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Heterogeneous preferences, atmospheric externalities, and environmental taxation

Marcelo Arbex (University of Windsor)
Christian Trudeau (University of Windsor)

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Marcelo Arbex* and Christian Trudeau†

Abstract

We model a federation of two jurisdictions where agents value consumption vs. nature differently. Consumption obtained through pollution-inducing production also generate a negative externality on neighbors. When regions are heterogeneous, we show that even with a decentralized policy we can obtain first-best efficiency by choosing a combination of pollution taxes in both regions and lump-sum transfers. We show that optimal pollution taxes are determined only by the externality parameters. For Cobb-Douglas preferences, the optimal transfer also depend on the initial stocks of nature, but not on preference parameters. Numerically we explore further the relationship among preferences for consumption versus nature, pollution externality and government policies.

Keywords: Externalities, environmental preferences, optimal taxation.

JEL Classification: D62; H23; H87; Q58.

*,† Department of Economics, University of Windsor, 401 Sunset Avenue, Windsor, ON, N9B 3P4, Canada. Email: arbex@uwindsor.ca. † *Corresponding Author;* Email: trudeauc@uwindsor.ca. We thank Maria Galego, Marcelin Joanis, Marcel Oestreich, Emilson Silva, Tracy Snoddon and participants at the 2015 CEA Meetings for helpful comments and discussions. We retain responsibility for any errors. A previous version circulated as "Heterogeneous preferences for environmental quality, decentralized policy and first-best efficiency".

1 Introduction

We study a two-region federation model where jurisdictions face trade-offs between consumption, obtained through pollution-generating economic activities, and the quality of the environment. Pollution not only damages the local environment, but also creates negative externalities on neighbors. We view environmental externalities as generators of public "bads", along the lines of Meade's (1952) concept of "atmospheric externalities" (Sandmo, 2011). This paper investigates how heterogeneity with respect to externalities (pollution), endowment of nature and agents' preferences for nature quality shape environmental policy interventions in the context of a federation.

The population in different jurisdictions may value the environment differently, or be willing to make different economic choices to preserve environmental quality. In our economy, regions are heterogeneous in three aspects: households preferences for consumption versus nature quality, initial endowment of nature and degree of environmental damage spillovers. A central government, in the spirit of a federation, maximizes the welfare by choosing two policies: a lump-sum transfer and a pollution tax.

Intervention by the central government can reduce the effect of externalities and allow for redistribution. In fact, the choice of instruments by the central government in our model mirrors those available in practice to federations, where there usually exists transfer mechanisms that may depend on the economic decisions of each jurisdictions. The lump-sum transfers and pollution tax are designed such that they generate no net revenues for the central government: the lump-sum transfer is from one region to the other, irrespective of the economic decisions taken by the jurisdictions, while the pollution tax has built-in liability, with the polluter compensating its neighbor.[1]

We show that when regions are heterogeneous in all three dimensions, i.e., nature endowment, damage spillovers and valuation of consumption vs. nature, we can achieve first-best efficiency by using both policies together, that is, pollution tax rates tailored for each region and a lump-

[1] For alternative federal, inter-jurisdictional settings see, for instance, Boadway, Song and Tremblay (2013) and Silva and Caplan (1997). The assumption that the central government returns all proceeds of its policies is particularly realistic if we think of supra-national agreements or cases where revenues originating from pollution policies are earmarked to compensate regions that have been polluted (Millock and Nauges, 2006).

sum transfer. The optimal pollution tax rates are determined only by the externality parameters (Pigouvian taxation). It aims to charge a jurisdiction with the social cost of their consumption, and its tax rate is thus increasing in the damage it causes on its neighbor.

We then turn our attention to Cobb-Douglas preferences, which allows us to completely describe the equilibrium. A striking result is that the optimal lump-sum transfer does not depend on preference parameters, something that is not true for arbitrary preferences. This is a major advantage. In an imperfect information version of the game where the preferences of the jurisdictions would be private information, strategy-proofness would follow immediately: jurisdictions would have no incentives to misreport their preferences and, in fact, the federation does not even need to know them.

We find that the optimal transfer is affected by each region's endowment of nature and the degree of environmental damage spillovers. Lump-sum transfers in our economy play a redistributive role and are larger the higher is the difference in the nature endowment of the regions. The lump-sum transfer of units of consumption is conceptually equivalent to the (unfeasible) transfer of units of nature from one region to another. If regions were homogenous with respect to their production damage spillover, it would be optimal to transfer resources in a lump-sum manner from the high nature endowment region to the region with the low nature endowment. Interestingly, as preferences do not affect optimal policies, the fact that a region prefers consumption or nature has no impact on its chance to pay or receive the lump-sum transfer. If the jurisdictions have different externality rates, the planner adjusts the stock of nature for these externality parameters before transferring consumption from the region with the large adjusted stock of nature to its neighbor. If both regions have the same adjusted stock of nature, the optimal transfer is zero, as the planner has no redistributive concerns to make transfers.

Recently, environmental awareness has reignited the debate about alternative policies to reduce environmentally damaging activities. Science and the economics related to pollution control have advanced to the point where regulations can now move from cost effectiveness to efficiency (Muller and Mendelsohn, 2009). Environmental damage can be viewed as an externality problem, which potentially calls for public intervention to limit harmful emissions (Jones, Keen and Strand, 2013).

There is an extensive literature dedicated to alternative policies, for instance, carbon taxation, cap-and-trade, tradable permits, and regulations related to pollution control (Montgomery 1972; Tietenberg 1980; Baumol and Oates 1988). However, the administrative implications of such measures differ markedly.[2] Muller and Mendelsohn (2009) argue that environmental policy could be designed to account for how the degree of environmental damage and spillovers (pollution externalities) varies across space. Moreover, the real world is very heterogeneous with respect to natural resources endowments, environmental consciousness and in the way agents are willing to trade consumption for improved environmental quality. Knowing about such information can be, in practice, a major hurdle for regulators and policymakers. And, households are not burdened equally by different policy interventions. For instance, the most-cited distributional effects of environmental policies are intergenerational transfers or transfers between different categories of residents inside the same country (Daubanes and Grimaud, 2010).

The inefficiency of decentralized policymaking has long been established as the norm in theoretical public and environmental economics literature on production efficiency in the face of externalities (Pigou, 1920; Samuelson, 1954). However, Ogawa and Wildasin (2009) find that in a model with heterogeneous jurisdictions and interjurisdictional environmental damage spillovers, such as CO_2 emissions that affect the global environment, decentralized policymaking leads to efficient resource allocation, even in the complete absence of corrective interventions by higher-level governments or coordination of policy. They show that decentralized policymaking can still result in globally efficient allocations, even when preferences and production technologies differ among jurisdictions and governments have information and care only about local environmental impacts. Fell and Kaffine (2014) argue that Ogawa and Wildasin (2009)'s result hinges on the fact that in their model, there is a fixed sum of environmental damages across jurisdictions, and their central result breaks down if the model is modified in ways that make the environmental damage endogenous. Even though in our model the total environmental damage is affected by the policy

[2] Implementing cap-and-trade, for example, requires new functions including determining baselines, allocating emissions rights, and verifying and enforcing compliance. It also raises a novel set of tax issues, many with complex international aspects. Implementing an emissions tax, by contrast, may often seem easier as systems of indirect tax collection, already in place in most countries, can be harnessed. In the context of a large and small open economies, Siddiqui (2015) studies two protection polices, i.e., border tax adjustment and free emissions allocations to emission intensive and trade exposed industries.

choices, the decentralized outcome is still efficient.

There is also a substantial theoretical literature on the effect of externalities on public policies in the study of second-best environmental taxation (de Mooij, 2000; Schwartz and Repetto, 2000; Williams, 2003). These studies uniformly agree that the substitution patterns between the externality, market goods, and labor may be important determinants of the excess burden of a new regulation. Our proposed model has no labor supply or government spending, so these effects are not present. Still, we believe that the main message of our paper would carry over: the combined use of pollution tax and lump-sum transfer generates significant gains of efficiency. We provide, in our setup, examples where, notably, our proposed policy is simpler and easier to implement than a simple pollution tax. For individuals' labor supply decisions under environmental regulations see, for instance, Williams (2002).

There are related papers that analyze environmental taxation policies when agents are heterogeneous in several dimensions. Daubanes and Grimaud (2010) address the taxation of a polluting non-renewable resource in an international, heterogeneous framework, although there are no heterogeneity relative to the environmental concern. They find that even if heterogeneous countries coordinate their taxation policies to correct the global environmental problem, their divergent strategic interests cause another global, non-environmental distortion in the allocation of the resource. Lundin (2001) considers a three-dimensional (earnings ability, household size, and geographical residence of households) tax reforms and shows that a carbon dioxide (CO_2) tax falls more heavily on households characterized by a low level of total expenditures, households with many members and households with limited access to public transport. And, Berliant, Peng and Wang (2014) study a model with two locations and two industries (clean and dirty) where pollution is a by-product of dirty good manufacturing. Their main result implies that taxing pollution with a fixed component independent of dirty good output can cause firm agglomeration. Their fixed cost component of the pollution tax is conceptually very close to our lump-sum transfers. While we do not allow agents to move across jurisdictions, we obtain that pollution (and production) will be concentrated in the regions that do not value nature as highly.

The paper proceeds as follows. Section 2 presents a simple general-equilibrium model that incorporates a household consumption decision along with a pollution externality. We consider two governmental policies: lump-sum transfers and a tax on pollution. We study first-best efficiency and the decentralized problems, solving analytically for the optimal policy instruments. In Section 3, we study the case with Cobb-Douglas preferences, present and discuss comparative statics and finally we conduct several numerical exercises to illustrate our main results and to explore further the relationship between preferences for environmental quality and government policies. Section 4 offers concluding comments and discussion.

2 Preferences for Nature Quality and Optimal Policy

2.1 The Economy

We consider an economy where two jurisdictions $i = 1, 2$ are inhabited by a large number of agents with identical preferences. For convenience we define all variables in per capita terms and consider the case of a constant population. Each region is endowed with an initial environment of quality N_i. That stock of nature is then reduced by environmental damages (i.e., pollution) e_i, which is linked to production: each unit of output produced in jurisdiction i, labelled as Y_i, results in α units of environmental damage there. We normalize $\alpha = 1$. In addition, production in jurisdiction i has a negative externality, i.e., an atmospheric externality, and causes environmental damage in the other jurisdiction. That is, there are environmental spillovers. The degree of environmental damage spillovers from the other jurisdiction is captured by a region specific parameter $\beta_j \in [0, 1]$, so that the environmental damage experienced by region i is given by

$$e_i = Y_i + \beta_j Y_j \tag{1}$$

In our economy, if β_i is positive, local economic activity (as represented by the level of production, Y_i) causes damage not only to the local environment but in other jurisdictions as well; a low value of β_i means that these environmental spillovers are small. Oates and Schwab (1988) assume no interjurisdictional environmental spillovers and environmental quality in any jurisdiction depends only on local economic activity, i.e., $\beta_j = 0$ in equation (1). The analysis of Ogawa and Wildasin (2009) and Fell and Kaffine (2014) are restricted to the case $\beta_1 = \beta_2 = \beta$. The upper limit of $\beta_i = 1$ corresponds to complete or perfect spillovers, where a unit of output produced in jurisdiction i does just as much damage elsewhere as it does locally.

To calculate the cumulative level of environmental damage, we sum across all jurisdictions:

$$\sum_{i=1}^{2} e_i = \sum_{i=1}^{2} (1 + \beta_i) Y_i \tag{2}$$

We do not assume that the sum of the environmental damage is equal to an exogenous constant. In such a case, the planner (e.g., regulator) can only shift environmental damages across jurisdictions, but not reduce aggregate damages. We, hence, depart from Ogawa and Wildason (2009) by allowing the planner to choose (indirectly) the optimal level of environmental damage in each region. The planner can choose from a vast menu of consumption-nature quality allocations. And, its choice is also affected by the heterogeneity of the regions with respect to their preferences for environmental quality and consumption.

The utility function of the representative agent residing in jurisdiction i is denoted as $u_i(c_i, n_i)$, where c_i is the agent's consumption of a private good in jurisdiction i, $n_i = N_i - e_i$ denotes nature quality enjoyed locally, and $0 < \theta_i < 1$ represents the weight put on consumption by the resident in jurisdiction i. We make the usual assumptions on utility functions (differentiable, increasing and strictly quasi-concave functions). We allow for agents in different jurisdictions to have different preferences for nature versus consumption. To make sure that jurisdictions put at least some value, as minimal as it might be, on consumption and nature, θ_i cannot be equal to 0 or 1. Without loss of generality, we suppose that $\theta_1 \geq \theta_2$, meaning that agents in region 2 care at least as much about nature than agents in jurisdiction 1.

2.2 First-best efficiency

Consider a federation where the central government cares equally about agents in both regions and can directly choose production and consumption in both jurisdictions, with the constraint that $c_1 + c_2 \leq Y_1 + Y_2$. Using the fact that $n_i = N_i - Y_i - \beta_j Y_j$, we reexpress the problem in terms of consumption and nature levels, c_i and n_i. Hence, the planner chooses a first-best allocation by solving the following problem:

$$\max_{\{c_1,c_2,n_1,n_2\}} \sum_{i=1}^{2} u_i\left(c_i, n_i\right)$$

under the constraint that

$$c_1 + c_2 \leq \frac{(N_1 - n_1)(1-\beta_1) + (N_2 - n_2)(1-\beta_2)}{1-\beta_1\beta_2}. \tag{3}$$

From the first order conditions of this problem we obtain the following conditions for first-best efficiency:

$$\frac{\partial u_1(c_1,n_1)}{\partial c_1} = \frac{\partial u_2(c_2,n_2)}{\partial c_2} \tag{4}$$

$$\frac{\partial u_1(c_1,n_1)}{\partial n_1}(1-\beta_2) = \frac{\partial u_2(c_2,n_2)}{\partial n_2}(1-\beta_1) \tag{5}$$

$$\frac{\partial u_1(c_1,n_1)}{\partial c_1} = \frac{\partial u_1(c_1,n_1)}{\partial n_1} + \beta_1 \frac{\partial u_2(c_2,n_2)}{\partial n_2} \tag{6}$$

Condition (4) and (5) impose that the marginal utilities for consumption and nature, respectively, are equalized across regions. According to condition (6), the marginal utility for consumption should be equal to the marginal disutility created by the additional pollution it generates. The feasibility constraint, equation (3), must hold with equality. From this system of equations, we can find the first-best optimal allocations c_1^*, c_2^*, Y_1^*, Y_2^*, n_1^* and n_2^*.[3]

2.3 The decentralized problem

Jurisdictions play a game between themselves and with the government. The timing structure of the game is as follows. First, the government announces the value of its policy instruments. Second, with this information households in both jurisdictions determine their productions, which cause externalities for both regions. Finally, given the decisions of the government and private agents, consumption, nature level and welfare are determined. All the parameters $(N_i, \theta_i, \beta_i)_{i=1,2}$

[3] We assume interior solutions throughout the paper.

are common knowledge. We solve the game by backward induction.

For each region i, t_i is the lump-sum transfer households make to (or receive from) the central government and p_i is the pollution tax they pay on each unit of output region i produces. We assume throughout that $\sum_{i=1}^{2} t_i = 0$, namely, region 1's transfer always equals the negative of region 2's transfer. We also assume that revenue collected with the pollution tax in region i is transferred to households in region j.

When the central government can make lump-sum transfers and levy a pollution tax, households in jurisdiction i face the the following budget constraint

$$c_i = Y_i(1 - p_i) - t_i + p_j Y_j \tag{7}$$

Hence, region i's household problem is:

$$\max_{Y_i} u_i \left(Y_i(1 - p_i) - t_i + p_j Y_j, N - Y_i - \beta_j Y_j\right) \tag{8}$$

Before solving these problems, we examine how the two policies can affect the behaviors of our agents. The pollution tax is well understood: it increases the cost of production towards its social cost. The lump-sum transfer also affects decisions: if a region has to pay a lump-sum amount, it increases its cost to consume the same amount as before, as it will need more production to keep the consumption constant, and thus creating more pollution. On the other hand, if a region receives a transfer, it will decrease the cost of production, which will induce the region to consume more. The lump-sum transfer of t units of consumption from jurisdiction i to region j is conceptually equivalent to the (unfeasible) transfer of t units of nature from one region to another.

The first-order condition of the region i's household is:

$$\frac{\partial u_i(c_i, n_i)}{\partial c_i}(1 - p_i) - \frac{\partial u_i(c_i, n_i)}{\partial n_i} = 0 \tag{9}$$

At the first-best optimal allocations, equation (9), imply:

$$\frac{\partial u_i(c_i^*, n_i^*)/\partial c_i}{\partial u_i(c_i^*, n_i^*)/\partial n_i} = \frac{1}{(1-p_i)} \tag{10}$$

which combined with equation (6), we have:

$$\frac{1}{(1-p_i)} = 1 + \beta_i \frac{\partial u_j(c_j^*, n_j^*)/\partial c_j}{\partial u_i(c_i^*, n_i^*)/\partial n_i} \tag{11}$$

The above equation together with equation (5), and after some manipulation, implies that the optimal pollution tax in jurisdiction i is not affected by the households preferences for consumption and nature:

$$p_i^* = \frac{\beta_i(1-\beta_j)}{1-\beta_i\beta_j}. \tag{12}$$

Interestingly, the optimal pollution tax is determined only by the (atmospheric) externality parameters (β_1, β_2). The pollution tax p_i^* aims to charge jurisdiction i with the social cost of their consumption, and it is thus increasing in β_i and decreasing in β_j.

Using the region i's household budget constraint, expression (7), in terms of n_i and n_j, as well as the optimal pollution tax rate (12), we obtain

$$t^* = \frac{N_1 - n_1^*}{1-\beta_1\beta_2}(1-\beta_1) - c_1^*. \tag{13}$$

Although for the general case we can not find a more specific expression for the optimal lump-sum transfer, we show in the next section that for standard Cobb-Douglas preferences such transfers are not affected by the households preferences for consumption and nature (similarly to the optimal pollution tax rates), but are determined by the endowments of nature and the externality parameters.

The final condition for first-best efficiency, the feasibility condition (3), is satisfied by definition of our policies. Hence (t^*, p_1^*, p_2^*) is a first-best policy. It is obtainable in a decentralized manner as it solves the first-order conditions for problem (8).

3 A special case: Cobb-Douglas preferences

For further analysis, we need more specific preferences to be able to solve for the optimal value of the lump-sum transfers as well as the equilibrium levels for consumption, nature and welfare. We use Cobb-Douglas preferences.

3.1 Optimal Environmental Taxation

For the purpose of this section, we assume that the utility function of the representative agent residing in jurisdiction i is denoted as

$$u_i(c_i, n_i) = \theta_i \ln c_i + (1 - \theta_i) \ln n_i \tag{14}$$

Using directly equations (4), (5) and (6) yields the optimal levels of consumptions and nature:

$$c_i^* = \frac{\theta_i \left(N_i(1-\beta_i) + N_j(1-\beta_j)\right)}{2(1-\beta_i\beta_j)}, \tag{15}$$

$$n_i^* = \frac{(1-\theta_i) \left(N_i(1-\beta_i) + N_j(1-\beta_j)\right)}{2(1-\beta_i)}. \tag{16}$$

These expressions with (13) allow us to obtain the optimal lump-sum transfer as follows:

$$t^* = \frac{(N_1 - N_2) - N_1\beta_1 + N_2\beta_2}{2(1-\beta_1\beta_2)} \tag{17}$$

Replacing for these optimal values, we obtain the following expression for the welfare in each jurisdiction:

$$W_i^* = \left(\begin{array}{l} \theta_i \ln(\theta_i) + (1-\theta_i) \ln(1-\theta_i) + \ln\left(N_i(1-\beta_i) + N_j(1-\beta_j)\right) \\ -\ln(2) - \theta_i \ln(1-\beta_i\beta_j) - (1-\theta_i)\ln(1-\beta_i) \end{array} \right).$$

The most striking result from expressions (12) and (17) is that the optimal pollution tax rates and the optimal lump-sum transfer are not affected by the households preferences for consumption and nature when preferences are Cobb-Douglas, as in equation (14). In this case, the substitution and income effects are of the same magnitude. This is not true for all utility functions. We present an example in the Appendix $A.1$ to show that optimal pollution taxes are determined by externality parameters only (as shown in Section 2.3), while the optimal lump-sum transfer does depend on regions' preferences for consumption versus nature.

When preferences are Cobb-Douglas, the jurisdictions' ex-ante heterogeneity with respect to environmental quality and consumption does not affect the design of optimal policies. In an imperfect information version of the game where the preferences of the jurisdictions would be private information, jurisdictions would have no incentives to misreport their preferences and, in fact, the federation does not even need to know them. We thus obtain strategy-proofness.

The optimal transfer t^* is affected by each region endowment of nature (N_1, N_2) and the degree of environmental damage spillovers (β_1, β_2). Lump-sum transfers in our economy play a redistributive role and are larger the higher is the difference in the nature endowment of the regions. The planner compares adjusted stocks of nature $N_1(1-\beta_1)$ and $N_2(1-\beta_2)$ and the transfer goes from the region with the largest adjusted stock of nature to its neighbor. The magnitude of this transfer depends on both the difference in adjusted stocks of nature and on the externality parameters.

If regions are homogenous with respect to their production damage spillover, i.e., $\beta_1 = \beta_2 = \beta$, it would be optimal to transfer resources in a lump-sum manner from the high nature endowment region to the region with low nature endowment. The optimal transfer in this case is $(N_1 - N_2)/(2(1+\beta))$. Notice that the region that receives the transfer is not necessarily the jurisdiction that prefers more consumption or nature, as preferences do not affect optimal policies. As long as the environmental damage experienced by both regions is affected in the same way by their neighbors' production, that is, same β, the optimal pollution tax rate is equal to $\beta/(1+\beta)$.

3.2 Comparative Statics

We now discuss how the optimal policies depend on the initial stocks of nature and damage spillovers. The optimal lump-sum transfer, equation (17), is affected by a region's initial endowment of nature (N_i) and its externality parameter β_i in opposite directions. For instance, a higher stock of nature in region 1 increases the lump-sum transfer, meaning that jurisdiction 1 will either transfer more resources to or it will receive less from region 2 (the sign of the transfer being determined by the difference in the adjusted nature endowment of the regions). On the other hand, if the degree of environmental damage spillovers from jurisdiction 1 (β_1) increases, the weighted nature stock available for redistribution decreases, and consequently, the optimal transfer decreases. Regarding the optimal pollution tax, equation (12), the effect of the externalities parameters on this policy is straightforward since a pollution tax is intended to correct for the pollution (externality) that affects nature quality across jurisdictions. The pollution tax p_i^* levied on jurisdiction i's households is (i) increasing on β_i, the environmental damage its production inflicts on region j's households, and (ii) decreasing on the negative externality generated by its neighbor (β_j). Finally, our results suggest that the planner tends to distribute the burden of policy interventions across jurisdictions. For instance, a high pollution tax levied on jurisdiction 1, due to an increase in this region's externalities (increase in β_1), is compensated by a lower lump-sum transfer - either meaning that jurisdiction 1's transfers to region 2 is smaller or that region 1 receives more in a lump-sum manner from region 2.

Optimal allocations and welfare are increasing in the initial endowment of nature in both regions. The more region i's households prefer consumption *vis-à-vis* nature (θ_i) the more they consume (c_i), while nature quality enjoyed in jurisdiction i is decreasing in θ_i. Preferences of region j's households (θ_j) do not affect optimal allocations - and thus welfare - of jurisdiction i's households. The effects of the degrees of environmental damage spillovers β_i and β_j on consumption c_i are unclear and depend on the signs of $(N_i - \beta_j N_j)$ and $(N_i \beta_i - N_j)$, respectively. The environmental quality households in jurisdiction i enjoy (n_i) is affected by β_i and β_j in the same way as the pollution tax p_i^* paid by them. That is, n_i is increasing on β_i, the environmental damage its production inflicts on region j's households, and it is decreasing on the negative externality generated by its neighbor (β_j). The intuition for this result is as follows. If β_i goes up it increases the pollution tax levied on jurisdiction i's households, discouraging production in that region. By producing less, region i creates less pollution and harm its own nature less. The net effect is an increase of environmental quality enjoyed by jurisdiction i's households (n_i). Regarding the effect of β_j, the same intuition applies but in opposite direction.

These results can be verified by the following expressions:

$$\frac{\partial t^*}{\partial \beta_1} = -\frac{2(1-\beta_2)(N_1+N_2\beta_1)}{4(1-\beta_1\beta_2)^2} < 0 \qquad \frac{\partial c_i^*}{\partial N_i} = +\frac{\theta_i(1-\beta_i)}{2(1-\beta_i\beta_j)} > 0 \qquad \frac{\partial n_i^*}{\partial N_i} = +\frac{(1-\theta_i)(1-\beta_i)}{2(1-\beta_i)} > 0$$

$$\frac{\partial t^*}{\partial \beta_2} = +\frac{2(1-\beta_2)(N_1+N_2\beta_1)}{4(1-\beta_1\beta_2)^2} > 0 \qquad \frac{\partial c_i^*}{\partial N_j} = +\frac{\theta_i(1-\beta_j)}{2(1-\beta_i\beta_j)} > 0 \qquad \frac{\partial n_i^*}{\partial N_j} = +\frac{(1-\theta_i)(1-\beta_j)}{2(1-\beta_i)} > 0$$

$$\frac{\partial t^*}{\partial N_1} = +(1-\beta_1) > 0 \qquad \frac{\partial c_i^*}{\partial \theta_i} = +\frac{\left(N_i(1-\beta_i)+N_j(1-\beta_j)\right)}{2(1-\beta_i\beta_j)} > 0 \qquad \frac{\partial n_i^*}{\partial \theta_i} = -\frac{\left(N_i(1-\beta_i)+N_j(1-\beta_j)\right)}{2(1-\beta_i)} < 0$$

$$\frac{\partial t^*}{\partial N_2} = -(1-\beta_2) < 0 \qquad \frac{\partial c_i^*}{\partial \theta_j} = 0 \qquad \frac{\partial n_i^*}{\partial \theta_j} = 0$$

$$\frac{\partial p_i^*}{\partial \beta_i} = +\frac{(1-\beta_j)}{\left(1-\beta_i\beta_j\right)^2} > 0 \qquad \frac{\partial c_i^*}{\partial \beta_i} = -\frac{1}{2}\frac{\theta_i(1-\beta_j)(N_i-\beta_jN_j)}{(\beta_i\beta_j-1)^2} \qquad \frac{\partial n_i^*}{\partial \beta_i} = +\frac{(1-\theta_i)N_j(1-\beta_j)}{2(1-\beta_i)^2} > 0$$

$$\frac{\partial p_i^*}{\partial \beta_j} = -\frac{\beta_i(1-\beta_i)}{\left(1-\beta_i\beta_j\right)^2} < 0 \qquad \frac{\partial c_i^*}{\partial \beta_j} = \frac{1}{2}\frac{\theta_i(1-\beta_i)(N_i\beta_i-N_j)}{(\beta_i\beta_j-1)^2} \qquad \frac{\partial n_i^*}{\partial \beta_j} = -\frac{(1-\theta_i)N_j}{2(1-\beta_i)} < 0$$

3.3 Numerical Exercise

In this section we illustrate the relationship among preferences for consumption versus nature, pollution externality and government policies numerically. For the purpose of this exercise, our baseline values for region's 1 stock of nature, preference for consumption and pollution externality are $N_1 = 8$, $\theta_1 = 0.8$ and $\beta_1 = 0.5$, respectively. These values are meant to resemble a federation where jurisdiction 1 has a relatively high preference for consumption. Table 1 presents consumption, nature quality and welfare in jurisdictions 1 and 2, the federation's welfare in the presence of lump-sum transfers and pollution taxation. For the purpose of comparison, in the discussion that follows we also present the case of no policy intervention, i.e., no lump-sum transfers or taxes. For all cases, the federation's welfare is higher under a lump-sum transfer and a pollution tax (T) than under no intervention (N). The magnitude of both policies and the recipient of the lump-sum transfer will depend on the combination of the initial endowment of nature and the externality parameters.

Our numerical exercise confirms that the optimal lump-sum transfer and pollution taxes do not depend on preferences for consumption and nature. When the degree of environmental damage spillovers is the same in both regions ($\beta_1 = \beta_2 = 0.5$) and regions are symmetric with respect to their preferences for consumption versus nature quality ($\theta_1 = \theta_2 = 0.8$) the planner equalizes consumption and nature across jurisdictions, regardless of the levels of nature endowment. However, if regions are different regarding their taste for consumption and nature, it is optimal to specialize and give households relatively more of the element they enjoy the most. For instance, consider the case where region 2's households have higher initial endowment of nature ($N_2 = 10$) and prefer more nature relative to consumption ($\theta_2 = 0.6$). In that case, households in this region will experience a better quality of nature ($n_2 = 3.60$ versus $n_1 = 1.80$), but agents in jurisdiction 1 will consume more of the good produced ($c_1 = 4.80$ versus $c_2 = 3.60$). Interestingly, transfers will be from the region with the higher initial endowment of nature to the one with the lower one, as such policy has a redistributive role. On the other hand, in accordance with equation (12), pollution tax rates are not affected by the stock of nature. Since both regions harm their neighbor equally, they both pay (and receive) the same pollution tax rates.

Table 1 also illustrates the case where regions are heterogeneous regarding the degree of environmental damage spillovers. In particular, the negative externality of region 1 on region 2's environment is larger ($\beta_1 = 0.5$; $\beta_2 = 0.3$). Pollution taxation in our economy plays the role of correcting for the negative externality and environmental damage and, hence, in the spirit of Pigouvian taxation, households in jurisdiction 1 pay a higher pollution tax than those in jurisdiction 2. From equation (17), the degree of environmental damage spillovers weights the stock of nature of both regions. As β_2 decreases from 0.5 to 0.3, for all other parameters constant, the lump-sum transfer increases as now there is more nature in region 2 to be redistributed, $N_2(1-\beta_2)$. The case $N_2 = 6$ and $\beta_2 = 0.3$ is quite illustrative of the effect of both N_2 and β_2 on the magnitude and sign of lump-sum transfer. Even though we have $N_1 > N_2$, the lump-sum transfer is still from region 2 to region 1, as the adjusted stocks of nature are $N_1(1 - \beta_1) = 8(1 - 0.5) = 4$ and $N_2(1 - \beta_2) = 6(1 - 0.3) = 4.2$.

Table 1 - Allocations, Welfare and Optimal Policies
Baseline: $N_1 = 8$; $\theta_1 = 0.8$ and $\beta_1 = 0.5$

		$N_2 = 10$				$N_2 = 6$			
		$\theta_2 = 0.6$		$\theta_2 = 0.8$		$\theta_2 = 0.6$		$\theta_2 = 0.8$	
		N	T	N	T	N	T	N	T
	c_1	4.54	4.80	3.81	4.80	5.64	3.73	5.33	3.73
	c_2	4.63	3.60	6.48	4.80	1.91	2.80	2.67	3.73
	n_1	1.14	1.80	0.95	1.80	1.41	1.40	1.33	1.40
	n_2	3.09	3.60	1.62	1.80	1.27	2.80	0.67	1.40
$\beta_2 = 0.5$	W_1	1.24	1.37	1.06	1.37	1.45	1.12	1.40	1.12
	W_2	1.37	1.28	1.59	1.37	0.48	1.03	0.70	1.12
	W_F	2.61	2.65	2.65	2.74	1.93	2.15	2.10	2.24
	t^*	–	-0.67	–	-0.67	–	0.67	–	0.67
	p^*	–	0.33	–	0.33	–	0.33		0.33
	c_1	5.34	5.18	4.96	5.18	5.97	3.86	5.81	3.86
	c_2	4.40	3.88	6.02	5.18	1.81	2.89	2.48	3.86
	n_1	1.34	2.20	1.24	2.20	1.49	1.64	1.45	1.64
	n_2	2.93	3.14	1.50	1.57	1.21	2.34	0.62	1.17
$\beta_2 = 0.3$	W_1	1.40	1.47	1.32	1.47	1.51	1.18	1.48	1.18
	W_2	1.32	1.27	1.52	1.41	0.43	0.98	0.63	1.11
	W_F	2.72	2.74	2.84	2.88	1.94	2.16	2.11	2.29
	t^*	–	-1.76	–	-1.76		-0.12	–	-0.12
	p^*	–	$(0.41, 0.18)$	–	$(0.41, 0.18)$		$(0.41, 0.18)$	–	$(0.41, 0.18)$

N: no intervention; T: transfer and pollution tax; Optimal policies: t^*, p^*
c_i, n_i, W_i: consumption, nature and welfare region i.

We also investigate the impact of a lower preference for consumption in jurisdiction 1 on both regions' optimal allocations, optimal policies and welfare, as well as on the federation's welfare. Consider an alternative economy, where we keep the stock of nature and the pollution externality as in our baseline economy ($N_1 = 8$ and $\beta_1 = 0.5$, respectively), but assume a higher value for region's 1 preference for nature ($\theta_1 = 0.6$). Table $A.1$ in the Appendix presents consumption, nature quality and welfare in jurisdictions 1 and 2, the federation's welfare for alternative policy instruments. As shown by expressions (12) and (17), optimal pollution tax rate and the optimal lump-sum transfer are not affected by the households preferences for consumption and nature.

Finally, we study numerically the implications of constraining the planner to use only one instrument, i.e., either a lump-sum transfer or a pollution tax. While each of these instruments can be used to solve respectively the problems of efficient consumption and efficient production, problems do occur when one of these instruments is used to solve both problems at once. Table 2 presents consumption, nature quality and welfare for the cases of no intervention, our optimal dual use of lump-sum transfers and pollution tax, as well as both lump-sum transfers and pollution taxation used independently. The welfare of the federation when the government makes a lump-sum transfer and levies a pollution tax (T) is the highest, followed by a pollution tax (P), lump-sum transfers (L), and no intervention (N). If the government can only use one instrument, the optimal policy is affected by all three heterogeneity dimensions present in our economy, i.e., households preferences for consumption versus nature quality, initial endowment of nature and degree of environmental damage spillovers. In the case of transfers only, jurisdiction 1 will still receive resources from region 2, as it has a smaller stock of nature ($N_1 = 8 < 10 = N_2$). However, as the preference for nature of households in region 2 increases relative to those in jurisdiction 1 ($\theta_2 = 0.6$ versus $\theta_2 = 0.8$), transfers to jurisdiction 1 increases ($t^* = -0.43$ from $t^* = -0.94$), although they are smaller then under transfer and pollution tax together.

Our results for the case in which the planner is constrained to used only a pollution tax to control environmental damage illustrate potential (political) hurdles associated with the implementation of such policy. Contrarily to our baseline case (two policy instruments), when pollution tax is the only instrument available, jurisdiction 2 - the region that prefers relatively more nature quality ($\theta_2 \leq \theta_1$), has the lower externality parameter ($\beta_2 < \beta_1$) and is endowed with more nature ($N_2 > N_1$) - pays a higher pollution tax rate than region 1 and than what it would pay under a system that uses transfer and pollution tax together.

Table 2 - Allocations, Welfare and Optimal Policies
Baseline: $N_1 = 8$, $N_2 = 10$; $\theta_1 = 0.8$, $\beta_1 = 0.5$ and $\beta_2 = 0.3$

	$\theta_2 = 0.6$				$\theta_2 = 0.8$			
	N	T	L	P	N	T	L	P
c_1	5.34	5.18	5.64	5.42	4.96	5.18	5.64	5.40
c_2	4.40	3.88	4.18	3.80	6.02	5.18	5.37	5.06
n_1	1.34	2.20	1.41	1.60	1.24	2.20	1.41	1.69
n_2	2.93	3.14	2.78	3.38	1.50	1.57	1.34	1.81
W_1	1.40	1.47	1.45	1.45	1.32	1.47	1.45	1.45
W_2	1.32	1.27	1.27	1.29	1.52	1.41	1.40	1.41
W_F	2.72	2.74	2.72	2.73	2.84	2.88	2.86	2.87
t^*		-1.76	-0.43			-1.76	-0.94	
p^*	–	$(0.41, 0.18)$		$(0.15, 0.25)$	–	$(0.41, 0.18)$		$(0.20, 0.30)$
NT	–	-0.78	-0.43	-0.22	–	-1.33	-0.94	-0.87

N: no intervention; T: transfer and pollution tax; L: transfer only; P: tax only; Optimal policies: t^*, p^*
c_i, n_i, W_i: consumption, nature and welfare region i. NT: net transfer.

4 Conclusions and Discussion

In our two-region federation model with pollution externality and heterogeneous preferences for consumption and nature, we show that even with a decentralized policy we can obtain first-best efficiency by choosing a combination of pollution tax and lump-sum transfers. The pollution tax rates depend only on the externalities parameter. As the tax rates are intended to correct for the externality, a region pays a higher tax rate if it generates more externality or if its neighbor generates less.

The optimal lump-sum transfer can depend on preferences, but we show that with Cobb-Douglas preferences, it is independent of preference parameters. In that case, the transfer goes from the region with the largest adjusted stock of nature to its neighbor, and not necessarily to the jurisdiction that prefers more consumption or nature.

Mathematically, it is no surprise that by widening the set of available policy instruments we increase the efficiency. However, the gains to move from, say, a pollution tax only to a combination of pollution tax and lump-sum transfer, are huge. Not only are we then able to achieve first-best efficiency, but we also obtain relatively simple forms for the instruments themselves. And, if the preferences are of the Cobb-Douglas form, optimal tax policy is independent of consumer preferences. In a version of the game in which preferences are private information, we would obtain strategy-proofness for free: the central government does not even need to know these preferences. We can then find the optimal values by obtaining values for parameters that are more readily measurable objectively: the externality parameters and the initial stocks of nature.

A federation that can only use a single of these parameters will not be able to obtain first-best efficiency. For example, it could obtain efficient but inefficient consumption levels by choosing tax rates as in equation (12). Alternatively, as we have done in Table 2, the planner can increase total welfare by choosing tax rates that try to correct, in a second-best manner, both the levels of production and consumption. The optimal tax levels can only be obtained numerically, even with Cobb-Douglas preferences, and depend on the preference parameters. As seen in Table 2, we can also obtain some very counterintuitive tax rates such that, for instance, the region that generates less externality per unit of output, prefers nature and has a larger initial stock of nature than its neighbor can end up paying a higher tax rate. This however might not be viable politically.

The model can be extended in a number of ways, notably by complexifying the production function or by giving a more active role to the central government. While mathematically, once again, using the lump-sum transfer and pollution tax combo can only be more efficient than using emission taxes only, it remains to be seen if the substantial gains that we obtain in our model extend to more complicated cases. The analysis is complicated by the fact that it becomes much harder to solve analytically as soon as we move away from a setup like ours. While the current analysis has focused on efficiency, it would also be interesting to explore what is a fair allocation in that context. In particular, how do we combine the desire of some regions to consume large amounts with the rights of others to not get polluted? We leave these extensions for future research.

References

[1] Boadway, R., Song, Z., Tremblay, J. F., (2013). Non-cooperative pollution control in an inter-jurisdictional setting, Regional Science and Urban Economics 43, pp. 783-796.

[2] Baumol, W. J., Oates, W. E., 1988, The Theory of Environmental Policy, Second Edition, Cambridge University Press, Cambridge.

[3] Berliant, M., Peng, S.-K., Wang, P., (2014). Taxing pollution: agglomeration and welfare consequences. Economic Theory 55, pp. 665–704.

[4] Daubanes, J., Grimaud A., (2010). Taxation of a Polluting Non-renewable Resource in the Heterogeneous World. Environmental & Resource Economics 47, pp. 567-588.

[5] de Mooij, R. A., 2000. Environmental Taxation and the Double Dividend. North Holland, Amsterdam.

[6] Fell, H., Kaffine, D. T., (2014). Can decentralized planning really achieve first-best in the presence of environmental spillovers?, Journal of Environmental Economics and Management 68, pp. 46-53.

[7] Jones, B., Keen, M., Strand, J., (2013). Fiscal implications of climate change. International Tax and Public Finance 20, pp. 29-70.

[8] Lundin, D., (2001). Welfare-Improving Carbon Dioxide Tax Reform Taking Externality and Location into Account. International Tax and Public Finance, 8, 815–835.

[9] Meade, J.E., (1952). External Economies and Diseconomies in a Competitive Situation. The Economic Journal 62, 54–67.

[10] Millock, K., Nauges, C., (2006). Ex Post Evaluation of an Earmarked Tax on Air Pollution. Land Economics 82, pp. 68-84.

[11] Montgomery, W. D., (1972). Markets in Licenses and Efficient Pollution Control Programs. Journal of Economic Theory 5, pp. 395-418.

[12] Muller, N. Z., Mendelsohn, R., (2009). Efficient Pollution Regulation: Getting the Prices Right. American Economic Review 99, pp. 1714-1739.

[13] Oates, W. E., Schwab, R. M. (1988). Economic Competition Among Jurisdictions: Efficiency-Enhancing or Distortion-Inducing? Journal of Public Economics 35, pp. 333-354.

[14] Ogawa, H., Wildasin, D., (2009). Think Locally, Act Locally: Spillovers, Spillbacks, and Efficient Decentralized Policymaking. American Economic Review 99, pp. 1206–1217.

[15] Pigou, A., 1920. The Economics of Welfare. Macmillan and Co., London.

[16] Samuelson, P., (1954). The Pure Theory of Public Expenditure. Review of Economics and Statistics 36, pp. 387–389.

[17] Sandmo, Agnar, (2011), Atmospheric Externalities and Environmental Taxation, Energy Economics, 33, issue S1, p. S4-S12.

[18] Schwartz, J., Repetto, R., (2000). Nonseparable Utility and the Double Dividend Debate: Re-considering the Tax-interaction Effect. Environmental and Resource Economics 15, pp. 149–157.

[19] Siddiqui, M. S., (2015). Environmental Taxes and International Spillovers: The Case of a Small Open Economy, Energy Economics, Elsevier, vol. 48(C), pages 70-80.

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

[21] Tietenberg, T. H., (1980). Transferable Discharge Permits and the Control of Stationary Source Air Pollution: A Survey and Synthesis. Land Economics 56, 391-416.

[22] Williams III, R. C., (2002). Environmental Tax Interactions When Pollution Affects Health or Productivity. Journal of Environmental Economics and Management 44, pp. 261–270.

[23] Williams III, R. C., (2003). Health Effects and Optimal Environmental Taxes. Journal of Public Economics 87, pp. 323–335.

Appendix

$A.1$ Preferences and the optimal lump-sum transfer

If instead of a Cobb-Douglas utility function, equation (14), we assume preferences as follows:

$$u_i = \theta_i c_i + (1 - \theta_i) n_i + c_i n_i \tag{18}$$

the optimal pollution tax is not affected by the households preferences for consumption and nature, as shown in Section (2.3) and repeated here for completeness - equation (12):

$$p_i^* = \frac{\beta_i (1 - \beta_j)}{1 - \beta_1 \beta_2}. \tag{19}$$

Following the steps of Section (2.2), we can show that for preferences such as in equation (18), the optimal lump-sum transfer t does depend on regions' preferences for consumption versus nature and it is as follows:

$$t^* = \frac{\begin{array}{c}\beta_1 \beta_2 \left[(1 - \theta_1) \beta_2 - (1 - \theta_2) \beta_1\right] + (N_1 - N_2 + 2\,\theta_1 - 2\,\theta_2) \beta_2 \\ -(\theta_1 \beta_1 + \theta_2 \beta_2) - (N_1 - N_2 - 1)(\beta_1 + \beta_2) + (N_1 - N_2)\end{array}}{(\beta_1 + \beta_2 - 2)(\beta_1 \beta_2 - 1)}. \tag{20}$$

To make clear the effect of preferences on the optimal lump-sum transfer, we consider a special case in which $N_1 = N_2 = N$ and $\beta_1 = \beta_2 = \beta$. We then can solve for the optimal lump-sum transfer and we obtain the following expression:

$$t^* = \frac{\beta}{2(1 + \beta)} \left(\theta_2 - \theta_1\right). \tag{21}$$

The optimal lump-sum transfer is zero when both regions care equally about consumption, i.e., $\theta_2 = \theta_1$. From equation (21) we can also see that the more a region cares about consumption *vis-à-vis* nature (θ_i) and *vis-à-vis* the other region's weight on consumption (θ_j), this region gets the transfer. For instance, if $\theta_2 < \theta_1$, region 1's residents receive the transfer (from region 2's residents).

$A.2$ **Lower preference for consumption in region 1**

We modify our baseline economy by lowering θ_1, the parameter of relative preference of region 1 for consumption over nature, from 0.8 to 0.6. Table $A.1$ presents consumption, nature quality and welfare in jurisdictions 1 and 2, the federation's welfare under different policy regimes.

Table $A.1$ - Allocations, Welfare and Optimal Policies
Baseline: $N_1 = 8$; $\theta_1 = 0.6$ and $\beta_1 = 0.5$

		$N_2 = 10$				$N_2 = 6$			
		$\theta_2 = 0.6$		$\theta_2 = 0.8$		$\theta_2 = 0.6$		$\theta_2 = 0.8$	
		N	T	N	T	N	T	N	T
$\beta_2 = 0.5$	c_1	3.30	3.60	2.73	3.60	4.09	2.80	3.82	2.80
	c_2	5.01	3.60	6.91	4.80	2.37	2.80	3.27	3.73
	n_1	2.20	3.60	1.82	3.60	2.73	2.80	2.55	2.80
	n_2	3.34	3.60	1.73	1.80	1.58	2.80	0.82	1.40
	W_1	1.03	1.28	0.84	1.28	1.25	1.03	1.18	1.03
	W_2	1.45	1.28	1.66	1.37	0.70	1.03	0.91	1.12
	W_F	2.48	2.56	2.50	2.65	1.95	2.06	2.09	2.15
	t^*		-0.67		-0.67		0.67		0.67
	p^*		0.33		0.33		0.33		0.33
$\beta_2 = 0.3$	c_1	3.93	3.88	3.62	3.88	4.39	2.89	4.24	2.89
	c_2	4.82	3.88	6.55	5.18	2.28	2.89	3.10	3.86
	n_1	2.62	4.40	2.41	4.40	2.93	3.28	2.83	3.28
	n_2	3.21	3.14	1.64	1.57	1.52	2.34	0.78	1.17
	W_1	1.21	1.41	1.12	1.41	1.32	1.11	1.28	1.11
	W_2	1.41	1.27	1.60	1.41	0.66	0.98	0.86	1.11
	W_F	2.62	2.68	2.73	2.81	1.98	2.09	2.14	2.22
	t^*		-1.76		-1.76		-0.12		-0.12
	p^*		(0.41, 0.18)		(0.41, 0.18)		(0.41, 0.18)		(0.41, 0.18)

N: no intervention; T: transfer and pollution tax; Optimal policies: t^*, p^*
c_i, n_i, W_i: consumption, nature and welfare region i.