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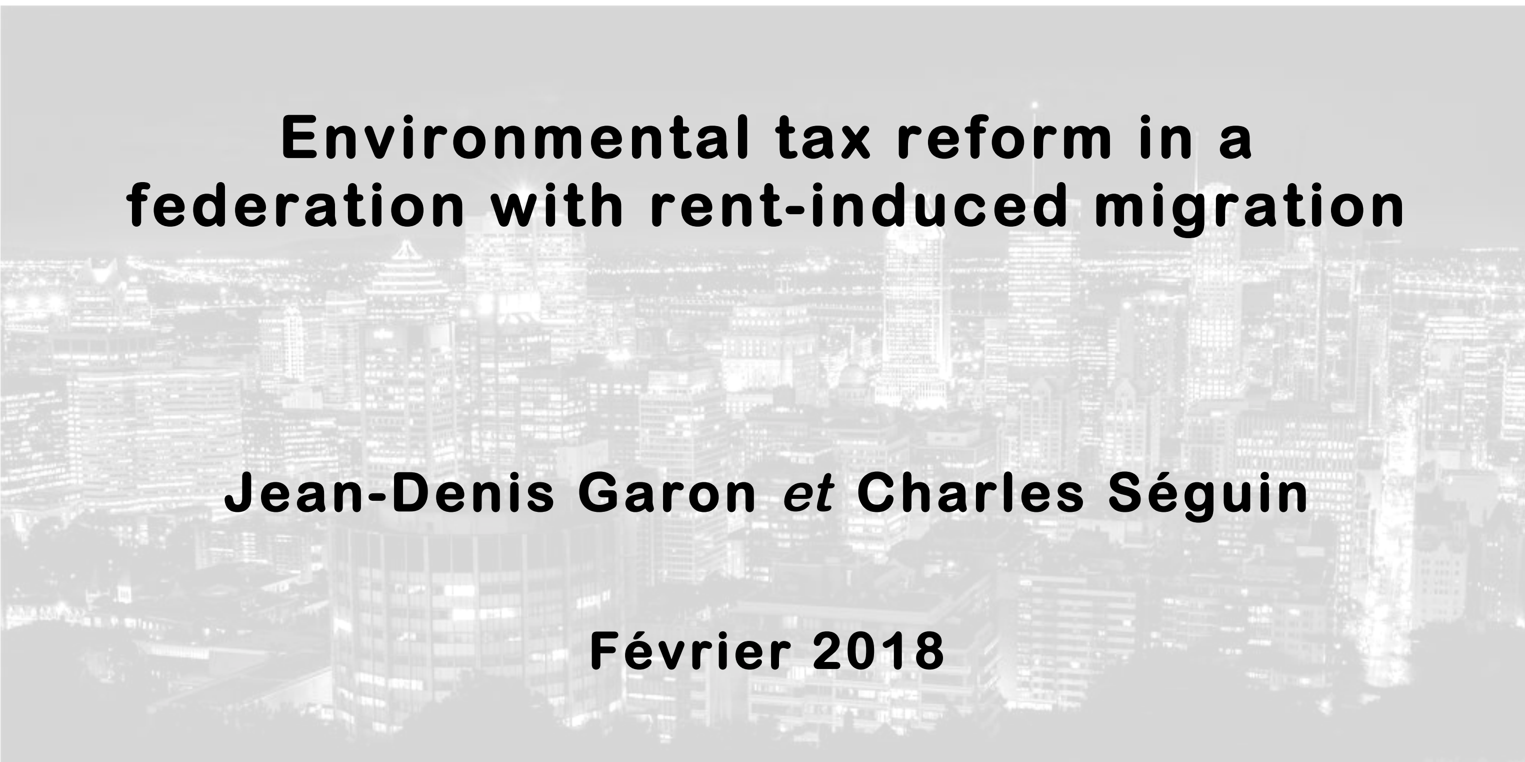

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ESG UQÀM
Département des sciences économiques
École des sciences de la gestion
Université du Québec à Montréal

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Jean-Denis Garon, Université du Québec à Montréal, Canada; CIRPÉE; et CESIfo
Charles Séguin, Université du Québec à Montréal, Canada; et CIREQ

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Département des Sciences Économiques
Université du Québec à Montréal
Case postale 8888,
Succ. Centre-Ville
Montréal, (Québec), H3C 3P8, Canada
Courriel : brisson.lorraine@uqam.ca
Site web : http://economie.esg.uqam.ca

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

Jean-Denis Garon and Charles Séguin

ESG-UQAM

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Abstract

We study the welfare effects of a revenue-neutral environmental 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 in equilibrium, the tax reform mitigates the scope of inefficient migration. This positive welfare effect may significantly reduce fiscal costs of pollution pricing 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

* ✉ Jean-Denis Garon, C.P. 8888, Succ. Centre-Ville Montreal QC Canada H3C 3P8. Email: garon.jean-denis@uqam.ca. Phone: +1 514 987 3000 ext. 2274. Fax: +1 514 987 8494. Garon is also affiliated with CESIfo and CIRPÉE, and Séguin with CIREQ. Both authors thank Robin Boadway, Craig Brett, Philippe De Donder, Pierre Lasserre, Andrew Leach, Marie-Louise Leroux, and Pierre Pestieau for their comments and suggestions. We also thank Guillaume Duff for outstanding research assistance. We acknowledge the Smart Prosperity group at the University of Ottawa and SSHRC for their funding and support. Any remaining mistakes are our own.

1 Introduction

This paper analyzes a environmental tax reform in a federation characterized by labor mobility, a polluting input, and heterogeneity in resource endowments across regions. Extracting the natural resource creates economic rents that are captured and redistributed on a residence basis, which introduces rent-seeking as a motive for inefficient migration. The environmental tax reform consists of simultaneously increasing taxes on a polluting input and reducing those on labor income while keeping tax revenues unchanged (Bovenberg, 1999). We obtain that optimal environmental tax on the polluting input is closer to its first-best pigouvian level than that of a standard, migration-free benchmark. The main driver of this result is an extensive-margin effect: an income tax break is more relieving for the inhabitants of resource-poor, high-productivity regions, making them more attractive to potential migrants.

An important strand of economic literature has indeed investigated the strong double dividend (SDD) hypothesis, in accordance to which substituting preexisting distortionary taxes for new environmental levies would improve the efficiency of the tax system (Bovenberg and Goulder, 1996; Bovenberg, 1999; Fullerton et al., 2010). However, the SDD remained mostly unverified in general equilibrium settings.[1] Since new environmental levies impose their own distortions by atrophying tax bases, abatement costs can be substantial. Thus, one crucial policy lesson from the literature is that environmental taxes should be considered first and foremost for their potential for abating pollution (Fullerton et al., 2010).

But another major policy lesson is that the pre-reform economic environment can be a strong determinant of abatement costs, which naturally include the preexisting tax mix and various institutional features. In particular, recent literature has shown an interest into the ability of environmental levies to capture economic rents, and also on factor mobility.

[1] The SDD 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).

In particular, Bento and Jacobsen (2007) conduct a welfare analysis when a fixed factor is used in the production of dirty goods. A SDD can be found at low abatement levels since environmental taxation may be beneficial due to its ability to tax economic profits. In a multijurisdictional context, Alexeev et al. (2016) adapt the model of Oates and Schwab (1988) and Ogawa and Wildasin (2009) to show that the choice of environmental rents allocation between private and public consumption can play a crucial role for generating a SDD. Other studies, such as Böhringer et al. (2016), argue that vertical fiscal externalities may induce local jurisdictions to substantially increase their environmental tax levels while indirectly shifting some of the costs to other federated states, a phenomenon commonly known as "tax exporting."[2] By postulating mobility of capital, these last two frameworks allow immobile workers to capture rents through higher salaries and, by the same token, local governments to capture them using local taxation.

The way economic rents are generated, whom they belong to, and the policy instruments used to capture them are of utmost importance to better understand the welfare effect of environmental taxes. We explore a new mechanism by modeling a federation where capital is immobile but where households inefficiently migrate to appropriate net fiscal benefits (NFB) for themselves (Flatters et al., 1974; Boadway and Flatters, 1982; Boadway, 2006). NFBs are typically defined as the difference between the monetary value of public goods, services and transfers obtained by citizens and taxes paid to states. Although efficient migration would only be motivated by differences in the marginal product of labor, asymmetric rents encourage some households to migrate to a region where their marginal product is lower, in exchange for an alternative compensation through higher rents. Then, a tax reform that reduces the federal income tax rate mitigates the scope for inefficient migration and improves the efficiency of the national allocation of labor.

As of now, most of the literature seem to abstract from rent-seeking behavior that can be induced by resource extraction and its implication for optimal environmental taxation,

[2] Williams (2012) also investigate the design of environmental policies with vertical interactions between levels of governments, focusing on an emission trading system.

even though these are quite common features of federal countries, as is illustrated 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: 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

Canada, where regionally-owned rents from natural resources provide local tax advantages, offers an illustrative example in which inter-provincial migration is positively correlated with net fiscal benefits that are not fully equalized.[3] Table II reports data to this effect. Mineral and oil royalties per capita for the fiscal year 2011–2012 in all Canadian provinces, a year when oil prices were especially high. Note that equalization payments per capita that are inversely related to royalties per capita, but not to the extent that their sum is similar across provinces. 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.[4] The population movement towards Alberta, which welcomed almost all net migrants, is

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

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

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, 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.[5] 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,

[5]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.

anticipated component of Alaska's households incomes (Hsieh, 2003). 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.

The rest of the paper is divided as follows. Sections 2 and 3 respectively introduce the theoretical model and characterize the welfare effect of a tax reform. As is typical in this literature, some of our theoretical results cannot be fully characterized analytically. Section 4 therefore provides numerical illustrations. Section 5 concludes.

2 Theoretical model

We consider a federation with a fixed population N allocated across two regions indexed by $i = 1, 2$. The number of residents in region i is N_i, such that $N_2 = N - N_1$. We assume that each household is small enough so we can treat regional populations as continuous variables.

In each region, a consumable output is produced using, as inputs, a nonrenewable resource o_i and aggregate labor $L_i \equiv N_i \ell_i$ where ℓ_i is the quantity of labor supplied by a representative household in i. The homothetic technology is expressed by $F(L^i, o_i)$. The production sector in region i acts is a price-taker with respect to wages (w_i) and the world price of the resource (P). It also takes N_i as given (migration occurs prior to production). Firms' economic profits in the production sector of region i are given by the profit function

$$\Pi_i^x(P + t_o, w_i, N_i) = \max_{\ell_i, o_i} F(N_i \ell_i, o_i) - w_i N_i \ell_i - (P + t_o) o_i, \tag{1}$$

where t_o is the federal proportional tax rate per unit of resources used (such as oil burned) in the country. The extent to which oil and labor may be combined in order to produce output depends on the elasticity of substitution between both inputs.[6]

We explicitly model a resource extraction sector to analyze the interactions between exogenous changes in the world price of the resource and the welfare consequences of an environmental tax reform.[7] Each region is endowed with a stock of a nonrenewable natural resource such as oil. A quantity O_i is *extracted* in region i, a quantity o_i is *used* as an input in each region i to produce a final consumption good, and a total quantity $\sum_i (O_i - o_i)$ is therefore *exported*. The federation is presumed to be a small oil exporter, such that the resource can be sold at the exogenous world price P. Extracting O_i costs $C_i(O_i)$, a function that satisfies $C_i(0) = 0$, $C_i'(\cdot) > 0$, and $C_i''(\cdot) > 0$, and that encompasses all direct and opportunity costs associated with extraction processes and depletion of reserves.[8] Economic rents generated by the extraction sector in each region equals:

$$\Pi_i^O(P) = \max_{O_i} PO_i - C_i(O_i), \ i = 1.2. \tag{2}$$

[6] In a similar model, Bovenberg and van der Ploeg (1998) also 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.

[7] The literature sometimes models natural resources rents as a simple windfall in each region (Beine et al., 2015; Raveh, 2013), which would also fit our analysis.

[8] We abstract from labor as an input in oil extraction, which would muddle the analysis by adding an economic opportunity channel as a motive for migration.

We adopt the convention that region 1 is resource poor and that region 2 is resource rich. So, $C_1'(O) > C_2'(O)\ \forall O$ which, used with the first-order condition of the extraction sector, $O_1(P) < O_2(P)\ \forall P$. The Envelope theorem implies that an increase in the world price P has a stronger positive rent effect on region 2 since $\partial \Pi_i^O(P)/\partial P = O_i$. [9]

Total economic rents generated in region i consists of the economic profits realized in both the production sector and the resource sector. We denote them by the shorthand

$$\Psi_i \equiv \Pi_i^o(\cdot) + \Pi_i^x(\cdot), \tag{3}$$

where in an equilibrium their components come from (1) and (2). 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.

Mobile households freely locate in the region of their choice. Their location decision depends on the utility they can get in each region. A representative household who decides to reside in region i maximizes utility

$$U_i = u(x_i, \ell_i) - \phi\left(\sum_i o_i\right) \tag{4}$$

subject to the budget constraint

$$x_i = (1 - t_l) w_i \ell_i + \Psi_i/N_i + T_i/N_i. \tag{5}$$

[9]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.

Consumption of a composite private good x_i enters positively ($u_x > 0$) and labor supply ℓ_i enters negatively ($u_\ell < 0$). Utility satisfies the following assumptions $u_{xx} \leq 0$ and $u_{\ell\ell} > 0$. The strictly convex function $\phi(\sum_i o_i)$ is the household's disutility caused by a global (or national) externality. It is caused by the use of a nationwide quantity $\sum_i o_i$ of polluting nonrenewable resources in the whole federation.

Ψ_i/N_i is the rent-benefit of being located in i and T_i/N_i is a lump-sum per-capita equalization transfer paid by the federal government on a residence basis. An increase in equalization payments to region i induces a pure income effect for households who reside in that region, just as an increase in local rents. Although the per-capita equalization payments are paid in a lump-sum fashion from the central government to the regions, they are paid for with revenues collected through distortionary taxation. This conforms with what is generally observed in the reality.

By separability of (4) with respect $\phi(\cdot)$, we express indirect utility as

$$V_i(T_i, t_l, \Psi_i, N_i, w_i, \sum_i o_i) \equiv v(T_i, t_l, \Psi_i, N_i, w_i) - \phi\left(\sum_i o_i\right), \ i = 1, 2. \tag{6}$$

We make three modelling assumptions that greatly improve tractability of the model without altering our qualitative results. First, we adopt the simplification that already existing stocks of externalities are implicitly incorporated in $\phi(\cdot)$. Second, the theoretical analysis concentrates on utility functions that are separable between consumption and labor ($u_{x\ell} = 0$) so as to avoid issues related to the multiple definitions of pigouvian tax levels (see Gahvari (2014)). Third, we derive welfare formulas with quasi-linearity of the utility function (u_x constant). Under this assumption, households' marginal utility of income is equalized across regions, meaning that welfare changes accounted for in units of consumption (divided by marginal utility of income) can be linearly aggregated across regions. Moreover, since individuals consume a composite good, one can presume that marginal utility of consumption does not decrease sharply with x, an assumption that generally comes along with a composite good.

Still, for the sake of completeness, the numerical examples presented later in the paper are generalized for decreasing marginal utilities.

The indirect utility functions defined in (6) allows to define a migratory equilibrium. Because households are forward-looking, public policies must satisfy the following equilibrium migration condition:

$$v_1(T_1, t_l, \Psi_1, N_1, w_1) = v_2(T_2, t_l, \Psi_2, N - N_1, w_2). \tag{7}$$

As long as it is not satisfied with strict equality, there is at least one inframarginal household that still has an incentive to migrate.[10] The properties of indirect utility function and the migration equilibrium condition give us the following lemma:

Lemma 1. Locational inefficiency with unequalized rents: *Suppose that rents are imperfectly equalized across regions. Then, the marginal product of labor is larger in the resource-poor region ($w_1 > w_2$), and gross labor income is greater in the resource-poor region $w_1\ell_1 > w_2\ell_2$. (Proof in the appendix).*

Lemma 1 extends Boadway and Flatters (1982)'s 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. The source of this problem is the pure income effect that comes from local rents (or, alternatively, the level effect on utility due to a more generous provision of public goods at similar tax rates). This comes at an overall efficiency cost for the federation, unless rent-seeking is completely neutralized through a first-best equalization system.[11] As this will become clear in the next section, and in our numerical simulation, the environmental tax reform will tend to induce a socially beneficial population movement towards the resource-poor region.

[10] Migration is costless. Boadway et al. (2003) consider a model with costly migration. Doing so here would not qualitatively change our results. In the numerical illustration we provide benchmarks without migration.

[11] 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.

3 Environmental reform and welfare

We now consider an arbitrary preexisting equalization system that is funded with distortionary taxation. The reform consists of marginally reducing labor income taxes t_l and, simultaneously, marginally increasing the environmental levy t_o, while keeping constant the overall size of its equalization $\sum_i T_i$. Since the federal government is the first mover, it maximizes social welfare while anticipating firms' and households reactions. Social welfare is defined by[12]

$$W = N_1 v_1(T_1, \Psi_1, N_1, w_1) + (N - N_1) v_2(T_2, \Psi_2, N - N_1, w_2) - N\phi\left(\sum_i o_i\right). \tag{8}$$

The federal government maximizes social welfare subject to the budget constraint

$$G + \sum_i T_i = t_l \sum_i w_i L_i + t_o \sum_i o_i. \tag{9}$$

and to the migration equilibrium constraint (7).

Consider the 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 (8) and (9) together. Making use of the envelope theorem on indirect utilities and profit functions in both the production and the resource sectors, substituting and reorganizing, we obtain the following variation in social welfare:

$$\frac{1}{\lambda}\frac{dW}{dt_o} = \underbrace{\left(t_o - \frac{N}{\lambda}\phi'\left(\sum_i o_i\right)\right)\sum_i \frac{do_i}{dt_o}}_{W^P} + \underbrace{\left(\frac{\Psi_2}{N_2} + \frac{T_2}{N_2} - \frac{\Psi_1}{N_1} - \frac{T_1}{N_1}\right)\frac{dN_1}{dt_o}}_{W^M} + \underbrace{t_l \sum_i w_i \frac{dL_i}{dt_o}}_{W^L}. \tag{10}$$

[12]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.

Three distinct welfare effects of the reform are pointed out in (10), each capturing either costs or benefits of substituting labor taxation for environmental taxation.

W^P is a standard Pigouvian welfare benefit. It is the only part of (10) that is not directly affected by migratory behavior because the externality is global. $N\phi'(\sum_i o_i)/\lambda$ is the 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.

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

$$\frac{\Psi_2}{N_2} + \frac{T_2}{N_2} > \frac{\Psi_1}{N_1} + \frac{T_1}{N_1}, \tag{11}$$

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.

Finally W^L is the welfare effect of the policy through 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:

$$\sum_i w_i \frac{dL_i}{dt_o} = \sum_i w_i N_i \underbrace{\frac{\partial \ell_i}{\partial t_l}\frac{dt_l}{dt_o}}_{RR>0} + \sum_i w_i N_i \underbrace{\frac{\partial \ell_i}{\partial w_i}\frac{dw_i}{dt_o}}_{TI<0} + \underbrace{(w_1\ell_1 - w_2\ell_2)\frac{dN_1}{dt_o}}_{MTB>0} \tag{12}$$

We identify three effects in (12). 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 (Bovenberg and de Mooij, 1994; Bovenberg, 1999; Mooij et al., 2002; Fullerton et al., 2010). 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 W^M 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.

Finally, 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 (7), and by applying the envelope theorem on utility and profit functions (in both sectors, for both regions), we find that

$$\frac{dN_1}{dt_o} = \frac{\overbrace{(w_2\ell_2 - w_1\ell_1)dt_l/dt_o}^{\text{Labor income }>0} + \overbrace{(o_2/N_2 - o_1/N_1)}^{\text{Profits per capita }\gtrless 0} + \overbrace{t_l\left(\ell_2 dw_2/dt_o - \ell_1 dw_1/dt_o\right)}^{\text{Tax wedge differential }\gtrless 0}}{\frac{1}{N_2}\frac{\Psi_2}{N_2} + \frac{1}{N_1}\frac{\Psi_1}{N_1} + \frac{1}{N_1}\frac{T_1}{N_1}}. \tag{13}$$

As is often the case with general equilibrium models, it is impossible to sign dN_1/dt_o analytically. However, some analysis can be performed, in which we can see that some effects that are not present in the standard environmental tax models push the sign of dN_1/dt_o towards the positive zone.

Note first that the sign of (13) depends only on that of its numerator. Its first term is identified 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. This effect appears because of rent-seeking behavior. The second component is 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.

Although its sign is generally ambiguous, this negative welfare effect is stronger in region 1 using most standard production functions, making the "profit per capita" term negative. Because wages are higher there, firms substitute labor for oil, and it has a smaller labor-oil ratio in production. For example, with a CES production function that has an elasticity of substitution σ and a relative share of labor, α, then the firm's first-order condition directly implies that[13] $o_i/N_i = w_i^\sigma \ell_i \left(\frac{1-\alpha}{\alpha}\frac{1}{P+t_o}\right)^\sigma$.

The fact that the "labor income" and the "per capita profits" effects go in opposite directions, for most production functions, contributes to the ambiguity of the sign of dN_1/dt_o. However, one may suspect that when the share of labor is larger than that of oil in production,

[13]The function $F(L_i, o_i) = \mu\left(\alpha L_i^{\frac{\sigma-1}{\sigma}} + (1-\alpha)o_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\nu\sigma}{\sigma-1}}$, is used in our numerical examples, where μ is total factor productivity and ν is a return-to-scale parameter.

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 has an ambiguous impact on the sign of dN_1/dt_o. Intuitively, this term should be positive, since 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. 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.

4 Numerical illustration

To address the analytical ambiguity of the welfare impacts of the environmental tax reform, we calibrate a computable version of the model. In this section, we first present the functional forms and parameters values of the calibration. Then we present the pre- and post-reform scenarios. Finally, we present the results of this numerical illustration and discuss them.

For the consumable output, we use a CES production function

$$F(L_i, o_i) = \mu \left(\alpha L_i^{\frac{\sigma-1}{\sigma}} + (1-\alpha) o_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\nu\sigma}{\sigma-1}}, \tag{14}$$

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:

$$U(x_i, \ell_i, o_i, o_{-i}) = \frac{x_i^{1-\gamma}}{1-\gamma} - \delta \ell_i^{1+\frac{1}{\eta}} - \phi \cdot (o_1 + o_2)^2. \tag{15}$$

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.

Table VI summarizes the benchmark values for the calibrated parameters. The relative share of labor and oil in production α, the elasticity of input substitution σ, and 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, around 30%, 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 alternative values of γ in our sensitivity analysis. The benchmark calibration uses the second best transfers (T_1 and T_2). Note that second best transfers to the ressource rich region will always be zero ($T_2 = 0$). We also consider arbitrary transfers in the sensitivity analysis, the range of which is all potential second best values of T_1. 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. A sensitivity analysis is conducted on all parameters.

The preferred measure of the welfare impact of an environmental tax reform in the double dividend literature is the relative size of the environmental tax to its Pigouvian level (Jaeger, 2012). If the environmental tax is higher than its Pigouvian level, there is a SDD, that is the reform improves the gross efficiency of the tax system. If the environmental tax is below its Pigouvian level, but above what it would have been with lump sum rebates of the environmental tax revenues, then there is a weak double dividend. That is, the welfare is higher under an environmental tax reform using the revenues to reduce distortionary taxes than with lump sum rebates.

Analytically, we have shown that our model yields at least a weak double dividend from equation (12). Numerically, we will investigate whether we have a SDD or not through the MTB effect in equation (12) and the W^M in equation (10).

These welfare impacts will be assessed by defining the environmental component of the oil tax. 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 includes 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 that is not a sufficient indicator of a SDD.

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, including transfer levels T_1 and T_2, is optimized so as to maximize non environmental welfare (setting implicitly $\phi = 0$).[14] This gives a positive tax on both labor and oil that funds equalization payments and that induces migration towards region 1, but for which the purpose is not to reduce pollution. The reform then consists in re-optimizing the tax mix, while keeping transfers fixed to their pre-reform levels, to take into account the environmental damages caused by the oil use ($\phi > 0$). We calculate the environmental tax by taking the difference between the oil tax before and after the reform. This is a conservative measure of the environmental tax, as the post-reform revenue-raising and migratory components of the oil tax both decrease.

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.

Finally, we construct a third reform allowing the government to reoptimize its transfers along with the introduction of the environmental tax, while keeping migration free. This possibility is not considered in the theoretical model for tractability purposes. Our results are qualitatively similar to those of Alexeev et al. (2016) which finds that governments can use environmental taxes to optimally increase their size in a different context involving inter-jurisdictional competition. In our model, it is optimal for the federal government to increase its transfers to the resource poor region along with the environmental tax introduction. Quantitatively however, this channel has a much smaller impact on the optimal environmental tax than the migration channel (see figure 1). Hence our discussion of the results focuses on the reform in which the size of the federal government is fixed.

[14] This optimization is subject to the the migration constraint (equation 7) and federal budget constraint (equation 9), to which we add on the left hand side an exogenous revenue requirement, G, for sensitivity analysis.

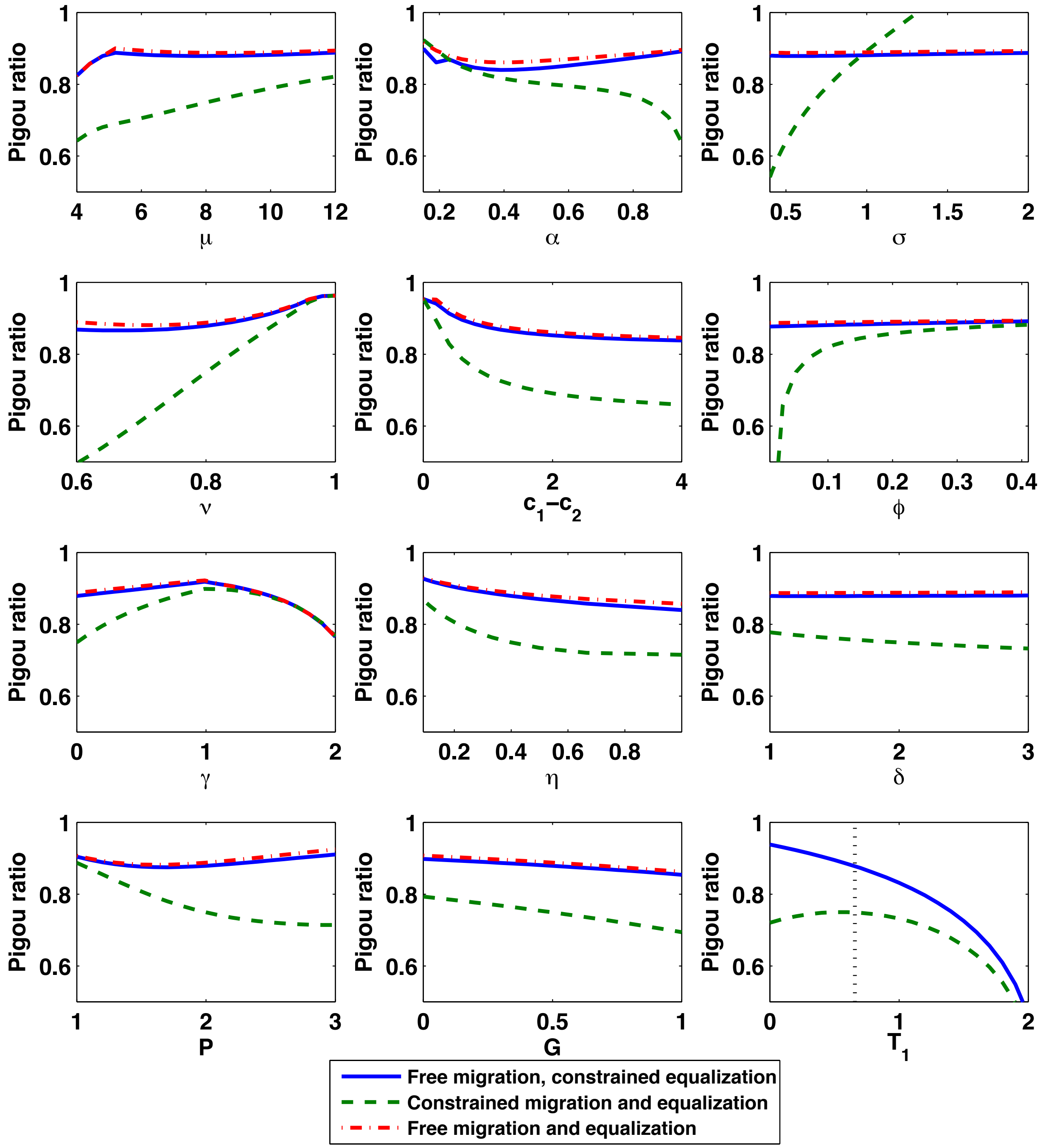

Figure 1: Environmental tax as a fraction of its Pigouvian level with and without migration

Our benchmark calibration results 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 (10) and MTB in (12) 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 (12). This is why the environmental tax remains below its Pigouvian level, which means that there is no strong double dividend.

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 the overwhelming majority of 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. But in none of the calibrations does a SDD arise.

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, our proxy for resource endowments. When $c_1 = c_2 = 0.1$, both regions have identical resource endowments and the optimal environmental tax does not change with 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 the resource P goes up. Then, 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. Indeed, while the environmental tax is a relatively constant fraction of its Pigouvian level with migration as oil price changes, it decreases with P when migration is constrained, as the tax interaction effect gets stronger.

Third, increasing the scope of fiscal equalization compensates region 1 for having smaller rents. Hence, we get the intuitive result that increasing T_1 reduces the migration benefits of the environmental levy. As T_1 grows, optimal environmental taxes with and without migration converge. 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 distortions associated to taxation. When revenue collections become high, the only reason the government taxes is for revenue-raising purposes. A vertical line in the bottom right panel of figure 1 indicates the optimal transfer with migration.

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, tax interaction 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 environmental taxes, as a fraction of their Pigouvian levels, under both scenarios gradually converge.

We also conduct a sensitivity analysis with respect to G, an exogenous revenue amount that the federal government must collect in addition to T_1. 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.

The sensitivity analysis reported in figure 1 also offers an alternative reform not considered in the analytical model for tractability purposes. In that reform, transfers are not fixed to their pre-reform levels, but can be reoptimized by the federal government. This in principle could increase the scope for a strong double dividend, as the tax reform induces beneficial migration to region 1 and reduces the need for equalization payments to region 1. Results in figure 1 show that allowing for reoptimized transfers does indeed increase the environmental tax level. However, the magnitude of that increase is very small and never yields a strong double dividend.

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.[15] 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 more similar. 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.[16]

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 $\frac{o_i}{N_i} = \ell_i \left(\frac{1-\alpha}{\alpha} \frac{w_i}{P+t_o} \right)^{\sigma}$. Hence the per capita oil consumption term of (13), 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

[15] Note that even with concave utility of consumption, the free migration condition imposes that individual welfare is always identical across regions. Hence there are no equity motives for equalization.

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

labor income tax payments more in region 1 than in region 2. But when the share of labor into production α becomes relatively small, most of 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 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.

The numerical exercise shows that an environmental tax reform may have better non-environmental benefits in a federation with rent-induced migration. The calibration is meant to sign an analytically ambiguous result. For a wide range of parameter values, the migration effect mitigates the tax interaction effect. However, the magnitude of the differences should not be interpreted literally as the calibration is not meant to represent the specific situation of a given country. As is the case with the more traditional double dividend literature, the results may change depending on the economic and policy environment in which the reform is implemented.

5 Concluding remarks

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 federation wide 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. We find the positive welfare effects of the environmental tax reform through migration are unlikely to be high enough to generate a SDD.

Some changes to the changes to model assumption reinforce our results. Suppose for instance that local and central governments share the personal income tax base, and denote by τ_i the local tax rate in region i. Then, the after tax labor income in i becomes $(1 - t_l - \tau_i)w_i\ell_i$. In such case the migration pattern is less obvious for two reasons. First, uncongested public goods also leads individuals to migrate. More importantly, one may believe that differences in local tax rates will qualitatively change our results. Assume first that $\tau_1 > \tau_2$ and that each local government has to finance an exogenously given amount of public expenditures. This is the most likely case since region 1 has less natural resource rents.

Then, the migration problem is worsened, and the non-environmental benefits of the reform may be higher than in our previous analysis. The opposite is true if $\tau_1 < \tau_2$, but our results qualitatively hold as long as some rent-induced migration remains.

Other changes may reverse them, such as the case when rents are not distributed directly to citizens through a cash payment, or through a public provision of public or private goods. Suppose instead that some workers (for example in the public sector) capture the rent by being paid at a wage rate higher than their marginal product. If rents are captured in this way by a significant number of public sector workers, and that at the same time $w_2 > w_1$ then our results may be reversed. By lowering the tax on labor income, the federal government would then deprive itself from some share of the rent.

Several other environments featuring migration remain to be explored 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 Mathematical appendix

Optimization problem of households

Using backward induction, households maximize their utility subject to their budget constraint. Residents take their wage rates w_i as given and faces a proportional federal labor income tax rate t_l. The associated Lagrangian for a resident of region i is

$$\mathcal{L} = u(x_i, \ell_i) - \lambda_i \left(x_i - (1-t_l)w_i\ell_i - \frac{T_i}{N_i} - \frac{\Psi_i}{N_i} \right) - \phi \left(\sum_i o_i \right). \tag{16}$$

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

$$\frac{\partial u}{\partial x_i} - \lambda = 0 \tag{17a}$$

$$\frac{\partial u}{\partial \ell_i} + \lambda w_i(1-t_l) = 0 \tag{17b}$$

$$x_i - (1-t_l)w_i\ell_i - \frac{T_i}{N_i} - \frac{\Psi_i}{N_i} = 0. \tag{17c}$$

Labor supply $\ell_i^s(w_i(1-t_l))$ is implicitly described by (17b) 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

$$V_i(T_i, t_l, \Psi_i, N_i, w_i, \sum_i o_i) = v(T_i, t_l, \Psi_i, N_i, w_i) - \phi\left(\sum_i o_i\right). \tag{18}$$

The envelope theorem applied to (18) gives

$$\frac{\partial v_i}{\partial T_i} = \frac{\lambda}{N_i} \qquad > 0 \tag{19a}$$

$$\frac{\partial v_i}{\partial t_l} = -\lambda w_i \ell_i \qquad < 0 \tag{19b}$$

$$\frac{\partial v_i}{\partial \Psi_i} = \frac{\lambda}{N_i} \qquad > 0 \tag{19c}$$

$$\frac{\partial v_i}{\partial N_i} = -\frac{\lambda}{N_i}\left(\frac{T_i + \Psi_i}{N_i}\right) \qquad < 0 \tag{19d}$$

$$\frac{\partial v_i}{\partial w_i} = (1 - t_l)\lambda \ell_i \qquad > 0 \tag{19e}$$

Optimization in production

N_i is taken as given and economic profits made in the final output sector are the solution to

$$\Pi_i^x(N_i, w_i, P + t_o) = \max_{\ell_i, o_i} F(N_i\ell_i, o_i) - w_i N_i \ell_i - (P + t_o)o_i. \tag{20}$$

Note that the economic profits defined in (20) 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.[17] The first-order conditions that characterize labor demand and

[17] 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.

oil use are

$$F_L(N_i\ell_i, o_i) = w_i \tag{21a}$$

$$F_o(N_i\ell_i, o_i) = P + t_o. \tag{21b}$$

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

$$\frac{\partial \ell_i^d}{\partial t_o} = \frac{\partial \ell_i^d}{\partial P} > 0; \quad \frac{\partial \ell_i^d}{\partial N} < 0; \quad \frac{\partial \ell_i^d}{\partial w_i} < 0; \quad \frac{\partial o_i}{\partial t_o} = \frac{\partial o_i}{\partial P} < 0; \quad \frac{\partial o_i}{\partial N} = 0; \quad \frac{\partial o_i}{\partial w_i} < 0. \tag{22}$$

Total regional rents

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

$$\Psi_i(N_i, w_i, P + t_o) = \Pi_i^O(P) + \Pi_i^x(N_i, w_i, P + t_o). \tag{23}$$

Using the envelope theorem on (2) and (20), while taking into account that wages are endogenous in our general equilibrium setting, we find that

$$\frac{d\Psi_i}{dt_o} = -L_i \frac{dw_i}{dt_o} - o_i \tag{24a}$$

$$\frac{d\Psi_i}{dP} = -L_i \frac{dw_i}{dP} + O_i - o_i \tag{24b}$$

$$\frac{d\Psi_i}{dN_i} = -L_i \frac{dw_i}{dN_i} \tag{24c}$$

$$\frac{d\Psi_i}{dt_l} = -L_i \frac{dw_i}{dt_l} \tag{24d}$$

Labor market clears

Equations (24a) to (24d) rely on equilibrium wage rates w_i adjusting 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

$$\frac{\partial w_i}{\partial t_o} < 0; \quad \frac{\partial w_i}{\partial P} < 0; \quad \frac{\partial w_i}{\partial t_l} > 0; \quad \frac{\partial w_i}{\partial N_i} < 0. \tag{25}$$

Proof of Lemma 1

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 (21a) and (21b). Joint with $w_1 > w_2$, this implies that both $N_1 < N_2$ and $\ell_1 > \ell_2$.*

B Tables and figures

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$USDD
(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	$ USDD	Year	$ USDD
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
T_1	0 to 1.94	Pre-reform optimized transfer to region 1
N	1	Total population

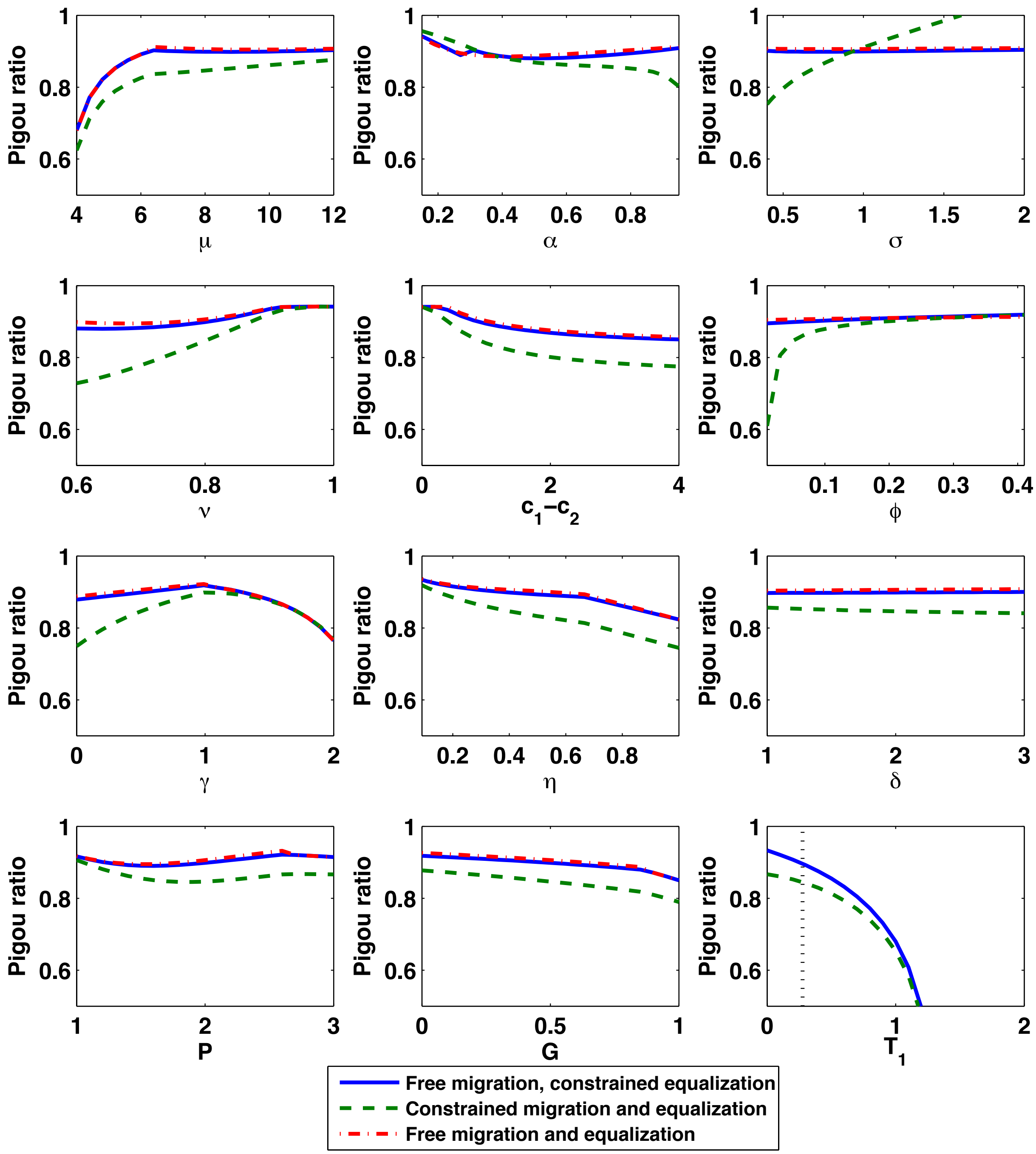

Figure 2: Extended sensitivity analysis with concave utility of consumption