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Environmental tax reform in a federation with rent-induced migration*

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Abstract

We study the welfare effects of a revenue-neutral green tax reform in a federation. The reform consists of increasing a tax on a polluting input and reducing that on labor income. Households are fully mobile within the federation. Regions are unequally endowed with a nonrenewable natural resource. Resource rents are owned by regions and are redistributed to citizens on a residence basis, which generates a motive for inefficiently relocating to the resource-rich jurisdiction. Since the resource-poor region has a higher marginal product of labor than does the resource-rich region, the tax reform mitigates the scope of inefficient migration. This positive welfare effect may significantly reduce abatement costs of pollution and calls for higher environmental tax, as compared with a model where migration is assumed away.

JEL Classification: D62, H21, H23, H77
Keywords: Federalism; Environment; Taxation; Equalization; Mobility; Externalities

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1 Introduction

This paper analyzes the welfare effects of a green tax reform in a federation characterized by perfect labor mobility, a polluting input, and heterogeneity in resource endowments across regions. Moreover, natural resource rents are local property and are redistributed to households on a residence basis. One consequence of local rent ownership is that households do not only locate on the basis of their marginal product, but also on rent-seeking. Thus, too large a share of the labor force flies away from the resource-poor region, where its marginal product of labor would be higher. The revenue-neutral green tax reform consists of increasing taxes on a polluting input, and reducing those on labor income.

In this context, the optimal environmental tax on the polluting input can be significantly higher than in a benchmark without migration. This result comes through two channels. First, reducing labor income taxation has a stronger positive effect on the disposable income of inhabitants of the resource-poor region. This induces some households to move back to where they are the most productive. Second, free migration generates an extensive margin effect that marginally increases the countrywide value of the labor income tax base. This mitigates labor market distortions due to an increase of the environmental tax, which are commonly called "tax interaction effects".

The welfare effect of a revenue-neutral green tax reforms has indeed attracted a lot of attention (Bovenberg and Goulder, 1996; Bovenberg, 1999; Fullerton et al., 2010). The main focus of the literature was to investigate the strong double dividend hypothesis, which asserts that substituting preexisting distortionary taxes for new environmental levies could improve the overall efficiency of the tax system. Unfortunately, the double dividend has mostly failed to materialize in simple general equilibrium settings. The main explanation is that new environmental levies impose their own distortions by atrophying previously existing tax bases. These adverse tax interaction effects, which dominate the benefits of recycling the revenues from the new tax into the public treasury, drive up abatement costs increasingly so when preexisting tax rates are high.

Nevertheless, one crucial lesson from the literature so far is that environmental taxes should be considered first and foremost for their potential for abating pollution (Fullerton et al., 2010). When introduced, their marginal environmental benefits must be carefully balanced with their marginal efficiency costs on the economy.[1] Another central lesson is that specific assumptions made about the pre-reform economic environment can drastically change abatement costs. This naturally includes the nature of preexisting taxes and tax bases that are subject to tax interaction effects. For example, Bovenberg and de Mooij (1994) study the taxation of polluting and labor inputs. When labor and the polluting input are complementary, the environmental levy reduces both the marginal product of labor and wages and the overall tax base. Parry (1995) and Bovenberg and Goulder (1996) also find no double dividend, respectively in cases where dirty goods cannot or can be used as an intermediary input.[2] Goulder et al. (1999) extend the analysis of the cost of pollution abatement to a larger set of environmental instruments. For plausible values of the preexisting tax system, they find that abatement costs are positive because of tax interaction effects.

So far, the literature has relied only on models with a single jurisdiction and immobile households. No studies have focused on the specific effects of environmental tax reforms in federations where labor is mobile and where natural resource rents are captured by regional governments[3] even though these are quite common features of federal countries, as is illus-

[1]For economies with frictional labor markets, some have found that the marginal cost of pollution abatement could be significantly reduced. Bovenberg (1999) surveys cases where a strong double dividend can be found if the rate of involuntary unemployment is high. Bovenberg and van der Ploeg (1998) consider a small open economy with unemployment and a fixed factor. When labor and the fixed factor are easily substitutable, there can also be a double dividend. Bento and Jacobsen (2007) conduct a welfare analysis when a fixed factor is used in the production of dirty goods. A strong double dividend can be found at low abatement levels. In this particular framework, environmental taxation may be beneficial due to its ability to tax economic rents.

[2]Parry and Bento (2000) show that when some commodities are zero rated, then the marginal cost of pollution abatement is reduced since preexisting distortions are larger.

[3]Williams (2012) investigate the design of environmental policies with vertical interactions between levels of governments. Courchene and Allan (2008) suggested the establishment of carbon taxes on a value-added basis, which would imply that the policy should be managed centrally. Otherwise, several issues in

trated in table I. One will find that in several federations, at least some share of natural resource rents are the property of regional governments. In most of them, inequities in resource endowments are not fully compensated through a proper equalization system, which fuels up inefficient migration.

Table I about here.

One would naturally expect that an environmental reform similar to these studied in the double dividend literature would have a significantly different effect in such a framework. In a federation, a green tax policy set by a central government will have an impact on states asymmetrically, depending on the structure of their respective economies. This means that introducing a new environmental tax and using the revenues to reduce another tax can affect individuals' welfare asymmetrically across regions. If so, the reform will change the population allocation across the federation, and possibly for the best if households tend to relocate to regions where they are most productive. For instance, a new tax on a polluting input will have more incidence in a region that uses it more intensively. Other taxes, for example labor income taxes, will have more incidence in regions where production is more labor intensive.

To illustrate this we build on the seminal two-region model of Flatters et al. (1974) and Boadway and Flatters (1982), to show that a revenue-neutral tax reform can have beneficial welfare effects through migration. We enrich the standard model to include an intensive margin on labor supply and extractions of nonrenewable and polluting natural resources. In the spirit of Boadway and Flatters (1982), we focus on the case where nonrenewable natural resources are owned by local governments, which redistribute economic rents to its residents only. This type of decentralization leaves sub-national governments with different fiscal capacities, and allows the governments of resource-rich states to provide net fiscal benefits

environmental federalism still need to be tackled (Boadway and Tremblay, 2012), such as issues related to inter-regional migration. For now, all the studies that we know abstract from rent-seeking behaviors that can be induced by resource extraction, and its implication for optimal environmental taxation.

(NFBs) to their residents.[4] This, in turn, induces migration inefficiencies, since too many households relocate to resource-rich states to benefit from rents.

The rest of the paper is divided as follows. Section 2 presents a few stylized facts. Section 3 introduces a simple theoretical model of environmental tax reform in a federation with labor mobility and regional resource ownership. Section 4 analyzes and decomposes the welfare effects of the environmental reform. As is typical in this literature, some of our theoretical results cannot be fully characterized analytically. Section 5 therefore provides numerical illustrations. Section 6 concludes.

2 A few stylized facts

The Canadian case, where Statistics Canada provides us with detailed inter-provincial migration data, gives us anecdotal but meaningful evidence of why net fiscal benefits can induce migration when revenues are not fully equalized.[5] Table II report mineral and oil royalties per capita for the fiscal year 2011–2012 in all Canadian provinces, a year when oil prices were high. Differences in royalties per capita are, in this example, the main driver of net fiscal benefits to migrate. We report equalization payments per capita that are inversely related to royalties. If net fiscal benefits were completely offset by equalization, the column showing the sum of per capita royalties and equalization payments would report roughly identical amounts for all provinces. The last two columns in Table II report net inter-provincial migration flows, both in number of migrants and per 1,000 inhabitants.[6] The population movement towards Alberta, which welcomed almost all net migrants, is striking. Net migratory flows may, of course, depend on other factors such as other tax bases, province size or various monetary or non-monetary migration costs (Boadway and Shah, 2009). Nonetheless,

[4] NFBs are simply the difference between the monetary value of public goods, services and transfers obtained by citizens and taxes paid to states.

[5] Empirical evidence also indicates that fiscally-induced migration may be important (Day and Winer, 2006).

[6] We report only inter-provincial migration and neglect immigration from outside Canada.

it seems that net fiscal benefits play a significant role in it, and that equalization of rents effectively increases efficiency in migration (Wilson, 2003).

Table II about here.

Alaska provides another illustration of net fiscal benefits caused by local oil revenues. Table III reports taxes paid to the Alaska state government by oil producing companies for the last three fiscal years. Although various oil taxes, contributions and royalties have fluctuated from year to year they have earned the government a yearly average $8.43 billion between 2011 and 2013. With a population just over 735,000 people, this represents tax collections of about $11,477 per capita.

Table III about here.

A significant share of all oil revenues are deposited in a permanent fund for future use. The remainder is used to fund public services such as schools and infrastructures. Since 1982, Alaska also engages in an oil-to-cash policy by virtue of which citizens can claim their share of oil revenues every year. This transfer, called the "Permanent Fund Dividend" (PFD), is paid equally to all eligible applicants. Table IV shows the yearly amount that has been paid to each citizen since 2010. In 2008, a one-time special payment of $1,100 to each Alaskan was also voted by the state legislature. The main eligibility criterion to receive the transfer is residence.[7] There is no age requirement, so parents claim the PFD of their children. Hence, a family of four could claim a total of $7,536 in 2014. This transfer has now become a regular, anticipated component of Alaska's households incomes (Hsieh, 2003). Interesting enough, some think thanks advocate "oil-to-cash" policies for all oil producing countries.[8]

[7]For example, eligibility for the 2014 payment requires that the applicant has lived in Alaska for the entire calendar year 2013 (except for allowable absences) and was physically present in Alaska for at least 72 hours in 2012 and 2013. Applicants must also show their "intent to remain an Alaska resident indefinitely," must not have claimed benefits as a result of residency in other countries. Other requirements apply, with some related to the applicant's criminal record.

[8]http://www.cgdev.org/initiative/oil-cash-fighting-resource-curse-through-cash-transfers

In 2005, Alberta also paid a one-time oil money transfer to each of its citizens. The amount was $400 per person.

Table IV about here.

One last illustration of unequalized net fiscal benefits can be found in table V. After discovering the Parshall oil field in 2006, the state of North Dakota has experienced a major oil boom. During the 2011-2013 biennial, the North Dakota tax department has collected $3.412 billion from oil drillings (about $2,358 per capita annually). The 6.5% oil extraction tax has raised $1.785 billion whereas the 5% oil and gas production tax has earned the state government $1.627 billion. A 30% share of these amounts is saved in the state Legacy Fund, and some smaller amounts are also saved in other funds, such as the Foundation Aid Stabilization fund. In the end, $1.381 billion have been used to fund public goods and services, but also to fund "political subdivisions."

Table V about here.

3 Theoretical framework

A federation has a fixed total population N. It comprises two regions $i = 1, 2$. The number of residents in region i is N_i, such that $N_1 + N_2 = N$. For convenience we treat all measures of residents as continuous variables. Households freely choose their region of residence, and migration is costless.[9] They derive utility from the consumption of a composite private consumption good x_i, disutility from supplying labor ℓ_i and also from a national pollution externality that is proportional to the total quantity $\sum_i o_i$ of a polluting natural resource

[9] Boadway et al. (2003) consider a model with costly migration. Doing so here would not qualitatively change our results.

used in producing final goods in the whole country. The utility function of a representative resident of i is

$$U_i = u(x_i, \ell_i) - \phi\left(\sum_i o_i\right) \tag{1}$$

where $u_x > 0, u_{xx} \leq 0, u_\ell < 0, u_{\ell\ell} > 0$. [10] To avoid issues related to the multiple definitions of the Pigouvian tax level (Gahvari, 2014) we concentrate on a separable utility function $u(\cdot)$, so $u_{x\ell} = 0$. The function $\phi(\cdot)$, which is convex and strictly increasing, captures the externality caused by the use of a quantity $\sum_i o_i$ of polluting nonrenewable resources. Making this national level externality a global stock pollutant externality (such as greenhouse gases causing climate change) would require adding an existing pollution stock and international emissions as variables. As long as these two variables are exogenous to national decisions with proper rescaling of the damage function, including them would not affect optimal environmental taxation within the modeled country.

In our theoretical section we use the specific case where household preferences are quasi-linear, where marginal utility of consumption u_x is a constant. By facilitating aggregation of marginal welfare effects across regions, this allows us to derive welfare effects of tax reforms that are tractable, but also comparable with those obtained in other papers in the literature. We relax this assumption in our numerical simulations, showing that our qualitative results are not driven by the quasi-linearity assumption.

3.1 Resource endowments

The literature on natural resources and fiscal federalism often models natural resources rents as a simple financial windfall in each region (Beine et al., Forthcoming; Raveh, 2013). Although this approach would also fit our model, we explicitly model the extraction sector to analyze the effect of a change in the world price of the resource. Each region is endowed

[10]When convenient, we use the subscript notation to denote partial derivatives with respect to the subscripted argument.

with a stock of a nonrenewable natural resource, for instance oil. A quantity O_i is extracted in region i, a quantity o_i is used as an input in each region $i = 1, 2$ to produce a final consumption good, and a total quantity $\sum_i (O_i - o_i)$ is therefore exported.

Extracting a quantity O_i of resources in region i costs $C_i(O_i)$, a cost function that satisfies $C_i(0) = 0$ and $C_i''(\cdot) > 0$, and that encompasses all direct and opportunity costs associated with extraction processes and depletion of reserves. The resource can be sold at the exogenous world price P, which means that economic rents generated by the extraction sector in each region equal

$$\Pi_i^O(P) = \max_{O_i} PO_i - C_i(O_i). \tag{2}$$

The first-order condition that characterizes the solution to (2) is $P = C_i'(O_i)$ for $i = 1, 2$. We adopt the convention that region 1 is resource poor and that region 2 is resource rich. So, $C_1'(O) > C_2'(O)\ \forall O$. From that and the first-order condition to (2), extractions satisfy $O_1(P) < O_2(P)$. The Envelope theorem teaches us that $\partial \Pi_i^O(P)/\partial P = O_i$. This implies that an increase in the world price P has a stronger positive rent effect on region 2. Note that oil production is not taxed directly by the federal government. Allowing for a federal tax on output or on Π_i^O would be equivalent to giving the property of rents to the federal government.

3.2 Production

The nonrenewable resource, along with labor, is used as an intermediate input in the production of a composite consumable output. The production technology is homothetic and is expressed by $F(L^i, o_i)$. The first input, L_i, is the aggregate labor supply in that region. Denoting by ℓ_i the labor supply of a single household, we have that $L_i = N_i \ell_i$. Thus, we allow labor efforts to vary along both the extensive and the intensive margins. The second input, o_i, is the total quantity of oil used in region i.

The production technology embeds the fact that oil and labor may be combined in order to produce output. The extent of this depends on the elasticity of substitution between the two inputs. This is similar to Bovenberg and van der Ploeg (1998), who introduce a third (fixed) factor in a constant returns to scale production function. If a fixed factor is present, we simplify our analysis by assuming that that it is supplied equally across regions. The production sector in region i acts is a price-taker and takes the wage rate w_i as given. Total profits in the production sector of region i are defined by

$$\Pi_i^x(P + t_o, w_i, N_i) = F(N_i \ell_i, o_i) - w_i N_i \ell_i - (P + t_o) o_i \tag{3}$$

where the term t_o in (3) is a federal tax per unit of resources used (ie. oil burned) in the country.

3.3 Residence-based transfers and federal equalization

Resource extractions and final goods production generate economic profits, or rents, in each region. Rents derived from the extraction and production sectors were denoted respectively by Π_i^o and Π_i^x. Total rents produced in region i are denoted by $\Psi_i \equiv \Pi_i^o + \Pi_i^x$.

What tier of government can appropriate these rents for its own citizenry is a central issue for this paper and for theories of fiscal federalism in general. When local governments capture them and redistribute them to households on a residence basis, rent-seeking becomes a motive for migration. Households can decide to migrate from region 1 to region 2, despite being more productive at work in the former.

To make a point clear, we assume that rents are returned lump-sum to households on a residence basis: each resident of a region i receives a per capita cash transfer that equals Ψ_i/N_i. Thus, the only way by which households can directly benefit from them is to move. Of course, there are other ways through which rents could be captured, in particular when local governments use rents to provide impure public goods that cannot be perfectly shared by all citizens (Boadway and Flatters, 1982; Flatters et al., 1974; Boadway et al., 1998). Our results follow through when local governments provide (partly) congested public goods, or publicly provide private goods. Such alternative assumptions can be made without qualitatively altering our results.

Asymmetric rents across regions can be mitigated through a federal equalization program, for which the only goal is to financially compensate the resource-poor region. We denote by T_i the aggregate lump-sum transfer paid from the federal government to each region i. Regional governments then transfer per capita amounts T_i/N_i to each of its residents. Equalization payments are therefore perfect substitutes for rents revenue in household budget constraints.

4 An environmental tax reform

In line with the literature on the double dividend debate (Bovenberg, 1999), we consider an arbitrary preexisting equalization system that is funded with distortionary taxation. The initial values for federal taxes on labor and resource inputs are denoted respectively by $\hat{t}_l$ and $\hat{t}_o$. Equalization transfers are denoted by T_i, $i = 1, 2$. Note that we do not identify them by a hat because we will keep them constant in the analysis. The reform consists of marginally reducing labor income taxes and marginally increasing the environmental levy t_o, while keeping constant the overall size of its equalization $\sum_i T_i$. Events unfold as follows:

Stage 0 At the origin, the federal government ignores all environmental externalities when making policies. Regions receive grants T_i and the budget constraint of the federal government initially satisfies

$$T_1 + T_2 = \hat{t}_l \sum_i w_i N_i \ell_i + \hat{t}_o \sum_i o_i$$

where $\hat{t}_l$ is an initial proportional tax rate on labor and $\hat{t}_o$ is a tax per unit of oil used in production.

Stage 1 The federal government announces a reform that consists of adjusting both of its tax rates to correct for externalities. The reform leaves equalization payments and the federal government's total revenue unchanged. It correctly anticipates the reactions of households and of regional governments.

Stage 2 Households observe federal policies and choose their regions of residence in a forward-looking way. Migration occurs until utility is equalized across regions.

Stage 3
- (i) A volume O_i of nonrenewable resources is extracted in region i, and firms use a quantity o_i of it. Firms demand a quantity $N_i\ell_i^d$ of labor.
- (ii) Households are now immobile and they supply ℓ_i^s units of labor each.
- (iii) Wage rates w_i clear both labor markets in $i = 1, 2$.
- (iv) The federal government collects labor income taxes, and pollution taxes and pays lump-sum transfers T_i to regional governments. Rents and equalization payments are evenly distributed to citizens on a residence basis. So, each resident of region i receives a cash transfer $(\Psi_i + T_i)/N_i$. Agents consume their disposable incomes and utility is realized.

The model can be solved by backward induction.

Stage 3 (i): Optimization problem of households

Households are immobile. They maximize their utility subject to their budget constraint. Each resident of region i takes the wage rate w_i as given and faces a proportional federal labor income tax rate t_l. The associated Lagrangean for a resident of region i is

$$\mathcal{L} = u(x_i, \ell_i) - \lambda_i \left(x_i - (1 - t_l) w_i \ell_i - \frac{T_i}{N_i} - \frac{\Psi_i}{N_i} \right) - \phi \left(\sum_i o_i \right). \tag{4}$$

Under constant marginal utility of consumption ($\lambda_1 = \lambda_2 = \lambda = u_x$) the first-order conditions are

$$\frac{\partial u}{\partial x_i} - \lambda = 0 \tag{5a}$$

$$\frac{\partial u}{\partial \ell_i} + \lambda w_i (1 - t_l) = 0 \tag{5b}$$

$$x_i - (1 - t_l) w_i \ell_i - \frac{T_i}{N_i} - \frac{\Psi_i}{N_i} = 0. \tag{5c}$$

Labor supply $\ell_i^s(w_i(1-t_l))$ is implicitly described by (5b) only. Strict concavity with respect to disutility of labor directly implies that $\ell^s(\cdot)$ increases with net wage $w_i(1-t_l)$. We denote the indirect utility function for a resident of region i by $V_i(T_i, t_l, \Psi_i, N_i, w_i, \sum_i o_i)$, which can be also expressed as

$$V_i(T_i, t_l, \Psi_i, N_i, w_i, \sum_i o_i) = v(T_i, t_l, \Psi_i, N_i, w_i) - \phi \left(\sum_i o_i \right). \tag{6}$$

For further use, the envelope theorem to (6) gives

$$\frac{\partial v_i}{\partial T_i} = \frac{\lambda}{N_i} \qquad > 0 \tag{7a}$$

$$\frac{\partial v_i}{\partial t_l} = -\lambda w_i \ell_i \qquad < 0 \tag{7b}$$

$$\frac{\partial v_i}{\partial \Psi_i} = \frac{\lambda}{N_i} \qquad > 0 \tag{7c}$$

$$\frac{\partial v_i}{\partial N_i} = -\frac{\lambda}{N_i} \left(\frac{T_i + \Psi_i}{N_i} \right) \qquad < 0 \tag{7d}$$

$$\frac{\partial v_i}{\partial w_i} = (1 - t_l) \lambda \ell_i \qquad > 0 \tag{7e}$$

Equations (7a) and (7c) show that each dollar in cash transfer increases utility by λ. They also show that per capita equalization transfers are perfect substitutes for per capita rents transfers. Equation (7d) is a negative sharing effect. When N_i increases, households must divide both equalization payments and rents among a larger number of citizens.

Stage 3 (ii): Optimization in production

Because the decision to migrate takes place prior to production, N_i is taken as given and economic profits made in the final output sector are the solution to

$$\Pi_i^x(N_i, w_i, P + t_o) = \max_{\ell_i, o_i} F(N_i\ell_i, o_i) - w_i N_i \ell_i - (P + t_o)o_i. \tag{8}$$

Note that the economic profits defined in (8) need not equal zero in equilibrium. For example the existence of a non-polluting fixed factor, such as land or fixed capital can be an additional source of rents.[11] The first-order conditions that characterize labor demand and oil use are

$$F_L(N_i\ell_i, o_i) = w_i \tag{9a}$$

$$F_o(N_i\ell_i, o_i) = P + t_o. \tag{9b}$$

By totally differentiating the firm's first-order condition and making use of the second-order condition, Cramer's rule gives that labor demand per worker and oil use satisfy

$$\frac{\partial \ell_i^d}{\partial t_o} = \frac{\partial \ell_i^d}{\partial P} > 0; \quad \frac{\partial \ell_i^d}{\partial N} < 0; \quad \frac{\partial \ell_i^d}{\partial w_i} < 0; \quad \frac{\partial o_i}{\partial t_o} = \frac{\partial o_i}{\partial P} < 0; \quad \frac{\partial o_i}{\partial N} = 0; \quad \frac{\partial o_i}{\partial w_i} < 0. \tag{10}$$

[11] We abstract from capital for simplicity. If capital is mobile, the analysis depends on who owns it. Since we rely on identical analysis, the returns of capital would not be captured on a residence basis and would not significantly affect the intuition of the model.

The sum of all economic rents Ψ_i that accrue to the local government in region i equals

$$\Psi_i(N_i, w_i, P + t_o) = \Pi_i^O(P) + \Pi_i^x(N_i, w_i, P + t_o). \tag{11}$$

Using the envelope theorem on (2) and (8), while taking into account that wages are endogenous in our general equilibrium setting, we find that

$$\frac{d\Psi_i}{dt_o} = -L_i \frac{dw_i}{dt_o} - o_i \tag{12a}$$
$$\frac{d\Psi_i}{dP} = -L_i \frac{dw_i}{dP} + O_i - o_i \tag{12b}$$
$$\frac{d\Psi_i}{dN_i} = -L_i \frac{dw_i}{dN_i} \tag{12c}$$
$$\frac{d\Psi_i}{dt_l} = -L_i \frac{dw_i}{dt_l} \tag{12d}$$

Stage 3 (iii): Labor market clears

Equations (12a) to (12d) make used that the equilibrium wage rates w_i adjust to clear regional markets. Aggregate labor supply in i is $N_i \ell_i^s(t_l, w_i)$, and labor demand of firms is given by $L_i^d(N_i, P, w_i, t_o) \equiv N_i \ell_i^d(N_i, P, w_i, t_o)$. Given N_i in each region, the equilibrium wage rate $w_i(t_l, t_o, P, N_i)$ equalizes supply and demand. Standard equilibrium analysis reveals that

$$\frac{\partial w_i}{\partial t_o} < 0; \quad \frac{\partial w_i}{\partial P} < 0; \quad \frac{\partial w_i}{\partial t_l} > 0; \quad \frac{\partial w_i}{\partial N_i} < 0. \tag{13}$$

Stage 2: Migration

Households migrate based on the utility level that can be reached in both regions. The equilibrium migration condition is

$$v_1(T_1, t_l, \Psi_1, N_1, w_1) = v_2(T_2, t_l, \Psi_2, N - N_1, w_2). \tag{14}$$

As long as (14) is not satisfied with strict equality, there is at least one inframarginal household that still has an incentive to migrate. It is therefore (14) that characterizes population allocation across regions. The properties of indirect utility function give us the following lemma:

Lemma 1. Rent-induced migration: *Suppose that rents are imperfectly equalized across regions. Then, the marginal product of labor is larger in the resource-poor region and* $w_1 > w_2$*, as well as* $w_1 \ell_1 > w_2 \ell_2$*.*

Proof of lemma 1. *Indirect utilities* v_i *are strictly increasing in* $(\Psi_i + T_i)/N_i$ *and also in* w_i*. Imperfectly equalized rents means that* $(\Psi_2 + T_2)/N_2 > (\Psi_1 + T_1)/N_1$*. A direct consequence is that* $w_1 > w_2$ *in the free migration equilibrium. To show that* $N_1 < N_2$*, note that households' labor supply* l_i^s *does not depend on* N_i*. However, labor demands per household* ℓ_i^d *is decreasing in* N_i *by virtue of (9a) and (9b). Joint with* $w_1 > w_2$*, this implies that both* $N_1 < N_2$ *and* $\ell_1 > \ell_2$*.*

Lemma 1 is analogous to Boadway and Flatters (1982)' claim that the labor force is misallocated over the federation because of rent-seeking. Households do not locate where their contribution to the federation's output is maximized. This comes at an overall efficiency cost for the federation, unless rent-seeking is completely neutralized through a first-best equalization system.[12] As this will become clearer soon below, and in our numerical simulation, the green tax reform will tend to induce a socially beneficial population movement towards the resource-poor region.

To analyze what happens to N_1 when an environmental tax reform takes place we derive an expression for dN_1/dt_o when an increase in t_o is followed by a reduction in t_l, so $dt_l/dt_o < 0$. By taking the total derivative of (14), and by combining it with (7a) – (7e) and (12a) – (12d),

[12] First-best equalization can only be achieved using lump sum taxation. When distortionary taxation is used, second-best equalization leaves some inefficient migration taking place.

we find that

$$\frac{dN_1}{dt_o} = \frac{\overbrace{(w_2\ell_2 - w_1\ell_1)dt_l/dt_o}^{\text{Labor income }>0} + \overbrace{(o_2/N_2 - o_1/N_1)}^{\text{Profits per capita }<0} + \overbrace{t_l\left(\ell_2 dw_2/dt_o - \ell_1 dw_1/dt_o\right)}^{\text{Tax wedge differential }>0}}{\frac{1}{N_2}\frac{\Psi_2}{N_2} + \frac{1}{N_1}\frac{\Psi_1}{N_1} + \frac{1}{N_1}\frac{T_1}{N_1}}. \tag{15}$$

Unfortunately it is impossible to unambiguously sign dN_1/dt_o analytically in this general equilibrium setup. Nonetheless, we discuss some elements that suggest dN_1/dt_o will tend to be greater than zero and will have suitable nonenvironmental efficiency properties.

Consider the numerator of (15), which takes the same sign as dN_1/dt_o. We identified its first component as a "labor income" effect. It is positive, since a reduction of labor taxes has more impact in region 1, where labor income is higher.

We called the second component the "profit per capita" effect. An increase in t_o reduces firms' profits by increasing the price of an input. The incomes of households, who cash in these profits, decrease accordingly. Surprisingly enough, this negative welfare effect is also stronger in region 1. Because wages are higher there, firms substitute labor for oil, and it has a smaller labor-oil ratio in production.[13]

The fact that the "labor income" and the "per capita profits" effects go in opposite directions make it impossible to sign dN_1/dt_o. However, one may suspect that when the share of labor is larger than that of oil in production, which is what the empirical literature suggests (Hassler et al., 2012; Dissou et al., 2012), the first effect will dominate.

Moreover, a last effect called the "tax wedge differential" effect comes into play to push dN_1/dt_o in positive territory. Region 1, which has higher wages, has also a larger labor tax wedge. This reduces the welfare of its households and is an incentive to leave the region.

[13] For example, with a CES production function that elasticity of substitution σ and a relative share of labor, α, then the firm's first-order condition directly implies that $o_i/N_i = \ell_i \left(\frac{1-\alpha}{\alpha}\frac{w_i}{P+t_o}\right)^{\sigma}$ which confirms that suspicion.

When t_o increases, firms' demands for both oil and labor decline, which causes w_1 and w_2 not only to diminish, but also to get closer to each other. This induces households to move back to the resource-poor region.

Stage 1: Welfare effects of an environmental tax reform

We can now turn to the environmental tax reform. Starting from an arbitrary initial tax system, the government keeps equalization payments (or any other expenditure level) fixed, increases t_o on the polluting input and reduces t_l on labor income. This "tax swap" approach helps us understand the effect of recycling environmental tax revenue into the preexisting tax system. Social welfare is defined by[14]

$$W = N_1 v_1(T_1, \Psi_1, N_1, w_1) + (N - N_1) v_2(T_2, \Psi_2, N - N_1, w_2) - N\phi\left(\sum_i o_i\right). \tag{16}$$

The federal government keeps its budget constraint balanced:

$$\sum_i T_i = t_l \sum_i w_i L_i + t_o \sum_i o_i. \tag{17}$$

We consider an incremental change dt_o in the environmental tax, while recycling the revenues into the government's budget constraint. The marginal welfare effect of this reform, accounted for in units of consumption, is obtained by taking the total derivative of (16) and (17) altogether. Substituting the envelope conditions (7a) — (7e) as well as conditions for

[14] We use a standard utilitarian social welfare function, as in Boadway et al. (2003) and (Hartwick, 1980). Imputing a different weight to households utilities based on their region of residence would not affect their own location decisions and the existence of rent-induced migration.

rents (12a) — (12d), we obtain

$$\frac{1}{\lambda}\frac{dW}{dt_o} = \underbrace{\left(t_o - \frac{N}{\lambda}\phi'\left(\sum_i o_i\right)\right)\sum_i \frac{do_i}{dt_o}}_{W^P} + \underbrace{\left(\frac{\Psi_2}{N_2} + \frac{T_2}{N_2} - \frac{\Psi_1}{N_1} - \frac{T_1}{N_1}\right)\frac{dN_1}{dt_o}}_{W^M} + \underbrace{t_l \sum_i w_i \frac{dL_i}{dt_o}}_{W^L}. \tag{18}$$

Equation (18) is a welfare formula, as it often appears in double dividend studies (for example in Bento and Jacobsen (2007)), but here it includes a migration effect. We have identified three welfare effects of the reform in (18), each capturing either costs or benefits of substituting labor taxation for environmental taxation. Each is detailed below.

Pigouvian welfare benefits (W^P)

W^P is a standard Pigouvian welfare benefit. It is the only part of (18) that is not directly affected by migratory behavior. $N\phi'(\sum_i o_i)/\lambda$ is the social marginal external cost of pollution, accounted for in units of private consumption whereas t_o is the pollution tax level. In a partial equilibrium model, the optimal policy would be to increase the price of the polluting input by exactly $t_o = N\phi'\left(\sum_i o_i\right)/\lambda$. In general equilibrium the optimal environmental tax will be pushed below or above its Pigouvian level because of migration efficiency benefits W^M and labor market effects W^L.

Migration efficiency benefits (W^M)

W^M is a direct migration effect, and is novel in our analysis. It captures the social welfare effect of allocating households to the region where they are most productive. With rent-induced migration in the federation, or if

$$\frac{\Psi_2}{N_2} + \frac{T_2}{N_2} > \frac{\Psi_1}{N_1} + \frac{T_1}{N_1}, \tag{19}$$

W^M is positive if a tax reform makes households migrate back to region 1. When this is the case, this effect pushes the optimal environmental tax upwards as compared with a migration free setup.

Labor markets effects (W^L)

Finally W^L is the welfare effect of the policy via the labor market. This is where the second dividend of environmental taxation is typically searched for, the argument being that increasing t_o potentially allows for a reduction of t_l, a more damageable tax. Further decomposition of W^L can help us clarify why this intuition may or may not be misguided:

$$\sum_i w_i \frac{dL_i}{dt_o} = \sum_i w_i N_i \underbrace{\frac{\partial \ell_i}{\partial t_l}\frac{dt_l}{dt_o}}_{RR>0} + \sum_i w_i N_i \underbrace{\frac{\partial \ell_i}{\partial w_i}\frac{dw_i}{dt_o}}_{TI<0} + \underbrace{(w_1\ell_1 - w_2\ell_2)\frac{dN_1}{dt_o}}_{MTB>0} \tag{20}$$

We identify three effects in (20). The first two terms, RR and TI, are standard in the literature. RR, the "revenue recycling effect," is the benefit of reducing the labor tax rate following the introduction of the environmental levy and is beneficial to the economy. TI is the "tax interaction effect" and is negative. When t_o is increased, firms' labor demand per worker diminishes. Equilibrium wage rates then decline in both regions, as well as l_i and households' labor income. But $\sum_i w_i L_i$ is a tax base on which t_l applies. This atrophy of the labor income tax base induces a welfare cost.

Most studies have found the negative tax interaction effect to dominate the revenue recycling one. But with mobile households, the tax-interaction effect may be mitigated through a third phenomenon that is brought about by our analysis. We call it the "migratory tax base" effect, MTB. When a tax reform induces some households to move back to the resource-poor region, labor is allocated more efficiently in the federation: individuals move from region 2 to region 1 while $w_2\ell_2 < w_1\ell_1$. This marginally increases the value of the labor income tax base across the federation. By doing so, it partly counterbalances the TI effect.

To sum up, allowing for migration has two new, potentially positive impacts on the welfare effects of a green tax reform. First, the direct migration effect ME is added to the standard Pigouvian effects of the reform. Second, the migration tax base MTB effect counteracts the tax-interaction effect in the labor supply. As usual, some ambiguity remains as to the strength and the sign of some of these effects, and there is a limit to what can be analytically characterized in general equilibrium. Thus, we perform numerical simulations to illustrate the effects of a green tax reform in a federation with free migration.

5 Numerical simulations

We simulate our theoretical model using standard specifications. We use a CES production function

$$F(L_i, o_i) = \mu \left(\alpha L_i^{\frac{\sigma-1}{\sigma}} + (1-\alpha) o_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\nu\sigma}{\sigma-1}}, \tag{21}$$

where $\mu \in (0, \infty)$ is total factor productivity, $\alpha \in (0, 1)$ is the share of labor into production, $\sigma \in (0, \infty)$ is the elasticity of substitution between factors, and $\nu \in (0, \infty)$ is a return to scale parameter. As in the model, we abstract from capital, which can be assumed constant over the span of the environmental tax reform. The cost of extraction is quadratic with $C_i(O_i) = c_i O_i^2$, where $c_i \in (0, \infty)$ for $i = 1, 2$ and $c_2 < c_1$.

The utility function of a representative household is additively separable in consumption, labor and pollution:

$$U(x_i, \ell_i, o_i, o_{-i}) = \frac{x_i^{1-\gamma}}{1-\gamma} - \delta \ell_i^{1+\frac{1}{\eta}} - \phi \cdot (o_1 + o_2)^2. \tag{22}$$

It yields a labor supply with a constant Frisch elasticity, η. Damages from pollution are quadratic, with scaling parameter $\phi \in (0, \infty)$. Marginal utility of consumption equals one when $\gamma = 0$, and is decreasing in x_i when $\gamma > 0$.

Table VI about here.

Without loss of generality, we take the case where the federal government pays equalization payments only to the region with the lower fiscal capacity, so we use $T_1 > 0$ and $T_2 = 0$. This allows us to vary the size and generosity of the equalization system through a single parameter. Increasing T_1 then has the effect of reducing rent-induced migration.[15]

Table VI summarizes the benchmark values for the calibration parameters. The relative share of labor and oil in production α, of the elasticity of input substitution σ, and of the Frisch elasticity of labor supply η are crucial to our results. Hence, they are chosen to reflect empirical estimates. We use $\eta = 0.4$, which is the midpoint of estimates reviewed by the Congressional Budget Office (Reichling and Whalen, 2012). Estimates for the share of oil into production and the elasticity of substitution between oil and labor are less prevalent. Hassler et al. (2012) estimate that the share of energy in the U.S. economy is somewhere between 2% and 6%. For selected industries in Canada, Dissou et al. (2012) find shares of between 2% and 20%. Abstracting from the share of capital, this gives energy a share relative to labor of between 3% and 30%. In our benchmark calibration we use $\alpha = 0.85$. Finally, Dissou et al. (2012) estimates elasticities of substitution between energy and labor between 0.6 and 1. Our benchmark parametrization uses $\sigma = 2/3$. A benchmark value of 0 is chosen for γ. This reflects our modeling assumption of quasilinear utility. We also consider, however, alternative values of γ in our sensitivity analysis. Finally, all other parameters are calibrated to prevent corner solutions, such as an underpopulated federation and insufficient production to fund the exogenous government expenses. The oil price and marginal extraction costs parameters are chosen to ensure the federation is a net oil exporter. All parameters are varied in a sensitivity analysis.

[15] Note that in any second-best equalization system funded through distortionary taxation, only region 1 will ever receive payments.

5.1 The numerical experiment

The impact of migration on the optimal environmental tax can only be assessed if the environmental component of the oil tax is well defined. As pointed out by Fullerton (1997) in the context of commodity taxation, an arbitrary normalization of the tax system can turn the tax on a dirty good into either a pure environmental levy, or into a tax instrument that also raises revenue even absent any environmental damage. In the latter case, the dirty good could be taxed at a rate that is higher than the purely Pigouvian rate, even if there is no double dividend.

Our model implicitly imposes a normalization free of consumption taxation. Thus, the tax on the dirty input will include both revenue-raising and purely environmental components. It also has a migration part since it induces agents to move from the rent rich to the rent poor region. Hence the oil tax will often be above the Pigouvian level in our simulations, but artificially.

The environmental component of the oil tax (henceforth referred to as the "environmental tax'") will be defined through the reform. In the pre-reform situation, the distortionary tax system is optimized so as to maximize non environmental welfare (setting implicitly $\phi = 0$). This gives a positive tax on oil that funds equalization payments and that induces migration towards region 1, but for which the purpose is not to reduce pollution at all. The reform then consists in re-optimizing the tax mix while taking into account the environmental damages caused by the oil use setting $\phi > 0$. We calculate the environmental tax by taking the difference between the oil tax before and after the reform.

Finally, we isolate the effect of migration by constructing an alternative reform in which population is fixed to its pre-reform distribution. Otherwise, all aspects of the model remain the same. The difference in environmental tax levels between these reforms give the impact of migratory forces on the optimal environmental taxation.

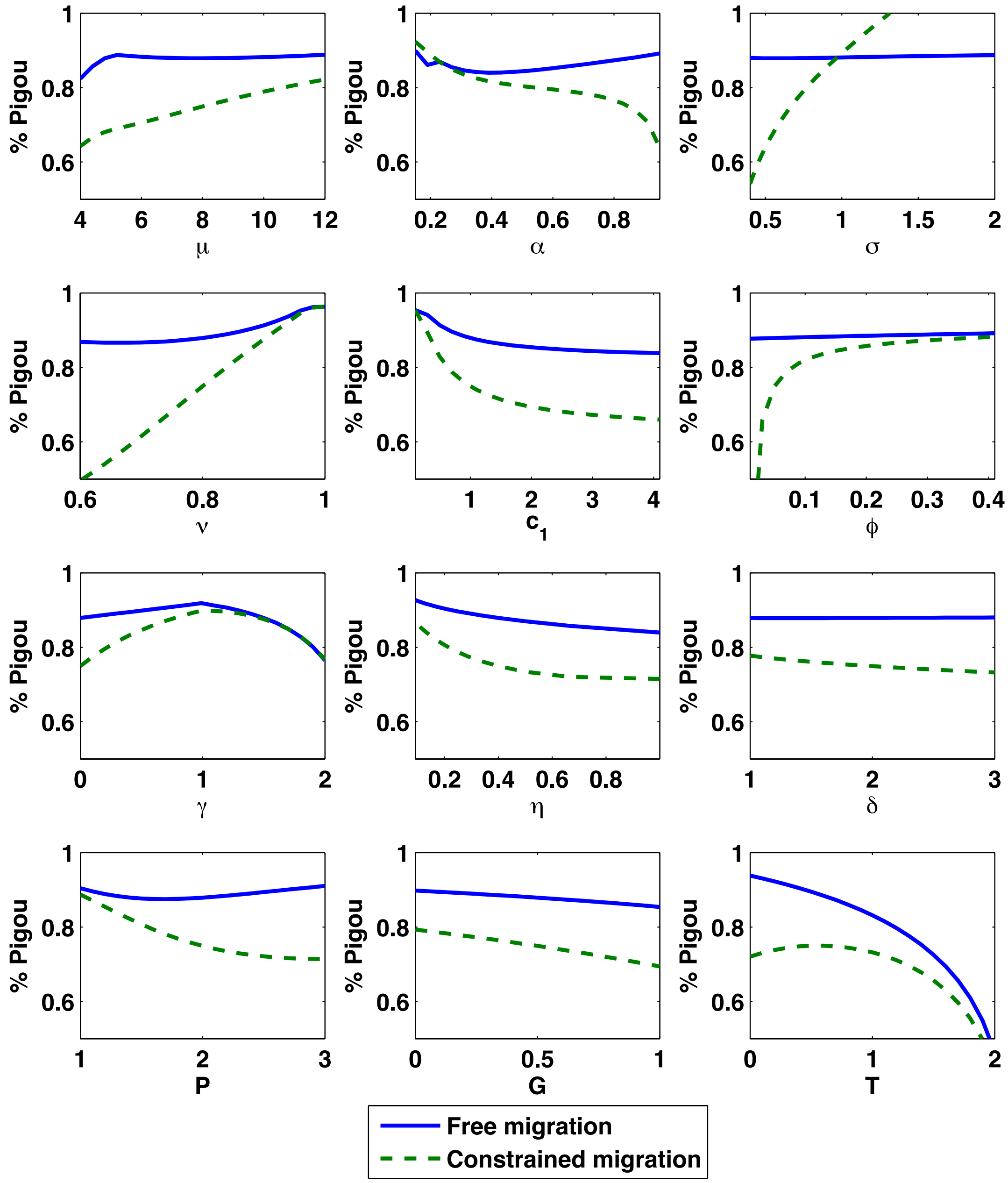

Figure 1: Environmental tax as a fraction of its Pigouvian level with and without migration

5.2 Benchmark results and sensitivity analysis

Our benchmark calibration results clearly show that environmental taxation is higher when households can migrate. It is optimally set at 88% of its Pigouvian level with migration, and it drops at 77% of it when there is no migration. Both the migration effect which W^M in equation (18) and ME in (20) increase environmental taxation in this general equilibrium framework. Note, however, that the migration effect — along with the traditional revenue recycling effect — taken together are not sufficient to compensate the tax interaction effect TI in (20). This is why the environmental tax remains below its Pigouvian level, which means that there is no strong double dividend.[16]

Results for the sensitivity analysis are shown in figure 1. In each panel, a single parameter is varied while others take on their benchmark values. In all reasonable cases, allowing for migration significantly increases the optimal environmental tax. That is, for almost every parametrization the migration effect increases the optimal general equilibrium environmental tax.

Asymmetry in non-equalized rents

Sensitivity analyzes with respect to three exogenous variables corroborate the intuition obtained from the theoretical analysis. First, when there is more asymmetry in natural resources endowments, the gap between environmental tax levels with and without migration grows. This can be seen when varying the parameter c_1, the marginal cost of extractions. When $c_1 = c_2 = 0.1$ both regions have identical resource endowments and the optimal environmental tax does not change when we allow for free migration. This is because migration is efficient. As long as c_1 increases, the environmental tax difference increases.

The same phenomenon is observed when the world price of resources P goes up. Then,

[16] The strong double dividend arises when pollution can be abated at no cost (or even negative costs) to the economy, while the weak double dividend only implies a gain in welfare when environmental tax revenues are recycled to reduce distortionary taxes (see Goulder (1995) for more on that distinction).

rents increase in both regions but more so in region 2. Accordingly, we find that the difference between optimal environmental tax rates with and without migration increases with P. This may have potentially important policy implications, especially when large oil price shocks arise. In this situation, an increase in oil use in production may lead one to think that oil should be taxed more because of environmental externalities. On the other hand, the fall of the world price reduces rent-seeking in our specific model, which leads to opposite policy prescriptions. Our simulations find that with free migration the environmental tax should remain roughly the same when there is a positive shock on P, whereas it should decrease when rent-seeking or free migration are assumed away.

Third, keeping equal endowments and world prices, increasing the scope of fiscal equalization compensates region 1 for having smaller rents. Hence, we get the intuitive result that increasing T reduces the migration benefits of the environmental levy. As T grows, optimal environmental taxes with and without migration converge with each other. One will notice that very high equalization payments drive the environmental tax toward zero. This makes sense because higher equalization payments imply that more revenue must be collected, which increases the distortions associated to taxation. When revenue collections become high, the only reason the government taxes is for revenue-raising purposes.

Marginal environmental damage

The fact that nonenvironmental distortions are lower in a model with free migration is exhibited in the sensitivity analysis exercise with respect to ϕ. With a small marginal utility cost of pollution and no migration, the social planner keeps the environmental tax low, because of the distortions it creates in the economy. With migration, these distortions are reduced and the environmental tax can go up by as much as 75% as compared with the nonmigration case. When ϕ becomes large the environmental tax under both scenarios gradually converge with each other.

Increasing the marginal cost of collecting public funds

We also conduct a sensitivity analysis with respect to G, an exogenous revenue amount that the federal government must collect in addition to T. Increasing this amount fuels up the tax distortions and pushes the environmental tax down in both the free-migration and the no-migration cases. However, the environmental tax decreases less in the free-migration scenario. Note that increasing disutility of supplying labor has the same effect.

Decreasing marginal utility of consumption

Another interesting result pertains to our use of a quasi-linear utility function, which is linear with respect to consumption. In the model, this assumption allowed us to neatly aggregate welfare effects across regions. However, it was important to verify that our results still held with concave utility of consumption. For all values of γ, we find that the environmental tax is higher in the free-migration framework. However, as utility of consumption becomes more concave, both scenarios become closer to each other. This happens because the marginal utility value of capturing rents is then decreasing, which reduces the incentive to migrate to capture rents. But overall, one can see that our results remain qualitatively unchanged when we add concave utility of consumption to the model.[17]

Special cases with an environmental tax is higher without migration

Interestingly, there are some situations in which the environmental tax is higher in the no migration scenario. These exceptions are for extremely low shares of labor into production (α falls below 1/4), and for especially high elasticities of input substitution (σ greater than one). These values for which the migration effect is reversed appear unrealistic according to empirical estimates (Hassler et al., 2012; Dissou et al., 2012). The impact of α can be explained by its relationship with per capita oil consumption. With a CES production function, it is always the case that per capita oil consumption will be higher in the resource poor region. Using the first-order conditions of the firm one obtains that $\frac{o_i}{N_i} = \ell_i \left(\frac{1-\alpha}{\alpha} \frac{w_i}{P + t_o} \right)^{\sigma}$.

[17] A sensitivity analysis over the full range of parameters with a concave utility of consumption ($\gamma = 0.5$) is presented in appendix B.

Hence the per capita oil consumption term of (14), is always negative. Intuitively, this means that increasing t_o reduces firms' profits, and more so in region 1 than in region 2. The reason why migration to region 1 still responds positively to an increase in t_o is because most of the household incomes comes from their labor supply, so the ensuing reduction of t_l reduces labor income tax payments more in region 1 than in region 2. But when the share of labor into production α becomes very small, most of the household incomes eventually come from firms profits and the tax reform can induce individuals to migrate to the resource-rich region instead. And when $dN_1/dt_o < 0$ all welfare effects related to migration change of direction. Regarding input substitution, we find that when the elasticity of substitution between factors becomes larger than one, the environmental tax with constrained migration can be larger than with migration. It can even reach its purely Pigouvian level. This captures the special case where inputs are very substitutable, and where the environmental levy increases the price of oil so much that, for the most part, only labor is used into production.

6 Conclusions and further research

This paper contributes to the debate about the nonenvironmental welfare effects of a tax reform, when the revenue from a new environmental levy is recycled into the government's budget. The key elements of our model is the presence of two regions in a federation with asymmetric endowments of a nonrenewable natural resource. Moreover, rents from these resources accrue to citizens on the basis of where they reside. Since households are fully mobile, some of them exhibit rent-seeking behavior. They relocate to the resource rich region even if they, as workers, would be more productive in the resource poor jurisdiction.

In this context, we find that the nonenvironmental distortions caused by the tax reform may be significantly lower than in a comparable model without mobility, such as a single jurisdiction setting. With inefficient rent-induced migration, the environmental tax reduces individual nonenvironmental welfare more in the resource poor region than in the resource rich one. However, the reduction in labor income tax that comes with the revenue-neutral reform more than compensates for this effect. Thus, it induces some households to migrate back to the resource-poor region, which increases efficiency in the countrywide allocation of labor.

Because the environmental tax reform reduces nonenvironmental distortions through this channel, it is therefore optimal to set a higher environmental tax than in a model with immobile households. The crucial element to our results is that the reform changes the pre-existing tax system so that nonenvironmental welfare in the region that is inefficiently underpopulated will be more positively affected. The choice of tax instruments and tax base that are subject to the reform is therefore important.

Making use of a simplified model helps us to lay down intuition and to obtain a meaningful numerical illustration. However, several other environments featuring migration could be worth exploring in further research. First, one could think of a model where the resource sector itself needs productive labor input. More generally, a tax reform in a Dutch disease model with more than one productive sector could provide substantial intuition as well. Questions of international migrations could also be investigated. Finally, one could consider other mobile factors of production, for instance capital.

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A Tables

Table I: Examples of ownership and equalization of natural resource revenues in some federations

Federation	Rent revenues	Equalization scheme	Rents equalized
Canada	Regions	Yes	50%
USA	Shared	No	N/A
Brasil	Shared	No	N/A
Nigeria	Shared	Yes	No
Australia	Regions (except offshore)	Yes	100%
Russia	Shared	Yes	Yes
South Africa	Central	Yes	N/A
UK	Central (with exceptions)	No (Barnett Formula)	N/A

Table II: Per capita royalties, equalization payments
and interprovincial migration in Canada, 2011-2012
(Statistics Canada, Finance Canada and Provincial Public Accounts)

Province	Royalties (per capita)	Equalization (per capita)	Roy. + Eq. (per capita)	Net migrants (number)	Net migrants (per 1,000 hab.)
Newfoundland	5,156	0	5,156	545	+1.04
Saskatchewan	2,814	0	2,814	1,878	+1.76
Alberta	2,592	0	2,592	27,652	+7.30
PEI	0	2,350	2,350	- 618	-4.29
New Brunswick	139	1,985	2,121	-1,806	-2.39
Nova Scotia	414	1,342	1,756	- 2,866	-5.42
Manitoba	158	1,353	1,511	-4,202	-3.41
Quebec	384	934	1,318	-6,915	-0.86
British-Columbia	733	0	733	-2,711	-0.60
Ontario	23	246	269	-10,611	-0.80

Table III: State oil revenue from oil exploitation in Alaska per fiscal year — M$USD
(Alaska Oil and Gas Association)

	2013	2012	2011
Production tax	4,042.5	6,136.7	4,543.2
Royalties Net	1,749.4	2,022.8	1,921.3
Petroleum Corp. income tax.	434.6	569.8	542.1
Property tax	99.3	111.2	110.6
Hazardous release	7.8	9.4	9.7
Royalties	19.4	9.9	22.0
Royalties to perm. and school funds	955.9	919.6	970.9
Tax to Consitutional budget reserve fund	176.6	102.1	167.3
NPR-a leases	3.6	4.8	3.0
Total	7,388.1	9,884.3	8,090.1

Table IV: Individual resource payout in Alaska
(Alaska Permanent Fund Corporation)

Year	$ USD	Year	$ USD
2014	1,884.00	2009	1,305.00
2013	900.00	2008	2,069.00
2012	878.00	2007	1,654.00
2011	1,174.00	2006	1,106.96
2010	1,281.00	2005	845.76

Table V: Direct payout to local institutions in North Dakota
(North Dakota Legislative Council)

	Fiscal year 2014	Sept. 2014
Hub cities	8,750,000	708,334
Counties	197,538,275	32,339,212
Cities	66,635,265	10,829,819
School districts	21,661,622	2,994,868
Townships	18,982,777	3,191,467
Total	313,567,939	50,043,700
Per capita	433.47	69.18

Table VI: Benchmark parametrization

Parameter	Benchmark value	Interpretation
μ	8	Total factor productivity
α	0.85	Share of labor in production
σ	2/3	Elasticity of input substitution
ν	0.8	Returns to scale
c_1	1	Region 1 marginal cost of extraction parameter
c_2	0.1	Region 2 marginal cost of extraction parameter
P	2	International oil price
η	0.4	Frisch elasticity of labor supply
δ	2	Scaling parameter on disutility of labor
ϕ	0.05	Marginal damage parameter
γ	0	Consumption elasticity of marginal utility
G	0.5	Government revenue requirement
N	1	Total population

B Figures

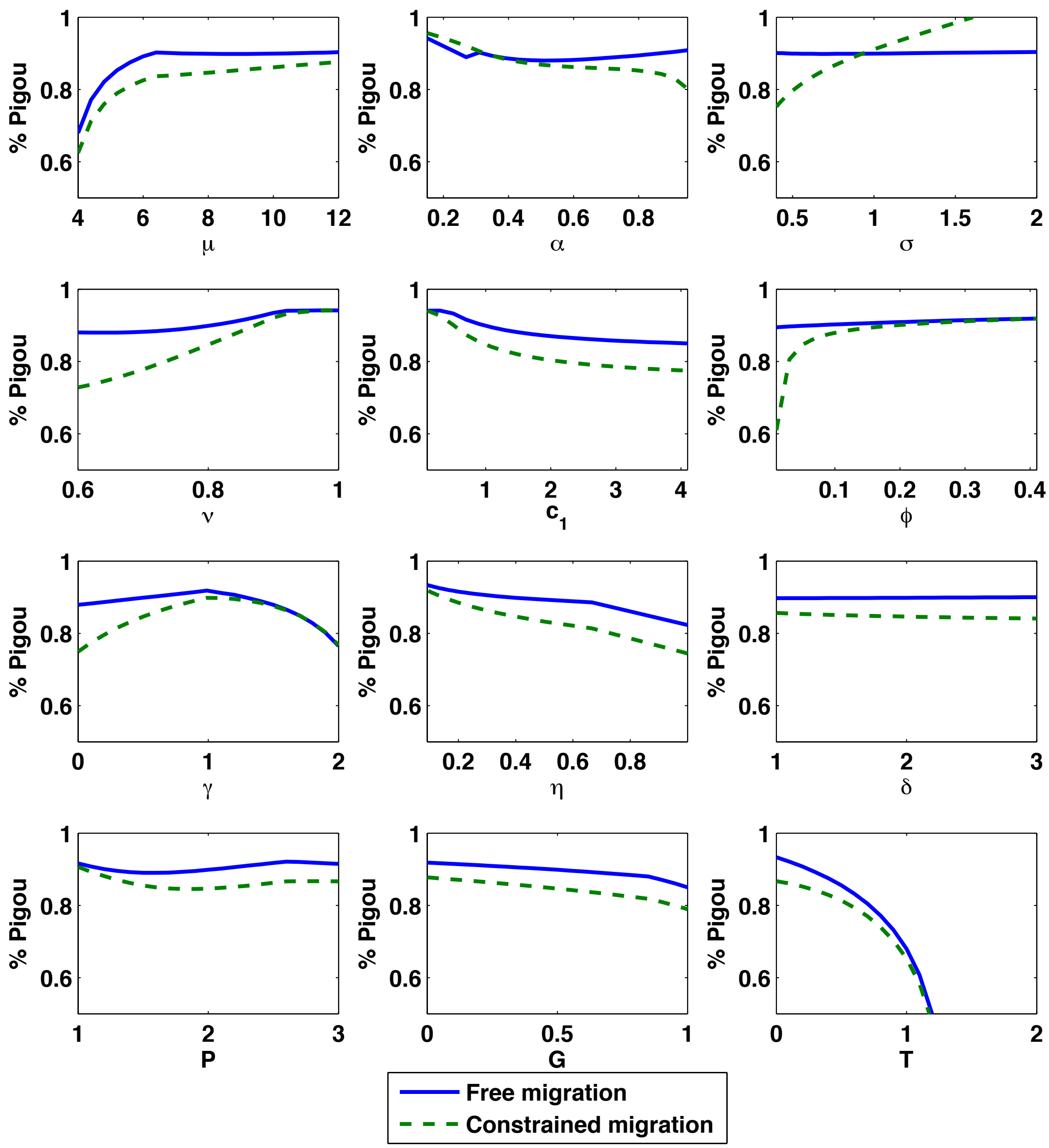

Figure 2: Extended sensitivity analysis with concave utility of consumption