))$, where x_j represents the quantity of the composite private good consumed by the individual. We assume that $\Phi(.)$ is quasi-concave. This function increases at a non-increasing rate in x_j, A and B. In order to allow for income effects, we assume that consumption of numeraire good and consumption of climate quality are complementary activities; namely, $\Phi_{xA} \equiv \partial^2\Phi / \partial x \partial A > 0$. Since the coarse abatement technology implies that the regional *production* of climate quality and ground-level quality are complementary activities and this complementarity is one of the crucial elements of our analysis, we will keep complementarities in consumption to a minimum and thus assume that $\Phi_{xB} = \Phi_{AB} = 0$. The last assumptions imply that the utility function $\Phi(.)$ is strongly separable in consumption of ground-level quality.

In keeping with most of the literature, we assume that each regional government is benevolent. Letting R_j denote the welfare level in region j, we postulate that $R_j \equiv n_j U_j$. We assume that the utility function is conditionally transferable.[6] A conditionally transferable utility function allows utility to be transferred across players, just like a quasi-linear utility function, but it also allows for income effects (unlike quasi-linear utility functions). Since most public goods appear to be normal goods, the conditionally transferable utility function is particularly appealing and appropriate. There is no loss in generality in considering the transferable utility function, $U_j(.) \equiv x_j A(Q(G)) + B(L_j(g_j, g_m))$ in what follows.

The central government is in charge of

interregional redistribution. The center possesses a general Bergson-Samuelson social welfare function. The center's utility is $W(R_1, R_2)$. We assume that this function is strictly concave, twice continuously differentiable and satisfies the following conditions: $W_j > 0$, $W_{jj} < 0$, $W_{jm} \geq 0$, where $W_j \equiv \partial W / \partial R_j, W_{jm} \equiv \partial^2 W / \partial R_j \partial R_m$ and $W_{jj} \equiv \partial^2 W / \partial R_j^2$, $j, m = 1,2$, $j \neq m$. The center possesses an income tax instrument, which it can use to tax and redistribute income across regions. Let τ_j denote the income transfer received (if positive) or paid (if negative) by a resident in region j. The interregional income transfer constraint faced by the center is $\sum_{j=1}^{2} n_j \tau_j = 0$.

Having examined abatement technological constraints, environmental quality levels and utility functions, let us now turn to the production of the composite numeraire good in the federal economy.

3 The Center's Most Preferable Allocation

In this section, we consider the center's most preferable allocation. This is the socially optimal allocation, which serves as our benchmark. For comparison purposes, we assume that the center must also utilize capital taxes to finance provision of pollution abatement in each region. The center chooses $\{t_j, \tau_j\}_{j=1,2}$ to maximize $W(R_1, R_2)$ subject to:

$$\sum_{j=1}^{2} n_j \tau_j = 0. \tag{2a}$$

To facilitate future comparisons, we solve the center's maximization problem in two steps. First, we assume that the center chooses $\{\tau_j\}_{j=1,2}$ to maximize $W(R_1, R_2)$ subject to (2a) for fixed regional capital tax rates. This allows us to obtain the socially optimal interregional transfer levels as functions of the capital tax rates. We then plug the optimal income transfer functions into the social welfare function and optimize with respect to the regional capital tax rates.

Let λ be the Lagrangian multiplier associated with constraint (2a). Since $R_j = n_j \left[x_j \left(t_1, t_2, \tau_j \right) A\left(Q\left(G\left(t_1, t_2\right)\right)\right) + B\left(L_j\left(g_j\left(t_1, t_2\right), g_m\left(t_1, t_2\right)\right)\right)\right]$, where $G(t_1, t_2) \equiv g_1(t_1, t_2) + g_2(t_1, t_2)$, the first order conditions in the first step are the constraint (2a) and the following equations, for $j = 1,2$:

$$W_j \left(\partial R_j / \partial x_j \right) = \lambda n_j \;\Rightarrow \tag{2b}$$

$$W_j A\left(Q(G)\right) = \lambda \;\Rightarrow\; W_1 = W_2$$

Equation (2b) is implied by equation (1f). According to equation (2b), the center's optimal redistribution scheme equalizes the social marginal utilities of income. Equations (2a) and (2b) define $\tau_j(t_1, t_2)$, $j = 1,2$. Let us $R_j(t_1, t_2) \equiv n_j \left[x_j(t_1, t_2) A\left(Q(G)\right) + B\left(L_j\left(g_j(t_1, t_2), g_m(t_1, t_2)\right)\right)\right]$, $j, m = 1, 2$, $j \neq m$, and $x_j(t_1, t_2) \equiv x_j\left(t_1, t_2, \tau_j(t_1, t_2)\right)$, $j = 1,2$.

Plugging $\tau_j(t_1, t_2)$, $j = 1, 2$, into equation (2a) and differentiating the implied expression with respect to t_j yields

$$\sum_{i=1}^{2} n_i \left(\partial \tau_i / \partial t_j \right) = 0. \tag{2c}$$

The center now chooses $\{t_j\}_{j=1,2}$ to maximize $W\left(R_1(t_1, t_2), R_2(t_1, t_2)\right)$. The first order conditions are

$$\sum_{i=1}^{2} W_i \left(\frac{\partial R_i}{\partial \tau_i} \frac{\partial \tau_i}{\partial t_j} + \frac{\partial R_i}{\partial t_j} \right) = 0, \quad j = 1, 2. \tag{2d}$$

where

$$\frac{\partial R_i}{\partial \tau_i} \frac{\partial \tau_i}{\partial t_j} = n_i A\left(Q(G)\right) \frac{\partial \tau_i}{\partial t_j}, \qquad i, j = 1,2, \tag{2e}$$

$$\frac{\partial R_i}{\partial t_j} = n_i A\left(Q(G)\right) \left(\frac{\partial x_i}{\partial t_j} \right) + n_i x_i A'\left(Q(G)\right) \left(\frac{\partial G}{\partial t_j} \right) + n_i B'(L_i) \sum_{m=1}^{2} \alpha_{mi} \phi'(g_m) \left(\frac{\partial g_m}{\partial t_j} \right), \; i, j = 1,2. \tag{2f}$$

Since $\sum_{i=1}^{2} k_i\left(\rho_i(t_1, t_2)\right) = K$ and $W_1 = W_2 > 0$, substituting equations (1f)-(1h), (2e) and (2f) into equations (2d) yields

$$\frac{1}{A(Q)}\left\{\sum_{i=1}^{2}\sum_{h=1}^{2}\left[n_h x_h A'(Q)+n_h B'\right.\right. \tag{2g}$$

$$\left.\left.(L_h)\alpha_{ih}\phi'(g_i)\right]\left(\frac{\partial g_i}{\partial t_j}\right)\right\}=k_j-\sum_{i=1}^{2}n_i\left(\frac{\partial \tau_i}{\partial t_j}\right),\ j=1,2.$$

Combining equations (2c) and (2g), we obtain:

$$\frac{1}{A(Q)}\left\{\sum_{i=1}^{2}\sum_{h=1}^{2}\left[n_h x_h A'(Q)+\right.\right. \tag{2h}$$

$$\left.\left.n_h B'(L_h)\alpha_{ih}\phi'(g_i)\right]\left(\frac{\partial g_i}{\partial t_j}\right)\right\}=k_j,\ j=1,2.$$

Equations (2h) are modified Samuelson conditions. The conditions show the equalization of the sum of the marginal rates of substitution between pollution abatement and numeraire and the marginal social cost, which is the rate which capital is sacrificed for the provision of the regional pollution abatement products. The marginal rates of substitution between pollution abatement and numeraire contain two components, one which gives us the marginal social benefit of improving air quality and another which gives us the marginal social benefits of improving ground-level environmental quality in both regions. The socially optimal allocation is characterized by equations (1b), (1c), (2a), (2b) and (2h). We use equation (2b) as our benchmark for equity and equation (2h) as our benchmark for efficiency.

4 Federal Policy Game

We are now ready to consider federal policy making. There are three policy games: simultaneous policy making, decentralized leadership and centralized leadership. We compare each equilibrium allocation with the center's most preferable allocation. Our analysis will enable us to clearly demonstrate the effects produced by the timing in federal policy making on efficiency and equity.

4.1 Simultaneous Policy Making

Suppose that the game played by the center and regional governments is of imperfect information. In other words, the players make simultaneous choices, taking each other's choice as given. In this simultaneous game, the central government chooses $\{\tau_j\}_{j=1,2}$ to maximize $W(R_1, R_2)$ subject to constraint (2a) and $x_j(\tau_j;t_1,t_2)$, $j=1,2$, taking $\{t_j\}_{j=1,2}$ as given.

Each regional authority chooses $\{t_j\}$ to maximize R_j subject to $x_j(t_j;t_m,\tau_j)$ and $g_j(t_1,t_2)$, taking $\{\tau_j, t_m\}_{j=1,2}$ as given, $j,m=1,2$ and $j\neq m$. Since the center's problem is identical to the problem it solved in section 3 except that here it does not control the regional policies, the solution for the center's maximization problem is given by equations (2a) and (2b).

Let us now consider the equilibrium allocation implied by the regions' maximization problems. The first order conditions are

$$\frac{\partial R_j}{\partial t_j}=n_j A(Q)\left(\frac{\partial x_j}{\partial t_j}\right)+\sum_{i=1}^{2}\left[n_j x_j A'(Q)+n_j\right. \tag{3a}$$

$$\left.B'(L_j)\alpha_{ij}\phi'(g_i)\right]\left(\frac{\partial g_i}{\partial t_j}\right)=0,\ j=1,2.$$

Inserting equation (1g) into equations (3a), we obtain

$$\frac{1}{A(Q)}\left\{\sum_{i=1}^{2}\left[n_j x_j A'(Q)+n_j B'(L_j)\alpha_{ij}\phi'(g_i)\right]\right. \tag{3b}$$

$$\left.\left(\frac{\partial g_i}{\partial t_j}\right)\right\}=k_j-(K_j-k_j)\frac{\partial r}{\partial t_j},\ j=1,2.$$

Pollution abatement products are determined according to conditions (3b). In each region, the rule equalizes the regional marginal rates of substitution between pollution abatement and numeraire and the regional marginal cost. Equations (3b) clearly demonstrate that the regional governments ignore interregional spillovers. This fact leads each region to under-provide pollution abatement.

In sum, the equilibrium allocation for the simultaneous game is characterized by equations, (1b), (1c), (2a), (2b) and (3b). Comparing this allocation with the socially optimal allocation leads us to the following conclusion:

Proposition 1. *The equilibrium for the simultaneous game is characterized by socially optimal redistribution and fully decentralized capital tax policies. Therefore, the allocation is socially equitable but inefficient.*

The center finds it desirable to intervene in the federal setting with simultaneous policy making because it has a strong taste for equity, as captured by the decreasing marginal social utilities of income. Thus, although the equilibrium for the simultaneous policy game examined here is not socially optimal, it represents an improvement in social welfare relative to a situation in which the center does not intervene. The latter would follow, for example, if the structure of the federal system was completely decentralized, with each regional government also being in charge of promoting intra-regional income transfers.

4.2 Decentralized Leadership

In this section, we show that federal policy making under decentralized leadership represents a social improvement relative to simultaneous federal policy making. The sequential game is as follows:

Stage 1: Regional government j chooses nonnegative $\{t_j\}$ to maximize $R_j(t_1,t_2)$ taking the choices of all other regional government as given, $j=1,2.$

Stage 2: The center observes regional policy choices and then chooses nonnegative $\{\tau_j\}_{j=1,2}$ to maximize $W\left(R_1(t_1,t_2), R_2(t_1,t_2)\right)$ subject to the federation's resource constraint (2a).

The equilibrium concept for the two-stage game is subgame perfection.

Applying backward induction, we first consider the second stage of the game. Since the center's problem is identical to the problem it solved in section 3 except that here it does not control the regional policies, the solution in the second stage is given by equations (2a) and (2b). The center's best response functions are $\tau_j(t_1,t_2)$, $j=1,2$. Inserting the center's best response functions into equations (2a) and (2b), we have

$$\sum_{j=1}^{2} n_j \tau_j(t_1,t_2)=0, \tag{4a}$$

$$W_1\left(R_1(t_1,t_2), R_2(t_1,t_2)\right)= W_2\left(R_1(t_1,t_2), R_2(t_1,t_2)\right). \tag{4b}$$

We now consider the equilibrium allocation for the first stage. The first order conditions are as follows for $j=1,2$:

$$\frac{\partial R_j}{\partial t_j}=n_j A(Q)\left(\frac{\partial x_j}{\partial t_j}+\frac{\partial x_j}{\partial \tau_j}\frac{\partial \tau_j}{\partial t_j}\right)+ \sum_{i=1}^{2}\left[n_j x_j A'(Q)+n_j B'(L_j)\alpha_{ij}\phi'(g_i)\right]\left(\frac{\partial g_i}{\partial t_j}\right)=0. \tag{4c}$$

Differentiating equations (4a) and (4b) with respect to $\{t_j\}_{j=1,2}$ yields equations (2c) and

$$\left(W_{11}-W_{12}\right)\left(\partial R_1/\partial t_j\right)= \left(W_{22}-W_{12}\right)\left(\partial R_2/\partial t_j\right),\quad j=1,2. \tag{4d}$$

Since $(W_{mm}-W_{jm})<0$ and $(\partial R_j/\partial t_j)=0$, $j,m=1,2$ and $j\neq m$, equations (4d) imply

$$\frac{\partial R_m}{\partial t_j}=n_m A(Q)\left(\frac{\partial x_m}{\partial t_j}+\frac{\partial x_m}{\partial \tau_m}\frac{\partial \tau_m}{\partial t_j}\right)+ \sum_{i=1}^{2}\left[n_m x_m A'(Q)+n_m B'(L_m)\alpha_{im}\phi'(g_i)\right]\left(\frac{\partial g_i}{\partial t_j}\right)=0. \tag{4e}$$

Adding up equations (4c) and (4e) yields

$$\frac{1}{A(Q)}\left\{\sum_{i=1}^{2}\sum_{h=1}^{2}\left[n_h x_h A'(Q)+n_h B'(L_h)\alpha_{ih}\phi' \right.\right. \tag{4f}$$

$$(g_i)]\left(\frac{\partial g_i}{\partial t_j}\right)\Bigg\} = k_j - \sum_{i=1}^{2} n_i\left(\frac{\partial \tau_i}{\partial t_j}\right), \ j=1,2.$$

Combining equations (4a) and (4f), we obtain:

$$\frac{1}{A(Q)}\left\{\sum_{i=1}^{2}\sum_{h=1}^{2}[n_h x_h A'(Q) + n_h B'(L_h)\alpha_{ih}\phi' \right. \qquad (4g)$$

$$\left.(g_i)]\left(\frac{\partial g_i}{\partial t_j}\right)\right\} = k_j, \ j=1,2.$$

The equilibrium allocation for the decentralized leadership is characterized by equations (1b), (1c), (2a), (2b) and (4g).

Proposition 2. *The subgame perfect equilibrium for the decentralized leadership game corresponds to the center's most preferred allocation.*

Proposition 2 follows from the fact that the redistributive policy implemented by the center provides the forward-looking regional governments with incentives to internalize all externalities. To see this, consider the center's optimal redistribution rule (4b): $W_1(R_1,R_2) = W_2(R_1,R_2)$. This condition can be used to express the welfare level of region 1 as an implicit function of the welfare level of region 2 (or vice-versa). Let $R_1 \equiv \Psi(R_2)$, where $\Psi(\cdot)$ is the implicit function. Then, the center's optimal redistribution rule can be rewritten as $W_1(\Psi(R_2),R_2) = W_2(\Psi(R_2),R_2)$. Differentiating this equation with respect to R_2 yields $\Psi'(R_2) = (W_{22}-W_{12})/(W_{11}-W_{21}) > 0$, since $W_{jj} < 0$ and $W_{jm} = W_{mj} \geq 0, \ j,m = 1,2, \ j \neq m.$ Thus, the center's optimal redistribution rule implies that one region's welfare level is an increasing function of the other region's welfare level. Knowing that the optimal redistributive rule will align regional welfare levels in the second stage, it is rational for each regional government in the first stage to choose the capital tax rate that internalizes all externalities.

4.3 Centralized Leadership

Suppose now that the center is the Stackelberg leader and the regions are the Stackelberg followers. Applying backward induction, we first consider the second stage of the game. Since the region's problem is identical to the problem it solved in section 4.1, the equilibrium conditions for regions' maximization problems are characterized by equations (1b), (1c) and (3b) provided the solutions are interior.

Let $t_j(\tau_1,\tau_2)$, $j=1,2$, denote the regional optimal policy responses. Let us define $g_j(\tau_1,\tau_2) \equiv g_j(t_1(\tau_1,\tau_2),t_2(\tau_1,\tau_2))$, $k_j(\tau_1,\tau_2) \equiv k_j(\rho_j(t_1(\tau_1,\tau_2),t_2(\tau_1,\tau_2)))$, $U_j(\tau_1,\tau_2) \equiv x_j(\tau_1,\tau_2)A(Q(G(\tau_1,\tau_2))) + B(L_j(g_j(\tau_1,\tau_2),g_m(\tau_1,\tau_2)))$, $G(\tau_1,\tau_2) \equiv g_1(\tau_1,\tau_2) + g_2(\tau_1,\tau_2)$ and $R_j(\tau_1,\tau_2) \equiv n_j U_j(\tau_1,\tau_2)$, $j=1,2$.

In the first stage of the game, the center chooses $\{\tau_j\}_{j=1,2}$ to maximize $W(R_1(\tau_1,\tau_2),R_2(\tau_1,\tau_2))$ subject to the federation's resource constraint (2a) and the regional tax policy responses. The first order condition of the first stage is

$$\sum_{i=1}^{2} W_i\left(\frac{\partial R_i}{\partial \tau_j} + \sum_{h=1}^{2}\frac{\partial R_i}{\partial t_h}\frac{\partial t_h}{\partial \tau_j}\right) = \lambda n_j > 0, \ j=1,2. \quad (5a)$$

Because $\partial R_j/\partial \tau_j = n_j A(Q)$, $j=1,2$, and $\partial R_i/\partial \tau_j = 0$, $i,j=1,2$, $i \neq j$, equations (5a) imply after some algebra

$$W_1 A(Q) + \left(W_1\frac{\partial R_1}{\partial t_1} + W_2\frac{\partial R_2}{\partial t_1}\right)\left(\frac{1}{n_1}\frac{\partial t_1}{\partial \tau_1} - \frac{1}{n_2}\frac{\partial t_1}{\partial \tau_2}\right) \quad (5b)$$

$$= W_2 A(Q) + \left(W_1\frac{\partial R_1}{\partial t_2} + W_2\frac{\partial R_2}{\partial t_2}\right)\left(\frac{1}{n_2}\frac{\partial t_2}{\partial \tau_2} - \frac{1}{n_1}\frac{\partial t_2}{\partial \tau_1}\right).$$

Substituting equations (3a) into equations (5b) yields,

$$W_1 = W_2 + \left[\frac{W_1}{A(Q)}\frac{\partial R_1}{\partial t_2}\left(\frac{1}{n_2}\frac{\partial t_2}{\partial \tau_2} - \frac{1}{n_1}\frac{\partial t_2}{\partial \tau_1}\right) - \right. \quad (5c)$$

$$\left.\frac{W_2}{A(Q)}\frac{\partial R_2}{\partial t_1}\left(\frac{1}{n_1}\frac{\partial t_1}{\partial \tau_1} - \frac{1}{n_2}\frac{\partial t_1}{\partial \tau_2}\right)\right].$$

Differentiating equations (3a) with respect to $\{\tau_j\}_{j=1,2}$ yields

$$\begin{bmatrix} \frac{\partial^2 R_j}{\partial t_j^2} & \frac{\partial^2 R_j}{\partial t_j \partial t_m} \\ \frac{\partial^2 R_m}{\partial t_m \partial t_j} & \frac{\partial^2 R_m}{\partial t_m^2} \end{bmatrix} \begin{bmatrix} \frac{\partial t_j}{\partial \tau_j} \\ \frac{\partial t_m}{\partial \tau_j} \end{bmatrix} = \begin{bmatrix} -\frac{\partial^2 R_j}{\partial t_j \partial \tau_j} \\ 0 \end{bmatrix}. \tag{5d}$$

By using Cramer's Rule, we obtain

$$\frac{\partial t_j}{\partial \tau_j} = -\frac{1}{\Delta}\left[\frac{\partial^2 R_j}{\partial t_j \partial \tau_j}\frac{\partial^2 R_m}{\partial t_m^2}\right] \text{ and} \tag{5e}$$

$$\frac{\partial t_m}{\partial \tau_j} = \frac{1}{\Delta}\left[\frac{\partial^2 R_j}{\partial t_j \partial \tau_j}\frac{\partial^2 R_m}{\partial t_m \partial t_j}\right]$$

where $\Delta \equiv \frac{\partial^2 R_j}{\partial t_j^2}\frac{\partial^2 R_m}{\partial t_m^2} - \frac{\partial^2 R_j}{\partial t_j \partial t_m}\frac{\partial^2 R_m}{\partial t_m \partial t_j}$, $j,m = 1,2$ and $j \neq m$. Substituting equations (5e) into equations (5c), we have

$$W_1 = W_2 + \frac{1}{A(Q)\Delta} \tag{5f}$$

$$\left\{ W_2 \frac{\partial R_2}{\partial t_1}\left(\frac{1}{n_1}\frac{\partial^2 R_1}{\partial t_1 \partial \tau_1}\frac{\partial^2 R_2}{\partial t_2^2} + \frac{1}{n_2}\frac{\partial^2 R_2}{\partial t_2 \partial \tau_2}\frac{\partial^2 R_1}{\partial t_1 \partial t_2}\right)\right.$$

$$\left. -W_1 \frac{\partial R_1}{\partial t_2}\left(\frac{1}{n_2}\frac{\partial^2 R_2}{\partial t_2 \partial \tau_2}\frac{\partial^2 R_1}{\partial t_1^2} + \frac{1}{n_1}\frac{\partial^2 R_1}{\partial t_1 \partial \tau_1}\frac{\partial^2 R_2}{\partial t_2 \partial t_1}\right)\right\}.$$

Equation (5f) clearly demonstrates that the center's interregional income transfer policy does not generally achieve the socially equitable goal of equalizing social marginal utilities of income. The policy rule implicit in equation (5f) balances the two objectives the center attempts to achieve; namely, equity and efficiency. Since the center knows that its redistribution policy influences the regions' tax policies, it finds it optimal to deviate from the socially equitable goal of equalizing social marginal utilities of income. Had redistribution policy been unable to influence the regions' tax policies, the center would have chosen to equalize social marginal utilities of income. The implied allocation would have been identical to the equilibrium allocation we obtained in the setting in which the center and the regions make simultaneous choices. Thus, the center's redistributive policy would have been neutral.

We gather the results we obtained in the paper in the following proposition.

Proposition 3. *The subgame perfect equilibrium for the centralized leadership game is generally socially inequitable and inefficient. The allocation differs from the subgame perfect equilibrium for the decentralized leadership game and from the Nash equilibrium for the simultaneous game played by the center and the regions. The center's redistributive policy is generally non-neutral.*

5 Conclusion

Following early and recent contributions to two important branches of the fiscal federalism literature, on transboundary pollution control and interregional tax competition, this paper makes contributions to each branch by demonstrating that efficient control of transboundary pollutants may be achieved even if regional governments do not have lump-sum taxes at their disposal and have thus to resort to tax schemes such as capital taxation that sacrifice some critical resources.

When capital taxes must be utilized, we show that tax competition is not necessarily wasteful, relative to what a fully coordinated system would accomplish, and that decentralized leadership may socially dominate alternative federal policy structures. A federal system characterized by decentralized leadership may be socially optimal, while federal systems characterized by centralized leadership or by simultaneous policy making cannot be. We show that simultaneous federal policies effectively implement socially optimal redistribution but cannot prevent distortions in the uncoordinated choices of capital taxes. We also show that federations characterized by centralized leadership do not set socially optimal redistribution rules or capital taxes. The redistributive transfers, however, are non-neutral. One of the implications of our analysis, therefore, is that the prevalent system adopted in the European Union may be superior to its alternatives and that much more attention should be devoted to its efficiency and equity properties.

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[1] For a detailed description of the EU ETS, see http://ec.europa.eu/clima/policies/ets/index_en.htm.

[2] See http://change.gov/agenda/energy_and_environment_agenda/.

[3] For a detailed history of measures undertaken by the European Union to reduce harmful tax competition, see http://ec.europa.eu/taxation_customs/taxation/company_tax/harmful_tax_practices/index_en.htm.

[4] See Caplan and Silva (2005) for an early model that examines emissions of correlated air pollutants.

[5] The Inada conditions guarantee that $g_j > 0$ in every equilibrium considered in this paper.

[6] See Bergstrom (1989).

References

Bergstrom, T. C. (1989) "A Fresh Look at the Rotten Kid Theorem - And Other Household Mysteries," *Journal of Political Economy* 97(5), 1138-1159.

Caplan, A.J. and E.C.D. Silva (1999) "Federal Acid Rain Games," *Journal of Urban Economics* 46, 25-52.

Caplan, A.J. and E.C.D. Silva (2005) "An Efficient Mechanism to Control Correlated Externalities: Redistributive Transfers and the Coexistence of Regional and Global Pollution Permit Markets," *Journal of Environmental Economics and Management* 49, 66-82.

Chirinko, R.S. and D.J. Wilson (2011) "Tax Competition among U.S. States: Racing to the Bottom or Riding on a Seesaw?," CESIfo Working Paper No. 3535.

Cremer, H. and F. Gahvari (2004) "Environmental Taxation, Tax Competition and Harmonization," *Journal of Urban Economics* 55, 21-45.

Devereux, M., B. Lockwood and M. Redoano (2007) "Horizontal and Vertical Tax Competition: Theory and Some Evidence from the USA," *Journal of Public Economics* 91, 451-479.

Hadjiyiannis, C., P. Hatzipanayotou and M.S. Michael (2009) "Public Pollution Abatement, Regional Capital Mobility, and Tax Competition," *Southern Economic Journal* 75, 703-719.

Oates, W. (1972) *Fiscal Federalism*. New York: Harcourt Brace Jovanovich.

Silva, E.C.D. and A.J. Caplan (1997) "Transboundary Pollution Control in Federal Systems," *Journal of Environmental Economics and Management* 34, 173-186.

Tiebout, C.M. (1956) "A Pure Theory of Local Expenditures," *Journal of Political Economy* 64, 416-424.

Wildasin, D.E. (1989) "Interjurisdictional Capital Mobility: Fiscal Externality and a Corrective Subsidy," *Journal of Urban Economics* 25, 193-212.

Wilson, J.D. (1986) "A Theory of Interregional Tax Competition," *Journal of Urban Economics* 19, 296-315.

Wilson, J.D. (1999) "Theories of Tax Competition," *National Tax Journal* 52, 269-304.