Eradicating Pollution Control Free-Riding through Decentralized Decision Making in a Federation with Mobile Labour

by

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Abstract

This paper builds primarily on Caplan and Silva (1997) and Caplan et al. (2000) to analyze the effects of an environmental externality on a federation under different assumptions about labour mobility. It is found that, with decentralized leadership, a central government can induce non-cooperative regional governments to choose federally optimal pollution policy even though pollution is a federal public bad. Moreover, under some assumptions, competing regions will choose nationally optimal pollution policy even without a central government if they can make voluntary lump sum transfers amongst themselves. With immobile labour, a central government, capable of making lump-sum transfers between competing regions after regions set policy, is necessary to achieve environmental efficiency. With perfectly mobile labour, no central government is needed to achieve environmental and population distribution utility if regions aim to maximize per capita utility. A central government is needed if they maximize total utility. With imperfectly mobile labour, population distribution efficiency is not achieved if there is no central government. These results suggest a role for a central government in a federal setting, and that both environmental and migrational efficiency can be achieved even with split policy options.

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Contents

1 Introduction

In recent years, climate change and other environmental problems have become serious issues of concern for the general public. Governments are increasing their efforts to control damages caused by pollutants by researching both effective scientific methods of control and policy frameworks to achieve environmental targets. In a world in which emissions do not respect regional boundaries, it is important for economists to design models which recognize the transboundary externalities pollutants cause. Moreover, we live in a world without a global government capable of enforcing the first-best allocation of production required to achieve the pareto optimal global pollution level. To make matters more complicated, many countries, such as Canada and Australia, are governed within a federal framework, meaning regional governments have control over some policy instruments while federal governments have control over others. Finally, globalization has brought with it an unprecedented level of labour mobility. Governments, both regional and national, must anticipate the effects their policy choices will have on labour migration.

This paper addresses these important issues. Drawing primarily on the work of Caplan and Silva (1997) and Caplan et al. (2000), this paper combines these models while expanding certain areas of their analysis using both original work and aspects from other papers. The main focus throughout the paper is the ability of governments to efficiently control the levels of transboundary pollutants. I examine an economy in which two competing regional governments choose policies so as to influence pollution levels in their jurisdiction. The two regions suffer different levels of damage from the pollutant and have different costs to clean up the pollution. This is the reality faced by different provinces in Canada as well as different countries across the globe. The paper looks at cases where there is a central government which can make lump sum income transfers between the two regions, analogous to the real world experience of countries such as Canada. The paper also looks at cases where there is no central government, which is the situation faced by competing countries in a global context.

This analysis is undertaken under different assumptions about population mobility. Transboundary pollutants are a public bad, so one would expect to observe free-riding pollution control behavior amongst competing regions within a federation. However, this paper finds that, if the central government makes transfers after regions set policy, free-riding can be eliminated. Regions will voluntarily set nationally optimal pollution controls in anticipation of the actions taken by the central government and the regions' citizens. Furthermore, with certain labour mobility conditions, free-riding can be avoided even without a central government.

With immobile labour and two levels of government, if the regional governments make their policy choices before the central government, environmental efficiency can be achieved. This is because regions anticipate that the central government will redistribute income to equalize regional utilities. In other words, they experience incentive equivalence[1] and set nationally optimal pollution controls. The case of perfectly mobile labour where the regional objective is to maximize per capita utility and regions can make voluntary lump sum transfers to each other is also analyzed. Once again, incentive equivalence leads to both environmental and population distribution efficiency, suggesting no role for the central government. However, if regions aim to maximize total utility, population distribution efficiency can only be achieved with the help of a central government. Lastly, we find that, with imperfect labour mobility and no central government, population distribution efficiency cannot be achieved.

The paper is organized as follows: section 2 gives an overview of the relevant economic literature. Section 3 analyzes the baseline model, in which there is no labour mobility. Section 4 introduces labour mobility to the baseline model. Finally, section 5 concludes.

[1] for a more detailed discussion of early literature regarding incentive equivalence, please see the literature review in Mansoorian and Myers (1993).

2 Literature Review

There is a large body of research on the topic of environmental federalism. I have divided the literature into two main streams as they relate to this paper:

1. Models which assume the pollution externality only effects the region in which it is generated
2. Models which assume pollution externalities are transboundary.

The first stream begins with the seminal paper by Oates and Schwab (1988). In their paper, they assume that environmental externalities do not cross jurisdictional borders. There are n jurisdictions with an immobile supply of labour, each competing for mobile, pollution-producing capital. Oates and Shwab's article is concerned with whether jurisdictional competition for mobile capital will result in inefficient environmental standards. Inefficiency could be due to a race to the bottom to attract capital, or a not in my backyard (NIMBY) scenario where not enough capital is attracted. Assuming the policy options available to the jurisdictions are a capital tax and environmental quality standard, Oates and Shwab find that if capital taxes are set to zero, the efficient allocation of pollution and production is achieved. However, if a political economy concern results in a capital tax greater than zero, environmental standards will be set too low.

Wellisch (1995) builds on Oates and Schwab (1988) by adding firm mobility to the analysis. This results in jurisdictions facing two problems; achieving (firm) locational efficiency as well as environmental efficiency. Wellisch finds that if decentralized environmental policies are used and the revenue is transferred to local households rather than local firms, locational and environmental efficiency can both be achieved. However, if direct controls are used, or revenue is transferred to firms, locational efficiency cannot be reached in general, and pollution levels are inefficiently low. Wellisch also touches on the idea of mobile households, but does so in an unrealistic manner. He assumes that there are two types of households; immobile and perfectly mobile. Therefore, the results above hold if revenue is transferred to the immobile households. This result is not surprising given the binary construction of household mobility. In contrast, Mansoorian and Myers (1993), discussed later, suggest a continuum of households with different degrees of mobility.

Kunce and Shogren have written a series of articles expanding on these models. Kunce and Shogren (2002), like Wellisch (1995), focuses on direct control of emissions, but rejects the assumption of the previously mentioned papers that jurisdictions have no market power. The authors allow residents to capture pollution rents through local ownership of firms, and allow profits to become endogenous based on jurisdictional policy. Using a Nash game framework, they find that, with a large number of jurisdictions, a race to the bottom (Race) will occur. With few jurisdictions, efficient pollution levels can be achieved.

In Kunce and Shogren (2005), they assume that firms are not always locally owned. This 'leakage' of environmental rents to foreign owners offers a reason as to why decentralized direct emission control leads to a socially inefficient result. Kunce and Shogren interpret jurisdictions as municipalities and assume they must rely on property taxes for public revenue. This revenue is used to fund a non-environmental public good while, at the same time, reducing emissions by increasing production costs for firms which use the emitting good as an input. In Kunce and Shogren (2008) the authors expand on the idea that, with immobile labour and public good provision, a property/fixed factor tax can be used which decreases pollution while raising money to fund the public good. If this is the only tax used, efficiency can be achieved. Returning to Kunce and Shogren (2005), they find that if public goods are funded efficiently, environmental efficiency can be achieved. However, if firm productivity is highly correlated with emissions (a reasonable assumption) and capital is taxed, a NIMBY scenario is more likely to occur. If, on the other hand, public goods are underfunded due to other factors, such as high capital mobility, an environmental race to the bottom will occur.

In Kunce and Shogren (2007), they introduce labour mobility into a competitive jurisdictional model. In this model, labourers are land and firm owners and wage earners. They find that as land value increases in relative importance, a race to the bottom is more likely to occur. When factors of production are mobile, whether an efficient, NIMBY, or Race outcome is likely to occur depends highly on firm production functions and the responsiveness of firms and factor location to environmental policy changes. The concept of labour mobility highlighted in Kunce and Shogren (2007) is central to the analysis of the model presented in this paper.

These articles provide an important contribution to the literature on environmental federalism and interjurisdictional competition. Their analysis of the effects of labour (and other factors of production) mobility is informative. However, the assumption that pollution is not a transboundary problem is ultimately quite limiting. This assumption is plausible for local pollutants such as smog or a polluted lake. However, it means these models clearly cannot address climate change, ozone depletion, and other international pollution problems which are of primary concern in the modern context. As a result, the second stream of articles, which focus on cross-boundary pollutant spillovers, is of more relevance to this paper.

The primary basis of the model presented in this paper is two articles; Caplan and Silva (1997), and Caplan et al. (2000). In Caplan and Silva (1997), they construct an environmental federalism model in which two competing regions set abatement policies while a central government can set taxes on the polluting good as well as make lump sum transfers between regions. In this model, there is no labour mobility. Caplan and Silva find that if the regional governments set their policy before the central government but anticipate how their choices will influence the actions of the central government, then a socially efficient outcome will be obtained. However, if the central government moves first, regions do not experience incentive equivalence, and the outcome will be inefficient.

Cornes and Silva (1999) highlights this concept, structuring its argument based on Becker's "Rotten Kids Theorem" (Becker, 1981). Selfish 'children' will provide the efficient amount of a public good to the family if they anticipate that, in the second stage, their parents will redistribute consumption to maximize total welfare. Anticipating the redistribution, the children voluntarily contribute optimally to the public good. This concept explains why selfish regions abate pollution efficiently rather than free-ride off of each other's abatement. They anticipate government redistribution in the second stage.

In Caplan et al. (2000), the authors study the effects of (im)perfect labour mobility on public good provision. They examine a federation where two regional governments provide a public good and a central government conducts a lump sum income transfer following regional policy choices. The authors find that, which such a division of policies and order of actions, the efficient public good provision can still be achieved despite labour mobility. However, this model does not examine the effects of labour mobility on the production of a consumption good which emits a negative environmental externality.

Another article in the same vein as those above is Hoel and Shapiro (2003). They discuss whether, with competing jurisdictions and perfect labour mobility, the environmentally efficient outcome is a Nash equilibrium. They find that, since perfect population mobility means regional utilities must all be equalized, the efficient outcome is a Nash equilibrium if the regions have access to a full range of policy options. However, the efficient outcome is not a unique Nash equilibrium, and often regional jurisdictions do not have a full range of policy choices. Hoel and Shapiro's assumption of perfect labour mobility is a strong assumption which is central for this result, as will be seen in my paper. I also introduce imperfect mobility into my model. Also of importance is choosing which policy options are available to regions. It will be shown that, in some cases, a central government is not necessary if regions can make voluntary lump-sum transfers between themselves.

The model in my paper can be seen as a synthesis of Caplan and Silva (1997) and Caplan et al. (2000). I adopt a framework similar to that of Caplan and Silva's 1997 article. However, as in Caplan et al's 2000 article, I only give the central government control over transfers. I also account for the effects of migration on the efficiency of policy choices where a negative environmental externality exists, rather than discussing public good provision.

Also important to this topic is a body of literature which focuses on efficiency problems when labour is mobile. Boadway (1982) discusses whether taxation and public good provision levels will be socially inefficient in a federation with migration. He contrasts his study with an earlier paper by Flatters et al. (1974) which finds taxes will be too high if individuals are taxed, but too low if land is taxed. This is because there are rents generated from production to be captured, and congestion to public good consumption to be avoided, so governments aim to control migration so as to fulfill the local optimal Samuelson rule. However, this earlier model assumes the possibility of different utilities in each region, which is incompatible with free migration. As a result, Boadway (1982) includes the constraint of equal utility between regions when designing his regional government problem. By doing so, he finds that, when communities account for the effect of their policies on migration, they will voluntarily follow the nationally optimal Samuelson rule, and social efficiency is achieved regardless of whether land/rents or labour is taxed. I extend this analysis to migration within a federation with a pollution externality and no public good. Moreover, my model assumes residents only garner rents generated within their jurisdiction. Boadway also mentions an extension would be to allow a central government to make lump sum transfers between regions. This concept is not expanded on in his paper, but is central to mine.

Boadway (2004) provides a summary of the existing equalization literature. Of particular interest is his discussion of the fiscal externality caused by migration when public goods are provided. There are offsetting benefits/costs to migration. A larger population increases the tax base available to fund a public good, but if use of the public good is congestible, increased population decreases access. Moreover, higher population decrease the marginal product of labour, which decreases wages and rents (i.e. income) available to households for private consumption. In the model of this paper, we deal with an environmental externality rather than a public good. To my knowledge, the migrational externality as it relates to a pollutant has not been analyzed in depth. The current equalization research with mobile labour is adapted to the case of a pollution externality. Boadway also mentions that the order of decision making can effect outcomes. He offers an example of public goods being under or over provided if regional governments set policies before the central government.

The benefits and costs of migration are also discussed in the early pages of Boadway and Flatters (1982). They present a model where regions do not account for migration. As such, there would be a net benefit, shown by the divergences in rent and public good levels between regions, in efficient migration. They argue that lump-sum transfers by a federal government (or by the regions) could lessen this inefficiency by internalizing the migrational externality. The model in my paper draws upon this idea by allowing transfers between regions, but I assume that regions anticipate migration, as in Boadway (1982), and Caplan et al. (2000).

Mansoorian and Myers (1993) focuses specifically on population distribution efficiency. They find that migration efficiency can be achieved in a federation even without a central government. In their paper, they assume there are two regions with a continuum of citizens, all with varying degrees of attachment to the region in which they begin. Regions can make voluntary income transfers to each other, after which citizens choose whether to move or not. Anticipating the move, regions will make transfers so that the marginal migrant is indifferent between the two regions, maximizing social welfare. This shows that, with voluntary transfers, no central government is needed because regions experience incentive equivalence due to migration.

However, their analysis does not consider the effects public goods or environmental spillovers have on the ability of regional governments to reach migration and environmental efficiency. My model discusses the migrational issues and equalization transfers brought up in these three articles, but applies the concept to the problem of pollution externalities.

The model presented in my paper combines and expands on concepts from the environmental federalism, mobile labour, and equalization payment literature. What distinguishes my paper is the focus on environmental externality within a federation with mobile labour. Most existing models focus on public goods within a federation with mobile labour or construct a federation where labour is either immobile or not the focus of the analysis. Moreover, I assume pollution regulation policies are solely controlled by regional governments, and the central government only controls income transfers. This model is highly relevant in the modern context, where transboundary pollution and labour flows are increasingly important issues for governments of all levels.

3 The Baseline Model

3.1 A Federation with Immobile Labour

Throughout the analysis in this paper, there are two regions, indexed by $j = 1, 2$. In this baseline model, there are two levels of government:

1. A central government
2. Two competing regional governments which make decisions independently and simultaneously and do not work together in the national interest.

Though there are only two regions, it is assumed regions face perfect competition in policy choices. There are two goods; a composite good and an emitting good which creates pollution. Moreover, abatement can be undertaken to decrease pollution levels instead of decreasing production of the emitting good. Goods and abatement cannot be traded between regions, though lumps sum income transfers can be made. We treat the regional governments as social planners and assume they can use the market-based policy options available to them, whether it be a tradable permit system or a tax, to influence consumers and producers to consume/produce the desired amounts of goods. The exact incentive system used is irrelevant to the thrust of the analysis presented in this paper, so will not be discussed further. As a result, we allow regional governments to choose levels of abatement and production of the two goods. By proxy, this means governments effectively choose pollution levels. The central government can make lump sum transfers of income between the regions, with no restrictions to the magnitude of the transfer.

Let n_j = the number of residents in region j, x = composite good (with a price of unity), e = emitting good, a = abatement, p = price of emitting good, I = fixed income, and T = lump sum transfer received/taken away from each region, where $\sum_{j=1}^{2} T_j = 0$. e produces pollution in a one-to-one ratio, so pollution is also represented by e in the damage function shown below. A unit of a abates e in a one-to-one ratio as well. It is assumed that all residents within the same region have the same representative utility functions, and individuals are immobile between regions. Within a region, original fixed income, the benefit from consumption of e, the damages from pollution, and the costs of a are identical for all consumers/producers. Any lump sum tax/subsidy is divided equally amongst all residents. Therefore, we aggregate the individual utility functions and budget constraints into regional representations. Per capita regional utility is represented by the quasi-linear utility function:

$$n_j U\left(\frac{x_j + B_j(e_j) - D_j(e_1 - a_1 + e_2 - a_2) + T_j}{n_j}\right) \tag{1}$$

Where $j = 1, 2$. The quasi-linearity of the utility function allows separatability of goods and eliminates any substitution effects between goods as income levels change. Moreover, it also implies that there is only a single argument in the utility function.

As will be seen later, this is a central assumption in the derivation of the results of this paper. The function $B_j(e_j)$ represents the utility obtained by consumers through consumption of the emitting good. Pollution generated is considered a pure public bad, so the damages accrued to a given region are the result of the total amount of emitting good consumed in both regions minus the total amount of abatement undertaken, and is represented by the function $D_j(e_1 - a_1 + e_2 - a_2)$. These two functions can vary between regions. Intuitively, this is because one region may have more use for the emitting good, or one region may be harmed more by high levels of pollution. Since consumers within a region are identical, the regional budget constraint is the aggregate of all production and consumption of goods and abatement in the region. The regional budget constraint is:

$$x_j + pe_j + C_j(a_j) = I_j + T_j \tag{2}$$

Note that we represent abatement as paid for through a lump sum levy on consumers, though in reality abatement would be undertaken by firms influenced by regional government policy choices. Moreover, the cost of abatement represented by the function $C_j(a_j)$, can vary from region to region. The possible difference in abatement costs can be interpreted as differences in abatement technology. It is assumed that all functions are differentiable and that $U'(\cdot), B_j'(\cdot) > 0; U''(\cdot), B_j''(\cdot) < 0$, and $D_j'(\cdot), C_j'(\cdot) > 0; D_j''(\cdot), C_j''(\cdot) > 0$.

3.2 The Social Planner's problem

It is useful to begin by considering the national social planner's problem. This serves as a benchmark by which one can compare if decentralized models and the relaxation of some of the assumptions in the baseline model can still achieve efficiency. It is assumed there is only one level of government which can choose policies so as to set e_j, a_j and T_j to desired levels in both regions. The goal of the national social planner is to maximize welfare for the federation as a whole, and we assume this is done by maximizing per capita income across the federation. The social planner problem is to maximize utility across regions subject to the regional budget constraints, which are substituted in for x_j using (2):

$$\begin{aligned}\text{Max}_{a_j,e_j,T_j}\ W = n_1 U\left(\frac{I_1 - pe_1 + T_1 - C_1(a_1) + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right)\\ + n_2 U\left(\frac{I_2 - pe_2 - T_1 - C_2(a_2) + B_2(e_2) - D_2(e_1 - a_1 + e_2 - a_2)}{n_2}\right) \quad (3)\end{aligned}$$

The first order conditions for this problem allow us to derive the socially efficient results:

$$\frac{\partial W}{\partial a_1} \Rightarrow U'(1)[-C_1' + D_1'] - U'(2)[D_2'] = 0 \quad (4)$$

$$\frac{\partial W}{\partial a_2} \Rightarrow U'(1)[D_1'] - U'(2)[-C_2' + D_2'] = 0 \quad (5)$$

$$\frac{\partial W}{\partial e_1} \Rightarrow U'(1)[-p + B_1' - D_1'] - U'(2)[-D_2'] = 0 \quad (6)$$

$$\frac{\partial W}{\partial e_2} \Rightarrow U'(1)[-D_1'] - U'(2)[-p + B_2' - D_2'] = 0 \quad (7)$$

$$\frac{\partial W}{\partial T_1} \Rightarrow U'(1) - U'(2) = 0 \quad (8)$$

Where $U(j)$ represents $U(I_j - pe_j + T_j - C_j(a_j) + B_j(e_1) - D_j(e_1 - a_1 + e_2 - a_2))$, C_j' represents $C_j'(a_j)$, and so forth. (8) is of special interest. It shows us that, to maximize national utility and achieve efficiency, interregional lump sum transfers are set to a level such that the marginal utility of residents in each region are equalized. We will see it is important in deriving the regional incentive equivalence scenario, which will lead to efficient outcomes in the decentralized solution.

Please note that, throughout this paper, only interior solutions are derived. From (4), (5), and (8), we see that

$$C_1' = D_1' + D_2' = C_2' \quad (9)$$

This shows that, when maximizing total welfare, The marginal costs of abatement in each region equal the total marginal damages from one more unit of pollution in the federation. From (6), (7), and (8), we see that

$$B_1' = D_1' + D_2' + p = B_2' \quad (10)$$

This shows that the marginal benefits of one more unit of the emitting good in each region equals the total marginal damages from one more unit of pollution to the federation plus the market price of good e. These two results show us that the environmental externality imposed through consumption of e on other regions in the federation is internalized by both regions.

3.3 The Federation with Decentralized Leadership

The paper now returns to the baseline model formulation with two levels of government. Regional governments set a_j and e_j and the federal government chooses T_j. It is assumed that first the regional governments make their policy choices, and then the federal government chooses transfer levels based on the actions of the regions. The solution concept is subgame perfect Nash equilibrium. Using backwards induction, we first look at the central government's problem. The central government takes levels of emitting good production and abatement as given when making its decision for T_1 and T_2. Substituting in the budget constraint (2), the central government's problem is:

$$\begin{aligned}\text{Max}_{T_1}\ W = n_1 U\left(\frac{I_1 - pe_1 - C_1(a_1) + T_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right) \\ + n_2 U\left(\frac{I_2 - pe_2 - C_2(a_2) - T_1 + B_2(e_2) - D_2(e_1 - a_1 + e_2 - a_2)}{n_2}\right)\end{aligned} \tag{11}$$

The first order condition is:

$$\frac{\partial W}{\partial T_1} \Rightarrow U'(1) - U'(2) = 0 \tag{12}$$

This condition matches (8). Since there is only one argument in the utility function, it follows that:

$$\Rightarrow U(1) = U(2). \tag{13}$$

where $U(1)$ and $U(2)$ represent the utility functions of regions 1 and 2, respectively. This is the equal utility constraint, and leads to incentive equivalence for the regions. The central government wants to equate the per capita marginal utility across regions.

Due to the nature of the utility function used, this is the same as equating per capita utility values across regions.

Now we consider the regional government problem for region one. As the regional government can anticipate the actions that the central government will take in the second period, the regional problem for region one becomes:

$$\text{Max}_{e_1,a_1,T_1}\; n_1 U\left(\frac{x_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right) \tag{14}$$

subject to the budget constraint (2) and utility constraint (13). The second constraint is included because the regional government knows that, given its actions, the central government will choose T_j subject to (13). Therefore, the regional government can internalize this constraint into its own actions and, by doing so, set the level of T_1 as well as a_1 and e_1. Substituting in the budget constraint for x and constructing a Lagrangian, we have:

$$\begin{aligned}\mathcal{L} = {} & n_1 U\left(\frac{I_1 - pe_1 - C_1(a_1) + T_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right)\\ & - \lambda[U\left(\frac{I_1 - pe_1 - C_1(a_1) + T_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right)\\ & - U\left(\frac{I_2 - pe_2 - C_2(a_2) - T_1 + B_2(e_2) - D_2(e_1 - a_1 + e_2 - a_2)}{n_2}\right)]\end{aligned} \tag{15}$$

Taking the first order conditions, we have:

$$\frac{\partial \mathcal{L}}{\partial a_1} \Rightarrow U'(1)(1 - \frac{\lambda}{n_1})[-C_1' + D_1'] + \frac{\lambda}{n_2}U'(2)[D_2'] = 0 \tag{16}$$

$$\frac{\partial \mathcal{L}}{\partial e_1} \Rightarrow U'(1)(1 - \frac{\lambda}{n_1})[-p + B_1' - D_1'] - \frac{\lambda}{n_2}U'(2)[D_2'] = 0 \tag{17}$$

$$\frac{\partial \mathcal{L}}{\partial T_1} \Rightarrow U'(1)(1 - \frac{\lambda}{n_1}) - \frac{\lambda}{n_2}U'(2) = 0 \tag{18}$$

Substituting (18) $\rightarrow$ (16) yields $\Rightarrow D_1' + D_2' = C_1'$. Substituting (18) $\rightarrow$ (17) yields $\Rightarrow B_1' = D_1' + D_2' + p$. By symmetry, we find that region two's problem yields the following results: $\Rightarrow D_1' + D_2' = C_2'$ and $\Rightarrow B_2' = D_1' + D_2' + p$. Therefore $\Rightarrow B_1' = B_2'$ and $C_1' = C_2'$. Clearly, this shows that conditions (9) and (10) are satisfied.

Even though competing regions are setting pollution control policies non-cooperatively, the efficient result is achieved and no free-riding occurs. If regions anticipate that, in the second stage, the central government will redistribute income between regions to fulfill its welfare goals, regions will take this into account when setting their own pollution policies. This incentive equivalence means regions will voluntarily internalize the pollution externality caused by the production of e in the same way they would if a central social planner were to choose regional levels of a and e. Interestingly, environmental efficiency is achieved even with this division of policy options between two levels of government with different objectives. This matches the findings of Caplan and Silva (1997) and Cornes and Silva (1999).

3.4 Federal Model with Centralized Leadership

Now, let us consider the case where the order of decision making is reversed. In the first stage, the central government sets its transfer policy. Following this, the regional governments simultaneously choose their levels of abatement and production of e to reach a non-cooperative Nash equilibrium in the second stage.

Solving the problem with backwards induction, we first look at the regional governments' problem. The regional governments take T_j and the actions of the other region as given and set a_j and e_j accordingly, subject to the budget constraint (2), which is substituted into the utility function. Due to the quasi-linearity of the utility function, T_j will be independent of a_j and e_j. For region one, the problem is:

$$\text{Max}_{a_1,e_1}\ n_1 U\left(\frac{I_1 - pe_1 - C_1(a_1) + T_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right) \tag{19}$$

And the first order conditions are:

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial a_1} &\Rightarrow U'(1)[-C_1' + D_1'] = 0 \\
&\Rightarrow C_1' = D_1' \qquad (20)\\
\frac{\partial \mathcal{L}}{\partial e_1} &\Rightarrow U'(1)[-p + B_1' - D_1'] = 0 \\
&\Rightarrow B_1' = p + D_1' \qquad (21)
\end{aligned}$$

By symmetry, we find equivalent results for region two.

Next, consider the central government's choice, anticipating the actions of the regional governments in the second stage:

$$\begin{aligned} \text{Max}_{T_1}\, W = n_1 U &\left(\frac{I_1 - pe_1 - C_1(a_1) + T_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1} \right) \\ +n_2 U &\left(\frac{I_2 - pe_2 - C_2(a_2) - T_1 + B_2(e_2) - D_2(e_1 - a_1 + e_2 - a_2)}{n_2} \right) \end{aligned} \tag{22}$$

This yields the first order condition:

$$\frac{\partial W}{\partial T_1} \Rightarrow U'(1) - U'(2) = 0 \tag{23}$$

$$\Rightarrow U(1) = U(2) \tag{24}$$

Notice that (23) and (24) match (8) and (13) respectively, but (20) $\neq$ (9) and (21) $\neq$ (10). Interpreting these results, we see that, with centralized leadership, the central government can make transfers so as to achieve uniform per capita utility across the two regions. However, since the regions receive the transfer before they make their abatement and production choices, the transfer does not lead to internalization of the pollution externality. Rather, the regional governments equate the marginal cost of abatement to the *regional* marginal damage of pollution, and equate the marginal benefit of e to the market price plus the *regional* marginal emission damage. This means the regions underprovide abatement and overproduce e. This free-riding results in lower absolute utility within the federation than with decentralized leadership. Thus, we achieve an inefficient result with centralized leadership. As shown in Caplan and Silva (1997) and Caplan et al. (2000), centralized leadership is, in general, inefficient for model formulations such as the one presented in this paper.

What if there was no central government at all, but regions could make voluntary non-negative transfers to each other? It is apparent that $T_1 = T_2 = 0$ in this case. A lump sum transfer to to the other region would lower regional income for the donor without influencing abatement levels or production of e for the receiver. Therefore, there would be no reason for regional governments to make transfers to each other, and there is a need for a central government. This suggests that, in the global context, optimal pollution control cannot be achieved if we assume there is no migration between countries. While this result is uninteresting in the baseline model, we will see below that when the assumption of immobile labour is relaxed, this is not necessarily the case.

4 The Federal Model with Mobile Labour

4.1 Introduction of Mobile Labour

We now relax the assumption of immobile labour, and adopt the more realistic assumption that residents will move from one region to the other if they expect their utility to increase through migration. Residents in either region can move between the regions according to their preferences, but each resident has an innate and heterogenous preference for one region over the other. Following Mansoorian and Myers (1993), residents have an 'attachment to home' parameter in their utility function to represent their regional preference. Residents move after all levels of government have set their policies, i.e. in the last stage of the game.

Each resident supplies one unit of labour, so residents are both consumers and labourers. It is assumed that each consumer supplies one unit of identical labour and, as before, all consumers have identical preferences for consumption. In the baseline model, we represented starting income as I_j and assumed it to be exogenous. However, with mobile labour, income can no longer be treated as exogenous, as the amount of labour in a region will determine the income each receives. As more labour enters a region, the average product of labour, and therefore the individual wage received for working, decreases.

At this point, we must add further notation. Let $L =$ land, a fixed factor within the region. $n =$ a consumer on a population continuum from 0 to 1. Setting the total population of the federation to one will streamline the analysis from here on in without loss of generality. Consumer $n = 0$ receives the most benefit from being in region one. Consumer n_1 is the marginal consumer who is indifferent between the two regions. n_j = the amount of consumer who choose to leave in each region. Note that $n_2 = 1 - n_1$. Let b = the attachment to home parameter. If $b = 0$, then labour is perfectly mobile. If b is sufficiently high, then residents will never want to move and labour is immobile, as in the simpler case above. Let $F(n, L) = f(n) =$ the production function of each region. $f(n_j)/n_j$ = the average product of labour in region j. This construction mimics the model presented in Caplan et al. (2000), though their work discusses public goods rather than environmental externalities.

For simplicity, we assume there is one representative firm in each region that produces x, e, and a. As with regional decision making, we assume that, despite the small number of firms, they face perfect competition. The firms have constant returns to scale in labour and land, but decreasing returns to scale in labour by itself. Residents in a given region receive the average product of labour generated in that region. In other words, they receive their marginal product of labour, supplied competitively, as well as an equal share of the economic rents generated by the firm from production in the region. The regional budget constraint, becomes $x_j + pe_j + C_j(a_j) = f(n_j) + T_j$. Written in per capita terms, we have:

$$\frac{x_j}{n_j} = \frac{f(n_j) - pe_j - C_j(a_j) + T_j}{n_j} \tag{25}$$

As mentioned previously, as consumers move to the region, per capita income decreases. In essence, migrants impose a 'wage-loss' externality on those who already reside within a region. Migrants move to a new region in order to garner higher wages. However, they do not take into account that, by moving, they decrease the average marginal product of labour in their destination region, lowering returns for everyone in the region. This is based on the assumption that rents generated by production are shared equally amongst all residents which end the game in the region. In other words, the division of rents amongst original residents and migrants leads to a smaller share for all. It is this mechanism which may lead to another reason for government intervention. Not only must environmental efficiency be achieved, but population distribution efficiency is a second issue which must be examined when the federation has mobile labour.

After substituting in budget constraint (25), the per person utility in region one is:

$$U\left(\frac{f(n_1) - pe_1 - C_1(a_1) + T_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right) + b(1-n)$$

and in region two, the utility function is:

$$U\left(\frac{f(n_2) - pe_2 - C_2(a_2) + T_2 + B_2(e_2) - D_2(e_1 - a_1 + e_2 - a_2)}{n_2}\right) + bn$$

Consumers will move so as to maximize utility, leaving us with the migration constraint:

$$\begin{aligned} &U\left(\frac{f(n_1) - pe_1 - C_1(a_1) + T_1 + B_1(e_1) - D_1(e_1 - a_1 + e_2 - a_2)}{n_1}\right) + b(1-n_1) \\ &= U\left(\frac{f(1-n_1) - pe_2 - C_2(a_2) + T_2 + B_2(e_2) - D_2(e_1 - a_1 + e_2 - a_2)}{1-n_1}\right) + bn_1 \quad (26) \end{aligned}$$

making use of the fact that $n_2 = 1 - n_1$. Note that, to simplify notation, I will often use E_j to represent $-pe_j - C_j(a_j) + B_j(e_j) - D_j(e_1 - a_1 + e_2 - a_2)$ from this point on.

4.2 The Social Planner's Problem with Mobile Labour

Let us now consider the social planner's problem with mobile labour. We assume the social planner wishes to maximize per capita utility across all regions. To do this, the social planner considers the final destination of residents. So, after substituting in (2), $n_2 = 1 - n_1$, and $T_2 = -T_1$, the social planner problem[2] becomes:

$$\begin{aligned} \text{Max}_{a_j,e_j,T_j,n_j}\ W = n_1 U\left(\frac{f(n_1) + E_1 + T_1}{n_1}\right) + bn_1 - \int_0^{n_1} n\mathrm{d}n \\ + (1-n_1)U\left(\frac{f(1-n_1) + E_2 - T_1}{1-n_1}\right) + \int_{n_1}^{1} n\mathrm{d}n \qquad (27) \end{aligned}$$

subject to (26). This yields the Lagrangian:

[2]The maximization problem follows the setup of Boadway et al. (2009) rather than of Mansoorian and Myers (1993) and Caplan et al. (2000), as we find the former a more realistic assumption.

$$
\begin{aligned}
\mathcal{L} = & n_1 U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) + bn_1 - \int_0^{n_1} n\mathrm{d}n \\
& + (1-n_1)U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right) + \int_{n_1}^{1} n\mathrm{d}n \\
& - \lambda(U\left(\frac{f(n_1)+E_1+T_1}{n}\right) + b(1-n_1) - U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right) + bn_1)
\end{aligned} \quad (28)
$$

And the first order conditions:

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial T_1} & \Rightarrow \frac{n_1 U'(1)}{n_1} - \frac{(1-n_1)U'(2)}{1-n_1} - \lambda\left[\frac{U'(1)}{n_1} + \frac{U'(2)}{1-n_1}\right] = 0 \\
& \Rightarrow U'(1)\left[\frac{n_1-\lambda}{n_1}\right] = U'(2)\left[\frac{1-n_1+\lambda}{1-n_1}\right] && (29) \\
\frac{\partial \mathcal{L}}{\partial a_1} & \Rightarrow U'(1)[-C_1'+D_1']\left[\frac{n_1-\lambda}{n_1}\right] - U'(2)[D_2']\left[\frac{1-n_1+\lambda}{1-n_1}\right] = 0 && (30) \\
\frac{\partial W}{\partial a_2} & \Rightarrow U'(1)[D_1']\left[\frac{n_1-\lambda}{n_1}\right] - U'(2)[-C_2'+D_2']\left[\frac{1-n_1+\lambda}{1-n_1}\right] = 0 && (31) \\
\frac{\partial W}{\partial e_1} & \Rightarrow U'(1)[-p+B_1'-D_1']\left[\frac{n_1-\lambda}{n_1}\right] - U'(2)[-D_2']\left[\frac{1-n_1+\lambda}{1-n_1}\right] = 0 && (32) \\
\frac{\partial W}{\partial e_2} & \Rightarrow U'(1)[D_1']\left[\frac{n_1-\lambda}{n_1}\right] - U'(2)[-p+B_2'-D_2']\left[\frac{1-n_1+\lambda}{1-n_1}\right] = 0 && (33) \\
\frac{\partial W}{\partial n_1} & \Rightarrow U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) + U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[1-\frac{\lambda}{n_1}\right] \\
& \quad + b - bn_1 - U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right) \\
& \quad + U'(2)\left[\frac{-(1-n_1)f'(1-n_1) + f(1-n_1) + E_2 - T_1}{1-n_1}\right]\left[1+\frac{\lambda}{1-n_1}\right] - bn_1 + 2\lambda b = 0 \\
& \Rightarrow U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[1-\frac{\lambda}{n_1}\right] \\
& \quad - U'(2)\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]\left[1+\frac{\lambda}{1-n_1}\right] = -2\lambda b && (34)
\end{aligned}
$$

(34) is derived from $\partial W/\partial n_1$ after cancelling out terms with the aid of the migration constraint.

Combining (29) and (30), (29) and (31), (29) and (32), and (29) and (33), we find that the optimal results are the same as those from the social planner's problem with immobile labour. Specifically, we find that $C_1' = D_1' + D_2' = C_2'$ and $B_1' =$

$D_1' + D_2' - p = B_2'$. These match conditions (9) and (10), so the environmental externality is internalized. However, due to labour mobility, we must also find the condition for migrational efficiency. Rearranging (29), we find:

$$\lambda = \frac{U'(1) - U'(2)}{\frac{U'(1)}{n_1} + \frac{U'(2)}{1-n_1}} \tag{35}$$

Substituting λ from (35) into (34) and eliminating the denominator $U'(1)/n_1 + U'(2)/(1-n_1)$, we have:

$$\Rightarrow U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1^2}\right]\left[\frac{n_1 U'(1)}{n_1} + \frac{n_1 U'(2)}{1-n_1} - U'(1) + U'(2)\right]$$
$$- U'(2)\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_12) - E_2 + T_1}{(1-n_1)^2}\right]$$
$$\left[\frac{(1-n_1)U'(1)}{n_1} + \frac{(1-n_1)U'(2)}{1-n_1} + U'(1) - U'(2)\right] = -2b[U'(1) - U'(2)]$$
$$\Rightarrow \left[\frac{U'(1)}{n_1}\right]\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[\frac{U'(2)}{1-n_1}\right]$$
$$- \left[\frac{U'(2)}{1-n_1}\right]\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]\left[\frac{U'(1)}{n_1}\right] = 2b[U'(2) - U'(1)]$$

Collecting like terms and rearranging:

$$\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1)f'(1-n_1) - f(1-n_12) - E_2 + T_1}{1-n_1}$$
$$= 2b[U'(2) - U'(1)]\left[\frac{n_1(1-n_1)}{U'(1)U'(2)}\right]$$
$$\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1)f'(1-n_1) - f(1-n_12) - E_2 + T_1}{1-n_1}$$
$$= 2b\left[\frac{n_1(1-n_1)}{U'(1)} - \frac{n_1(1-n_1)}{U'(2)}\right] \tag{36}$$

Equation (36) is the standard efficient population distribution condition as discussed in Mansoorian and Myers (1993), Wellisch (1995), and Caplan et al. (2000). It shows us the efficient population distribution, which can be achieved by the social planner through its choice of transfers. From this, we see that T_j is a function of n_1. With imperfectly mobile labour, utilities in each region can differ based on the preferences for population size in each region, giving us an equation similar to (8, but accounting for migration (Wellisch, 1995, p. 172).

4.3 Analysis of Condition (36) Under Perfectly Mobile Labour

To simplify matters, this paper will first study the mobile labour model under the assumption of perfectly mobile labour. In this case, residents have no attachment to home, and therefore the parameter $b = 0$. Therefore, the efficient population distribution condition (36) simplifies to:

$$\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} = \frac{(1-n_1)f'(1-n_1) - f(1-n_12) - E_2 + T_1}{1-n_1} \tag{37}$$

Note that $f(n_j) - n_j f'(n_j) = R_j(n_j)$, where $R_j(n_j)$ is the rents accrued to the firms from production, and is a function of the labour force employed. Substituting in $R_j(n_j)$, denoted as R_j below, and rearranging our population distribution equation (37) to isolate for T_1, we have:

$$\begin{aligned}
&\Rightarrow \frac{-R_1 - E_1}{n_1} - \frac{T_1}{n_1} = \frac{-R_2 - E_2 + T_1}{1-n_1} + \frac{T_1}{1-n_1} \\
&\Rightarrow \frac{T_1}{n_1(1-n_1)} = \frac{(1-n_1)E_2 - n_1E_1 + (1-n_1)R_2 - n_1R_1}{n_1(1-n_1)} \\
&\Rightarrow T_1 = n_2R_2 - n_1R_1 + n_2E_2 - n_1E_1 \qquad (38)
\end{aligned}$$

This rearrangement of the population distribution condition shows us that T_1 and T_2 are functions $T_j(n, a, e)$. The transfer level depends on two main aspects. The first is the difference in rents accrued by the firm in each region due to the differing populations. Since rents are assumed to be distributed equally within the region in which they are accrued, one region may accumulate higher production rents. As a result, there may be a need for a lump sum transfer from the high rent region to the low rent region, as shown by the $n_2R_2 - n_1R_1$ portion of (38). This is a standard result in the federal equalization literature (see Boadway and Flatters (1982), Boadway (2004)).

The second factor affecting T_1 is the difference between the effects of pollution on the two regions. Recall that E_j represents $-pe_j - C_j(a_j) + B_j(e_j) - D_j(e_1 - a_1 + e_2 - a_2)$. Differences between E_1 and E_2 are the result of differing costs of abatement, damages from pollution, and benefits from consumption of e. These differences result in a possible need for a lump sum transfer from the region with low costs of abatement/low damages from pollution to the region more susceptible to clean-up/pollution damages. This is shown by the $n_2E_2 - n_1E_1$ portion of (38).

4.4 Decentralized Leadership with Perfectly Mobile Labour

Let us now consider the decentralized solution with perfectly mobile labour. With mobile labour, a third stage in which labour has the option to move between regions is added to the game. Mitsui and Sato (2001) discusses whether, when the goal of the central government is equity, a migration equilibrium can be reached. They show that, even if migration takes place before governments commit to their policies, migrants anticipate the policy and migrate according to their perceived best interest. There are a multiplicity of equilibria, but migration efficiency can be achieved. Though our welfare function aims to maximize efficiency, in the immobile labour case in section 3.3, and in the mobile case below, our results also maximize equity. It might be interesting to allow labour to migrate before policies are chosen. However, this paper solely follows the ordering used in both Caplan and Silva (1997) and Caplan et al. (2000). The three stage game played in the decentralized solution is ordered as follows:

1. competing regions choose policies which set abatement levels and production of emitting goods
2. the central government chooses the lump sum transfer level between jurisdictions
3. consumers choose whether to move or reside in their original district.

It is apparent that actions taken in the third stage lead to the migration constraint. When $b = 0$, the migration constraint (26) simplifies to:

$$U\left(\frac{f(n_1) + E_1 + T_1}{n}\right) = U\left(\frac{f(1-n_1) + E_2 - T_1}{1-n_1}\right) \tag{39}$$

In the second stage, The central government anticipates the migration pattern which will take place in the third period and taking e_j and a_j as given. Therefore, the government chooses T_j and n_j so as to maximize per capita welfare subject to the budget and migration constraint. Substituting budget constraint into the utility functions (25), the Lagrangian is:

$$\begin{aligned}\mathcal{L}_{n_1,T_1} &= n_1 U\left(\frac{f(n_1)+E_1+T_1}{n}\right) + (1-n_1)U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right) \\ &\quad - \lambda(U\left(\frac{f(n_1)+E_1+T_1}{n}\right) - U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right)) \end{aligned} \tag{40}$$

And its first order conditions are:

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial T_1} &\Rightarrow \frac{n_1 U'(1)}{n_1} - \frac{(1-n_1)U'(2)}{1-n_1} - \lambda\left[\frac{U'(1)}{n_1} + \frac{U'(2)}{1-n_1}\right] = 0 \\ &\Rightarrow U'(1)\left[\frac{n_1-\lambda}{n_1}\right] = U'(2)\left[\frac{1-n_1+\lambda}{1-n_1}\right] \end{aligned} \tag{41}$$

$$\begin{aligned}\frac{\partial W}{\partial n_1} &\Rightarrow U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) - U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right) \\ &\quad + U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[1 - \frac{\lambda}{n_1}\right] \\ &\quad + U'(2)\left[\frac{-(1-n_1)f'(1-n_1) + f(1-n_1) + E_2 - T_1}{1-n_1}\right]\left[1 + \frac{\lambda}{1-n_1}\right] = 0 \\ &\Rightarrow U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[1 - \frac{\lambda}{n_1}\right] \\ &\quad - U'(2)\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]\left[1 + \frac{\lambda}{1-n_1}\right] = 0 \end{aligned} \tag{42}$$

after eliminating the first terms in (42) using (39). Substituting (41) into (42):

$$\begin{aligned}&\Rightarrow U'(1)\left[1 - \frac{\lambda}{n_1}\right]\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right] \\ &\quad = 0 \\ &\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} = \frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1} \end{aligned} \tag{43}$$

This is the same population distribution condition (37) derived from the social planner's problem, so migrational efficiency is achieved.

Next, consider the first stage of the game and the actions of region one, which must maximize per capita welfare for citizens which end the game within their jurisdiction, subject to the budget constraint and the population distribution condition.

Note that, since the condition derived from the the central government's stage already takes into account the migration constraint and maximizes n_j accordingly, the region governments' problems only involve maximization subject to a_j, e_j, and $T_j(a_j, e_j, n_j) = T_j$. The regional government can maximize subject to T_j by treating T_j as an artificial control variable. The regions know how the central government will react when choosing T_j, so by treating this reaction as a constraint on their own actions, they can anticipate T_j and therefore choose policies based on this anticipation. The Lagrangian for region one becomes:

$$\mathcal{L}_{a_1,e_1,T_1} = U\left(\frac{f(n_1) + E_2 + T_1}{n_1}\right) \\ - \lambda\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right] \tag{44}$$

and the first order conditions are:

$$\frac{\partial \mathcal{L}}{\partial T_1} \Rightarrow \frac{U'(1)}{n_1} - \lambda\left[\frac{-1}{n_1} + \frac{-1}{1-n_1}\right] = 0$$

$$\Rightarrow \frac{U'(1)+\lambda}{n_1} = -\frac{\lambda}{1-n_1} \tag{45}$$

$$\frac{\partial \mathcal{L}}{\partial a_1} \Rightarrow \frac{U'(1)+\lambda}{n_1}(-C_1' + D_1') - \frac{\lambda}{1-n_1}(D_2') = 0 \tag{46}$$

$$\frac{\partial \mathcal{L}}{\partial e_1} \Rightarrow \frac{U'(1)+\lambda}{n_1}(-p + B_1' - D_1') - \frac{\lambda}{1-n_1}(-D_2') = 0 \tag{47}$$

Substituting (45) into (46), we find

$\Rightarrow \frac{U'(1)+\lambda}{n_1}(-C_1' + D_1') + \frac{U'(1)+\lambda}{n_1}(D_2') = 0$

$\Rightarrow C_1' = D_1' + D_2'$

Substituting (45) into (47)

$\Rightarrow \frac{U'(1)+\lambda}{n_1}(-p + B_1' - D_1') + \frac{U'(1)+\lambda}{n_1}(-D_2') = 0$

$\Rightarrow B_1' = p + D_1' + D_2'$

By symmetry, we find the same results in region two. These conditions match (9) and (10), so the regions internalize the environmental externality and the socially efficient conditions for the production of a and e are realized for region one. We find that with decentralized leadership, lump sum transfers by the federal government, and perfect labour mobility, efficiency can be achieved.

4.5 Decentralized Leadership, Maximizing Total Regional Utility

In section 4.4, it was assumed that regional governments wished to maximize per capita utility of final residents in their region. In this case, regions have an interest in influencing migration levels to or from their region. However, the number of final residents does not inherently matter to them; it can be high or low, as long as it maximizes per capita utility of the residents. This also holds when regions want to maximize per capita utility of original residents. The number of original residents are fixed, so such an analysis would resemble the no mobility case in section 3.3.

Now, consider a scenario where the regions aim to maximize total regional utility rather than per capita regional utility. A plausible explanation for this would be a political economy motivation. Perhaps regional governments also compete for the prestige and power associated with becoming the most populous region or country while still maintaining a high standard of living. Another explanation would be if the government was also providing a public good, with the per person tax needed to fund the good decreasing as population increases. The addition of a public good will not be modeled explicitly here, but rather serves as a theoretical concept to explain why a region might care about its population size. Golden et al. (1996, pp. 35-36, 111-17) and Slack (2002) discuss the importance of dense development over suburban development to increase municipal government revenues. If regions are considered to be municipalities, this provides motivation for maximizing total rather than per capita utility.

The third and second stages of the game remain the same in this new formulation. As a result, population distribution efficiency will hold, as the central government sets lumps sum transfers to fulfil this condition. However, the regional governments have a slightly different problem, and wish to maximize $n_jU([f(n_j)+E_j+T_j]/n_j)$. Notice the n_1 term preceding the utility function. Therefore, the Lagrangian for region one becomes:

$$\mathcal{L}_{T_1,a_1,e_1} = n_1 U\left(\frac{f(n_1)+E_2+T_1}{n_1}\right) - \lambda\left[\frac{n_1 f'(n_1)-f(n_1)-E_1-T_1}{n_1} - \frac{(1-n_1)f'(1-n_1)-f(1-n_1)-E_2+T_1}{1-n_1}\right] \tag{48}$$

The first order conditions are:

$$\frac{\partial\mathcal{L}}{\partial T_1} \Rightarrow \frac{n_1U'(1)}{n_1} - \lambda\left[\frac{-1}{n_1}+\frac{-1}{1-n_1}\right]=0$$

$$\Rightarrow \frac{n_1U'(1)+\lambda}{n_1}+\frac{\lambda}{1-n_1}=0 \tag{49}$$

$$\frac{\partial\mathcal{L}}{\partial a_1} \Rightarrow \frac{n_1U'(1)+\lambda}{n_1}(-C_1'+D_1') - \frac{\lambda}{1-n_1}(D_2')=0 \tag{50}$$

$$\frac{\partial\mathcal{L}}{\partial e_1} \Rightarrow \frac{n_1U'(1)+\lambda}{n_1}(-p+B_1'-D_1') - \frac{\lambda}{1-n_1}(-D_2')=0 \tag{51}$$

Substituting (49) into (50), we find:

$\Rightarrow \frac{n_1U'(1)+\lambda}{n_1}(-C_1'+D_1') + \frac{n_1U'(1)+\lambda}{n_1}(D_2')=0$

$\Rightarrow C_1' = D_1' + D_2'$

Substituting (49) into (51)

$\Rightarrow \frac{n_1U'(1)+\lambda}{n_1}(-p+B_1'-D_1') + \frac{n_1U'(1)+\lambda}{n_1}(-D_2')=0$

$\Rightarrow B_1' = p + D_1' + D_2'$

By symmetry, optimizing for region two yields the same results. These results match equations (9) and (10). Somewhat surprisingly, we find that, even when competitive regions try to maximize total utility, we achieve the socially efficient environmental and migrational outcomes, and no free-riding takes place. This is because regions know that, in stage two, the central government will set lump sum transfers so as to achieve efficiency in population distribution. In essence, despite the change in priorities for the regions, they have no more control than before over population distribution, and can not change their respective populations effectively. They can, however, maximize utility for their residents by achieving environmental efficiency, so incentive equivalance remains and regions choose nationally optimal levels of a and e.

4.6 A Federation with Perfectly Mobile Labour and No Central Government

In this section, we consider the case where there is no central government at all. Regional governments, which wish to maximize per capita utility, set their abatement and emissions policies and can also make a voluntary non-negative lump sum transfer to the other jurisdiction (as introduced by Mansoorian and Myers (1993)). For the purposes of this paper, the transfer received can be negative or positive[3], so we ignore the non-negative condition in the analysis. Since there is no central government, the regions maximize per capita welfare with respect to a_j, e_j, T_j, and n_j subject to the budget and migration constraints (where $b = 0$) (25) and (26), respectively. This yields the following Lagrangian for region one:

$$\begin{aligned}\mathcal{L}_{a_1,e_1,T_1,n_1} = {} & U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) \\ & - \lambda(U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) - U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right))\end{aligned} \tag{52}$$

and first order conditions:

$$\frac{\partial \mathcal{L}}{\partial T_1} \Rightarrow U'(1)\left[\frac{1-\lambda}{n_1}\right] - U'(2)\left[\frac{\lambda}{1-n_1}\right] = 0 \tag{53}$$

$$\frac{\partial \mathcal{L}}{\partial a_1} \Rightarrow U'(1)\left[-C_1' + D_1'\right]\left[\frac{1-\lambda}{n_1}\right] + U'(2)\left[D_2'\right]\left[\frac{\lambda}{1-n_1}\right] = 0 \tag{54}$$

$$\frac{\partial \mathcal{L}}{\partial e_1} \Rightarrow U'(1)\left[-p + B_1' - D_1'\right]\left[\frac{1-\lambda}{n_1}\right] + U'(2)[-D_2']\left[\frac{\lambda}{1-n_1}\right] = 0 \tag{55}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial n_1} \Rightarrow {} & U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[\frac{1-\lambda}{n_1}\right] \\ & + U'(2)\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]\left[\frac{\lambda}{1-n_1}\right] = 0\end{aligned} \tag{56}$$

[3] Though transfers are technically non-negative, we know $\sum_{j=1}^{2} T_j = 0$, $T_2 = -T_1$, so one region will receive a positive net transfer and one a negative net transfer (except in the special case where $T_1 = T_2$). This is the case even if regions are not optimizing and both give positive transfers to each other.

From (53) and (54) we derive:

$$\Rightarrow C_1' = D_1' + D_2'$$

From (53) and (55) we derive:

$$\Rightarrow B_1' = p + D_1' + D_2'$$

From (53) and (56) we derive:

$$\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} = \frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{(1-n_1)}$$

By symmetry, the same results hold for region two. These conditions match (9), (10), and (37), the efficient results derived from the social planner's problem. Note that the ability for the regions to achieve condition (53) depends critically on the assumption that voluntary transfers can be made. If regions cannot make voluntary lump sum transfers, as in Boadway (1982), population distribution efficiency cannot be achieved. However, assuming transfers are a policy option for the regions, both types of externalities present in this model are internalized by the regional governments when faced with perfectly mobile labour. Even though the regions are not cooperating, they induce levels of a_j, e_j, T_j and n_j such that pollution levels are socially efficient for the federation as a whole. Regions are aware that higher a and lower e can more effectively combat global pollution levels in one region over the other, and make production and transfer choices accordingly. Moreover, the population distribution between the two regions is also socially efficient, despite the fact that regions can raise per capita wages by inducing labour to migrate to the other region. This important result shows us that, if regions are able to make voluntary transfers to each other and with perfectly mobile labour, there is no need for a central government to achieve incentive equivalence. The regions will voluntarily make the necessarily transfers to achieve both environmental and population distribution efficiency without federal guidance. This matches the results of Mansoorian and Myers (1993). This is positive news for global pollution problems. If we believe the assumptions made in this section, than it is possible that countries will optimally control pollution even without a global governing body.

4.7 No Central Government and Regions Maximizing Total Utility

We again consider the case where regional governments wish to maximize total regional utility rather than per capita utility. However, this time, there is no central government, and regions can make voluntary lump sum transfers between themselves. The Lagrangian for region one is:

$$\mathcal{L}_{a_1,e_1,T_1,n_1} = n_1 U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) - \lambda(U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) - U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right)) \tag{57}$$

and the first order conditions are:

$$\frac{\partial \mathcal{L}}{\partial T_1} \Rightarrow U'(1)\left[\frac{n_1-\lambda}{n_1}\right] - U'(2)\left[\frac{\lambda}{1-n_1}\right] = 0 \tag{58}$$

$$\frac{\partial \mathcal{L}}{\partial a_1} \Rightarrow U'(1)[-C_1'+D_1']\left[\frac{n_1-\lambda}{n_1}\right] + U'(2)[D_2']\left[\frac{\lambda}{1-n_1}\right] = 0 \tag{59}$$

$$\frac{\partial \mathcal{L}}{\partial e_1} \Rightarrow U'(1)[-p+B_1'-D_1']\left[\frac{n_1-\lambda}{n_1}\right] + U'(2)[-D_2']\left[\frac{\lambda}{1-n_1}\right] = 0 \tag{60}$$

$$\frac{\partial \mathcal{L}}{\partial n_1} \Rightarrow U(1) + U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[\frac{1-\lambda}{n_1}\right] + U'(2)\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]\left[\frac{\lambda}{1-n_1}\right] = 0 \tag{61}$$

From (58) and (59) we derive:

$$\Rightarrow C_1' = D_1' + D_2'$$

From (58) and (60) we derive:

$$\Rightarrow B_1' = p + D_1' + D_2'$$

These conditions are the same as the socially efficient results (9) and (10). From (58) and (61) we derive:

$$\Rightarrow U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]\left[\frac{1-\lambda}{n_1}\right] + U(1) = 0 \tag{62}$$

By symmetry, we would find the same results for region two. It is apparent that environmental efficiency is achieved within both regions. However, (62) $\neq$ (37). With no central government and regions competing to maximize total utility, population distribution efficiency is not achieved. In section 4.5, regions could not control their own population levels because the central government would make lump sum transfers in the following stage. The externality of attracting to many (few) residents was internalized. In this section, regions can influence n_j, so will draw more than the socially efficient number of migrants to their region. This case highlights that, even with perfect labour mobility, political economy concerns provide a reason for central government intervention in regional policy making to achieve efficiency. In the global context, if we believe countries are concerned with total rather than per capita utility, this result does not bode well for achieving social efficient levels of pollution and migration. While environmental efficiency can be achieved given the number of people living in each country, distortions in the population levels of each country mean that absolute levels of emissions and abatement will likely be too high and low, respectively.

4.8 Analysis of Federal Model with Imperfectly Mobile Labour

With both immobile labour and perfectly mobile labour, the central government will equate utilities between regions when maximizing welfare, as show in equations (8) and (13). In the first case, since mobile labour does not act as a constraint, the central government chooses transfer levels so as to maximize per capita welfare across regions as seen in section 3.3. With perfectly mobile labour, the migration actions of residents handcuff the government into equating utilities, as residents will move to the region with higher utility. Therefore, utility in each region will equalize as migrants relocate, as discussed in section 4.4. Having analyzed the simpler cases of decentralized solutions with immobile and perfectly mobile labour, the analysis now returns to the model using imperfectly mobile labour.

With imperfectly mobile labour, each individual achieves a different utility based on their attachment to home. Utility is not equalized across regions or individuals. Rather, it is only equalized for the inframarginal individual who is indifferent between which region they will live in. Those with high attachments to home will have higher utility than the inframarginal person in this case. Next, we will show results when there are competing regional governments capable of making voluntary, non-negative lump sum transfers between themselves.

4.9 A Federation with No Central Government and Imperfectly Mobile Labour

Consider the case where there is no central government, and regions can make voluntary lump sum transfers to each other. Recall that, with perfectly mobile labour, this formulation could achieve both environmental and migrational efficiency. With immobile labour, environmental efficiency is not achieved, and migrational efficiency is not an issue as migration cannot take place. With only a central government acting as national social planner, environmental efficiency could be obtained for the country as a whole with immobile, imperfectly mobile, and perfectly mobile labour, and migrational efficiency is obtained for imperfectly and perfectly mobile labour. It is now assumed regions aim to maximize the utility of those who begin the period in their region. It is also assumed that consumer utility maximization in the federation requires migration from region one to region two[4].

In addition to the existing notation, we must add some new variables. Let: n_0 = the population which begins in region one. Note that this means the population beginning in region two $= 1 - n_0$. n_M = the population which migrates away from region one to region two. This means $n_1 = n_0 - n_M$ and that n_1 changes inversely as n_M changes, so $n_1 + n_M = n_0$ is a constant and does not vary.

First, the maximization problem for region one subject to the budget constraint (25) and the migration constraint (26) is solved using the familiar Lagrangian:

[4]In other words, we ignore the special case where no migration is needed by sheer coincidence. This arbitrary choice of migration direction is without loss of generality, as if it were reversed, the results would be equivalent.

$$\mathcal{L}_{a_j,e_j,n_j,T_j} = n_1 U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) + bn_1 - b\int_0^{n_1} n dn$$
$$+ (n_0 - n_1)U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right) + b\int_{n_1}^{n_0} n dn$$
$$- \lambda(U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right) + b(1-n_1) - U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right) + bn_1) \tag{63}$$

Note the change in the interval over which the integrals are taken. Moreover, since region one cares about all the residents which start in its region, it cases about the fraction $n_M = n_0 - n_1$ which will garner their utility in region two. Taking the first order conditions yields:

$$\frac{\partial \mathcal{L}}{\partial T_1} \Rightarrow U'(1)\left[\frac{n_1-\lambda}{n_1}\right] - U'(2)\left[\frac{n_0-n_1+\lambda}{1-n_1}\right] = 0 \tag{64}$$
$$\Rightarrow \lambda = \frac{U'(1) - \frac{n_0-n_1}{1-n_1}U'(2)}{\frac{U'(1)}{n_1} + \frac{U'(2)}{1-n_1}}$$
$$\Rightarrow \lambda = \frac{n_1(1-n_1)U'(1) - n_1(n_0-n_1)U'(2)}{(1-n_1)U'(1) + n_1 U'(2)} \tag{65}$$
$$\frac{\partial \mathcal{L}}{\partial a_1} \Rightarrow U'(1)[-C_1' + D_1']\left[\frac{n_1-\lambda}{n_1}\right] + U'(2)[D_2']\left[\frac{n_0-n_1+\lambda}{1-n_1}\right] = 0 \tag{66}$$
$$\frac{\partial \mathcal{L}}{\partial e_1} \Rightarrow U'(1)[-p + B_1' - D_1']\left[\frac{n_1-\lambda}{n_1}\right] + U'(2)[-D_2']\left[\frac{n_0-n_1-\lambda}{1-n_1}\right] = 0 \tag{67}$$
$$\frac{\partial \mathcal{L}}{\partial n_1} \Rightarrow U(1) + n_1 U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1^2}\right] + b - bn_1$$
$$- U(2) + (n_0-n_1)U'(2)\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-{n_1}^2}\right] - bn_1$$
$$- \lambda[U'(1)\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1^2}\right] - b]$$
$$- \lambda[U'(2)\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-{n_1}^2}\right] + b] = 0$$
$$\Rightarrow U(1) + b(1-n_1) - U(2) - bn_1 + U'(1)\left[\frac{n_1-\lambda}{n_1}\right]\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]$$
$$- U'(2)\left[\frac{n_0-n_1+\lambda}{1-n_1}\right]\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right] = -2b\lambda \tag{68}$$

Combining (64) and (66) shows that:

$$\Rightarrow C_1' = D_1' + D_2'$$

Combining (64) and (67) shows that:

$$\Rightarrow B_1' = p + D_1' + D_2'$$

So conditions (9) and (10) are satisfied. Finding the population distribution condition is more complicated. Substituting the value for λ from (65) into (68), cancelling out terms due to the migration constraint, and eliminating the common denominator give us:

$$\Rightarrow \frac{U'(1)}{n_1}\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\left[\frac{n_1}{n_1}U'(1) + \frac{n_1}{1-n_1}U'(2) - U'(1) - \frac{n_0 - n_1}{1-n_1}U'(2)\right] +$$
$$\frac{U'(2)}{1-n_1}\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]$$
$$\left[\frac{n_0 - n_1}{n_1}U'(1) + \frac{n_0 - n_1}{1-n_1}U'(2) + U'(1) - \frac{n_0 - n_1}{1-n_1}U'(2)\right] = -2b[U'(1) - \frac{n_0 - n_1}{1-n_1}U'(2)]$$
$$\Rightarrow \frac{U'(1)}{n_1}\left[\frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1}\right]\frac{n_0}{1-n_1}U'(2)$$
$$+ \frac{U'(2)}{1-n_1}\left[\frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}\right]\frac{n_0}{n_1}U'(1) = -2b[U'(1) - \frac{n_0 - n_1}{1-n_1}U'(2)]$$
$$\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}$$
$$= -2b[U'(1) - \frac{n_0 - n_1}{1-n_1}U'(2)]\left[\frac{n_1(1-n_1)}{n_0 U'(1)U'(2)}\right]$$
$$\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1)f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}$$
$$= 2b\left[\frac{n_1(n_0 - n_1)}{n_0 U'(1)} - \frac{n_1(1-n_1)}{n_0 U'(2)}\right] \tag{69}$$

Clearly, however, (69) $\neq$ (36), thus population distribution efficiency is not achieved in region one. Region one only considers the difference in population size preferences for those residents which start in region one when making decisions. Therefore, they do not face the global population distribution condition. Next, the same exercise is preformed for region two, which has positive immigration. Unlike region one, region two's maximization problem will consider a fraction of those which end up in region two, but no residents who live in region one. Following the same process as for region one, the Lagrangian is:

$$\mathcal{L}_{a_j,e_j,n_j,T_j} = (1-n_0)U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right)+b\int_{n_0}^{1} n\mathrm{d}n \\ -\lambda(U\left(\frac{f(n_1)+E_1+T_1}{n_1}\right)+b(1-n_1)-U\left(\frac{f(1-n_1)+E_2-T_1}{1-n_1}\right)+bn_1) \quad (70)$$

Taking the first order conditions:

$$\frac{\partial \mathcal{L}}{\partial T_1} \Rightarrow -U'(2)\left[\frac{1-n_0+\lambda}{1-n_1}\right]-U'(1)\left[\frac{\lambda}{n_1}\right]=0 \quad (71)$$

$$\Rightarrow \lambda = \frac{-\frac{1-n_0}{1-n_1}U'(2)}{\frac{U'(1)}{n_1}+\frac{U'(2)}{1-n_1}} \quad (72)$$

$$\frac{\partial \mathcal{L}}{\partial a_1} \Rightarrow U'(2)\left[\frac{1-n_0+\lambda}{1-n_1}\right][-C_2'+D_2']-U'(1)\left[\frac{\lambda}{n_1}\right][D_1']=0 \quad (73)$$

$$\frac{\partial \mathcal{L}}{\partial e_1} \Rightarrow U'(2)\left[\frac{1-n_0+\lambda}{1-n_1}\right][-p+B_2'-D_2']+U'(1)\left[\frac{\lambda}{n_1}\right][D_1']=0 \quad (74)$$

$$\frac{\partial \mathcal{L}}{\partial n_1} \Rightarrow -U'(2)\left[\frac{1-n_0+\lambda}{1-n_1}\right]\left[\frac{(1-n_1)f'(1-n_1)-f(1-n_1)-E_2+T_1}{1-n_1}\right] \\ -\frac{\lambda}{n_1}U'(1)\left[\frac{n_1f'(n_1)-f(n_1)-E_1-T_1}{n_1}\right]+2b\lambda=0 \quad (75)$$

Combining (71) and (73) shows that:

$$\Rightarrow C_1' = D_1' + D_2'$$

Combining (71) and (74) shows that:

$$\Rightarrow B_1' = p + D_1' + D_2'$$

From these conditions, it is clear to see that, once again, the efficient levels of e_2 and a_2 are obtained. The n_1 condition must be examined in more detail, as for region one. Cancelling out terms using the migration constraint, substituting in λ from (72), and cancelling out the denominators, we find:

$$\Rightarrow -\frac{U'(2)}{1-n_1}\left[\frac{1-n_0}{n_1}U'(1)+\frac{1-n_0}{1-n_1}U'(2)-\frac{1-n_0}{1-n_1}U'(2)\right] \\ \left[\frac{(1-n_1)f'(1-n_1)-f(1-n_1)-E_2+T_1}{1-n_1}\right] \\ +U'(1)U'(2)\left[\frac{1-n_0}{n_1(1-n_1)}\right]\left[\frac{n_1f'(n_1)-f(n_1)-E_1-T_1}{n_1}\right]=2b\left[\frac{1-n_0}{1-n_1}U'(2)\right]$$

$$\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1) f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}$$
$$= 2b \left[\frac{1-n_0}{1-n_1} U'(2) \right] \left[\frac{n_1(1-n_1)}{U'(1)U'(2)} \right]$$
$$\Rightarrow \frac{n_1 f'(n_1) - f(n_1) - E_1 - T_1}{n_1} - \frac{(1-n_1) f'(1-n_1) - f(1-n_1) - E_2 + T_1}{1-n_1}$$
$$= 2b \left[\frac{n_1(1-n_0)}{U'(1)} \right] \tag{76}$$

Since (76) $\neq$ (36), in region two, the efficient population distribution is not achieved for the same reason as in region one. With imperfectly mobile labour, regional governments will achieve environmental efficiency without a central government to guide them. However, even when they wish to maximize per capita utility and not total utility, regional governments cannot be relied on to provide incentives to reach population distribution efficiency with imperfectly mobile labour. This suggests a role for the central government if a country wishes to achieve social efficiency, though this paper does not explicitly show if a central government would be able to satisfy the population distribution condition. This is a negative result in the global context. It suggests that, if we assume low levels of labour mobility between counties, optimal pollutant levels will not be achieved.

5 Conclusion

There is a large body of literature on the role of mobile labour in a federation, especially in terms of its effect on public good provision. However, there has been little research on the effect of mobile labour on a federation where regions face an environmental externality. This shortcoming in the literature is addressed by this model. One would expect free-riding to occur due to the environmental externality. In a decentralized leadership scenario, however, competing regions can still be induced to set nationally optimal pollution policies depending on the degree of labour mobility. The baseline model showed that, with immobile labour and decentralized leadership, environmental efficiency can be achieved in a federation, as found in Caplan and Silva

(1997). When perfectly mobile labour is added to the model, both environmental and population distribution efficiency could be achieved with or without a central government if regions aimed to maximize regional utility. However, if regions try to maximize total utility within their region, a central government is required to achieve migrational efficiency. Population distribution efficiency is not achieved with imperfectly mobile labour and no central government. We could not discern whether social efficiency could be obtained with imperfectly mobile labour and two levels of government. Such an analysis would be an interesting topic for future research.

The results of this paper are positive for federal systems. It suggests that, even with labour mobility, nationally optimal levels of pollution control can be reached no matter what the goals of specific regions. The paper's results are mixed for the world system as a whole, however. If we assume there is a high degree of global labour mobility, and countries aim to maximize the per capita welfare of their citizens, there is hope that efficient levels of emissions and abatement will be undertaken. On the other hand, due to political economy motivations, we might plausibly assume countries try to maximize the absolute level of welfare in their country by attracting more citizens. In this case, migrational efficiency is not achieved. If we assume a lower degree of global labour mobility, we run into the same problem. To make matters worse, all of these results are based on the assumption that countries are willing to make voluntary transfers to each other. For political economy reasons, this assumption is, at best, suspect in a global context.

This paper suggests many other areas of future research, a few of which are discussed here briefly. One interesting extension would be to explicitly model the policy choices made by the regions. Perhaps introducing a tax versus a permit market to control production of the emitting good could affect outcomes. The product being taxed or the number of free permits distributed could also affect outcomes. Moreover, the order of decision making for the different levels of government and the migrants could be changed in the federal model with mobile labour. Another extension would be to make production a function of labour, land, and capital. The effects of capital mobility on the ability of governments to achieve efficiency could be discussed. Finally, N regions, rather than two, could be introduced.

Multiple levels of government are a reality faced by almost all countries. Furthermore, many pollution problems affect multiple countries, and methods of dealing with these transboundary problems must be devised. This article, which discusses how labour mobility can affect efficiency, suggests how to regulate environmental externalities in a federal system. It demonstrates that, depending on the mobility of labour and the objectives of regional governments, there likely is an important role for the central government of a federation. In the global context, a global governing body with the power to transfer funds between countries to combat pollution would also be ideal.

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