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DISCUSSION
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ENVIRONMENTAL TAX REFORM WITH VERTICAL TAX EXTERNALITIES

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Abstract

The paper studies a regional environmental tax reform in a federal state. A region unilaterally improves the environmental quality by increasing its energy taxes. The regional government recycles the excess tax revenues by lowering either pre-existing distorting labor or capital taxes. This regional tax reform causes a vertical tax externality in the federal budget. We show how the nature of this externality depends on the environmental goal, the tax-recycling scenario, the initial local and federal tax shares, and the relative importance of the reforming region in the federal state. Simulations illustrate the effects for Belgium and US.

Keywords: Tax Reform; Vertical Tax Externality; Federalism

J EL-classification: H23; H77

1. INTRODUCTION

Governments increasingly share their competences in environmental and fiscal matters with other government levels. These multi-level governments may arise from decentralization (e.g. Belgium and Spain) or from voluntary cooperation between regions and nations (e.g. Germany, US and EU). In a federal state, regional policy typically affects the federal government (and vice versa). We show how environmental policy causes vertical externalities to the other government levels.

The paper studies a regional environmental tax reform in a federal state. One region increases its energy tax and recycles the excess tax revenues by lowering distorting labor or capital taxes. This tax reform may improve or deteriorate the non-environmental efficiency of the regional tax system. We show that the vertical externality depends on the improvement in environmental quality, the recycling of the tax revenues, the local and federal shares in the overall tax rate, and the number of regions. The theoretical results are illustrated with simulations for Belgium (2 regions) and the US (50 regions).

The paper combines the tax reform literature with fiscal federalism. In the early nineties, economists argued that substituting environmental taxes for pre-existing distorting taxes may yield a “double dividend” i.e. not only a cleaner environment but also a less distorting way of raising revenue (for an overview see Goulder, 1995). More recent literature describes the conditions under which environmental taxes exacerbate rather than alleviate tax distortions (see e.g. de Mooij and Bovenberg, 1998).

A large share of literature on federalism deals with horizontal tax competition for mobile production factors. In a model with mobile capital, immobile labor and environmental quality, Oates and Schwab (1988) show that environmental quality can be set optimally if there are no spillovers and if non-distorting taxes finance the budget. When distorting capital taxes are present, the regions set the capital tax ratio and the environmental quality too low in order to attract capital. Higher capital tax ratios and better environmental quality not only reduce output, the capital tax base also erodes and the regional government foregoes tax revenues. The regional government however does not take into account that the local tax base erosion increases the tax base of other regions. The social cost of local public goods or environmental quality is lower than the private cost. Hence, the capital tax level and environmental quality are set inefficiently low.

Vertical tax competition arises when different levels of government (i.e. federal and regional governments) co-occupy the same tax base. The tax imposed by one government level diminishes the tax base available to the other level. These vertical interactions are complex to study and the results depend heavily on the relations between the government levels. Up to now, they have received relatively little attention from economists and are usually neglected in environmental policy (for an overview, see Keen, 1998).

In section 2 we establish the model. We extend de Mooij and Bovenberg (1998) by adding a regional/federal dimension. Section 3 explains the welfare effects. Section 4 analyzes theoretically the model for a local labor tax cut and a local capital tax cut. The simulations of section 5 illustrate the theoretical results. We conclude in section 6.

2. MODEL

2.1. Structure of the Model

Each federal state is the result of a unique historical process. The competences of government levels differ significantly across federal states. Therefore we use a highly stylized model. Our model describes a federal government, ruling over N regions. The regions are small open economies (S.O.E.). They face fixed world prices for perfectly mobile commodities. In each region we find a regional government, a representative household and a representative firm.

The federal and regional governments co-occupy the same tax bases, i.e. both government levels tax the three input factors: labor income (T^L), capital (T^K), and energy (T^E). The three local taxes can differ inter-regionally, whereas the three federal taxes are uniform across regions. Labor is assumed to be immobile. Capital and energy are perfectly mobile. The model distinguishes three types of public goods: environmental quality, local public good and federal public good. The local public good and local environmental quality do not have any transboundary effects. The federal government supplies a single federal public good in all regions.

We assume that initially all regions are symmetric. The initial levels of production factors and local taxes are identical across regions. The paper investigates the welfare effects in all regions when one region deviates from the initial equilibrium by reforming its environmental tax policy[2]. The model is medium-run static as we do not include growth or accumulation nor do we account for short run adjustments.

Table 1: The Model

	Firms	
Profits	$0 = Y_i - (1+T_i^L + T_F^L)W_i L_i - (1+T_i^K + T_F^K)K_i - (1+T_i^E + T_F^E)E_i$	(1)
Production Function	$Y_i \le f\left[L_i, K_i, E_i\right]$	(2)
First-Order Conditions	$\frac{\partial f}{\partial L_i} = (1+T_i^L + T_F^L)W_i$	(3)
	$\frac{\partial f}{\partial K_i} = 1+T_i^K + T_F^K$	(4)
	$\frac{\partial f}{\partial E_i} = 1+T_i^E + T_F^E$	(5)
	Households	
Utility Function	$U_i = u_i\left[M_i, Q_i(V_i, C_i), G_i, G_F\right]$	(6)
Household Budget Constraint	$W_i L_i^S + K_i^* + E_i^* = C_i$	(7)
First-Order Conditions	$\frac{\partial u_i}{\partial V_i} = \lambda_i W_i$	(8)
	$\frac{\partial u_i}{\partial C_i} = \lambda_i$	(9)
Labor Supply	$L_S^i = 1 - V_i$	(10)
	Regional Government	
Regional Government Budget Constraint	$G_i = T_i^L W_i L_i + T_i^K K_i + T_i^E E_i$	(11)
Regional Labor-Market Equilibrium	$L_i = L_i^S$	(12)
Regional Environmental Quality	$M_i = g(E_i)$	(13)
Regional Walras Law: Balance of Payments	$Y_i = C_i + G_i + (K_i - K_i^*) + (E_i - E_i^*) + G_{ToF}^i$	(14)
	Federal Government	
Regional Payment to Federal Government	$G_{ToF}^i = T_F^L W_i L_i + T_F^K K_i + T_F^E E_i$	(15)
Federal Government Budget Constraint	$G_F = \sum_{i=1}^{N} G_{ToF}^i$	(16)
Endogenous variables	$G_F, Y_i, L_i, E_i, K_i, V_i, C_i, L_i^S, W_i, M_i, G_{ToF}^i, G_{-j}, T_j^L$ or T_j^K	
Exogenous variables	$E_i^*, K_i^*, T_{Fi}^L, T_{Fi}^K, T_{Fi}^E, T_{-j}^L, T_{-j}^K, T_{-j}^E, G_j, T_j^E$ and T_j^K or T_j^L	

$Y_i =$ Output in region i	$W_i =$ Market wage rate in region i	$G_F =$ Federal public good	$T_i^L =$ Local ad-valorem tax on labour income
$L_i =$ Labour demand in region i	$L_i^S =$ Labour supply in region i	$G_i =$ Local public good in region i	$T_i^K =$ Local ad-valorem tax on capital
$E_i =$ Energy demand in region i	$M_i =$ Environmental quality in region i	$G_{ToF}^i =$ Payment of region i to federal government	$T_i^L =$ Local energy tax
$K_i =$ Capital demand in region i	$C_i =$ Private consumption in region i	$\lambda_i =$ Lagrange multiplier of the household budget constraint in region i (= marginal utility of income)	$T_i^L =$ Federal ad-valorem tax on labour income
$K_i^* =$ Regional endowment of capital	$V_i =$ Leisure in region i		$T_i^K =$ Federal ad-valorem tax on capital
$E_i^* =$ Regional endowment of energy			$T_{Fi}^L =$ Federal energy tax

(a) Firms

Firm behavior is described by the representative firms. All firms produce an identical commodity. The constant return to scale production function with perfect competition reduces a firm's profit to zero (1). We use three inputs: labor (L_i), clean capital (K_i) and energy (E_i). The mobile factors, capital and energy, face fixed world market prices. Normalization sets prices of capital, energy, and output to one. Solving the maximization problem gives the implicit demand functions for labor (3), clean capital (4), and energy (5).

(b) Households

The representative household maximizes a homothetic utility function (6), subject to a budget constraint (7). This household budget consists of after-tax labor income ($W_i L_S^i$), and the domestic endowments of energy (E_i^*) and capital (K_i^*). We distinguish three public goods in the utility function, namely, environmental quality (M_i), local public good (G_i), and federal public good (G_F). The household optimizes by choosing the level of leisure (V_i) and consumption (C_i). The utility function has a weakly separable form, as public goods do not affect private demand for consumption and leisure. The three public goods are exogenously given from the household's perspective. Equations (8) and (9) represent the implicit functions for labor supply and consumption demand. We normalize the time endowment to one (10).

(c) Regional Government

The regional government supplies a local public good (G_i), which is financed by local taxes on labor (T_i^L), capital (T_i^K), and energy (T_i^E) (11). The tax reform is budget neutral for the regional government, as the excess tax revenues of the environmental tax are used to reduce local labor or capital taxes. The tax reform does not affect the local taxes and tax bases of the non-reforming regions. The tax reform is budget neutral for them as well.

(d) Federal Government

The federal taxes on labor (T_F^L), capital (T_F^K), and energy (T_F^E) finance the supply of the single federal public good (G_F). The tax reform changes the tax bases of the federal government in region j. With unchanged federal taxes, the regional tax reform affects the tax revenues of the federal government (15 and 16). The reform causes a vertical tax externality to federal government. The regional tax reform influences the welfare of all regions through the federal budget.

(e) Labor-Market Equilibria, Environment and Balance of Payments

Equation (12) represents the regional labor market clearing. With regionally immobile labor, the federal labor market clearing is redundant. Equation (13) formalizes the inverse relationship between the energy[3] demand and the environmental quality. The regional Walras law combines the output (1), the implicit demand function for clean capital (4), the household budget constraint (7) and the regional budget constraint (11). The federal Walras Law is redundant as it is the sum of all regional Walras Laws.

Table 2: Linearized Model

	Firms	
Domestic Output	$\tilde{Y}_i = \omega_i^L \tilde{L}_i + \omega_i^K \tilde{K}_i + \omega_i^E \tilde{E}_i$	(17)
Energy Demand	$\tilde{E}_i = \tilde{L}_i - \varepsilon^*_{E_iL_i}(\tilde{W}_i + \tilde{T}_i^L) - \varepsilon^*_{E_iK_i}\tilde{T}_i^K - \varepsilon^*_{E_iE_i}\tilde{T}_i^E$	(18)
Capital Demand	$\tilde{K}_i = \tilde{L}_i - \varepsilon^*_{K_iL_i}(\tilde{W}_i + \tilde{T}_i^L) - \varepsilon^*_{K_iK_i}\tilde{T}_i^K - \varepsilon^*_{K_iE_i}\tilde{T}_i^E$	(19)
Non-Profit Condition	$0 = \omega_i^L(\tilde{W}_i + \tilde{T}_i^L) + \omega_i^K \tilde{T}_i^K + \omega_i^E \tilde{T}_i^E$	(20)
	Households	
Household Budget Constraint	$\omega_i^C \tilde{C}_i = \omega_i^L(1 - \theta_i^L - \theta_{Fi}^L)(\tilde{L}_i + \tilde{W}_i)$	(21)
Labor Supply	$\tilde{L}_i^S = \eta_{L_iL_i}\tilde{W}_i$	(22)
	Regional Government	
Regional Government Budget Constraint	$\omega_i^G \tilde{G}_i = \theta_i^L\omega_i^L(\tilde{W}_i + \tilde{L}_i) + \omega_i^L\tilde{T}_i^L + \theta_i^K\omega_i^K\tilde{K}_i + \omega_i^K\tilde{T}_i^K + \theta_i^E\omega_i^E\tilde{E}_i + \omega_i^E\tilde{T}_i^E$	(23)
Regional Labor-Market Equilibrium	$\tilde{L}_i^S = \tilde{L}_i$	(24)
Regional Environmental Quality	$\tilde{M}_i = -\gamma_i \tilde{E}_i$	(25)
Regional Walras Law: Balance of Payments	$\tilde{Y}_i = \omega_i^C\tilde{C}_i + \omega_i^G\tilde{G}_i + (1-\theta_i^E-\theta_{Fi}^E)\omega_i^E\tilde{E}_i + (1-\theta_i^K-\theta_{Fi}^K)\omega_i^K\tilde{K}_i + \omega_{ToFi}^G\tilde{G}_{ToF}^i$	(26)
	Federal Government	
Regional Payment to Federal Government	$\omega_{ToFi}^G\tilde{G}_{ToF}^i = \theta_{Fi}^L\omega_i^L\tilde{L}_i + \theta_{Fi}^L\omega_i^L\tilde{W}_i + \omega_i^L\tilde{T}_F^L + \theta_{Fi}^K\omega_i^K\tilde{K}_i + \omega_i^K\tilde{T}_F^K + \theta_{Fi}^E\omega_i^E\tilde{E}_i + \omega_i^E\tilde{T}_F^E$	(27)
Federal Government Budget Constraint	$\tilde{G}_F = \frac{1}{N}\sum_{i=1}^{N}\tilde{G}_{ToF}^i$	(28)
Endogenous variables	$\tilde{G}_F, \tilde{Y}_i, \tilde{L}_i, \tilde{E}_i, \tilde{K}_i, \tilde{\pi}_i, \tilde{L}_i^S, \tilde{C}_i, \tilde{W}_i, \tilde{M}_i, \tilde{G}_{\mathrm{ToF}}^{\mathrm{i}}, \tilde{G}_{-j}, \tilde{T}_j^L$ or $\tilde{T}_j^K$	
Exogenous variables	$\tilde{T}_j^E; \tilde{T}_j^K = 0$ or $\tilde{T}_j^L = 0; \tilde{T}_{Fi}^L = \tilde{T}_{Fi}^K = \tilde{T}_{Fi}^E = 0; \tilde{T}_{-j}^L = \tilde{T}_{-j}^K = \tilde{T}_{-j}^E = 0; \tilde{K}_i^* = \tilde{E}_i^* = 0; \tilde{G}_j = 0$	

Parameters

ε^*_{ab} = Uncompensated direct or indirect price elasticity of factor a with respect to the price b $(a, b = L_i, E_i, K_i)$ in the model

$\eta_{L_iL_i}$ = Uncompensated wage elasticity of labor supply

γ_i = Elasticity that measures the effect of more energy on environmental quality

Taxes

$$\tilde{T}_i^E = \frac{dT_i^E}{1+T_i^E+T_F^E}, \tilde{T}_i^L = \frac{dT_i^L}{1+T_i^L+T_F^L}, \tilde{T}_i^K = \frac{dT_i^K}{1+T_i^K+T_F^K}$$

$$\theta_i^E = \frac{T_i^E}{1+T_i^E+T_F^E}, \theta_i^L = \frac{T_i^L}{1+T_i^L+T_F^L}, \theta_i^K = \frac{T_i^K}{1+T_i^K+T_F^K}$$

$$\theta_{Fi}^E = \frac{T_F^E}{1+T_i^E+T_F^E}, \theta_{Fi}^L = \frac{T_F^L}{1+T_i^L+T_F^L}, \theta_{Fi}^K = \frac{T_F^K}{1+T_i^K+T_F^K}$$

Shares

$$\omega_i^K = (1+T_i^K+T_F^K)\frac{K_i}{Y_i} \quad \omega_i^{K*} = (1+T_i^K+T_F^K)\frac{K_i^*}{Y_i} \quad \omega_{ToFi}^G = \frac{G_{ToF}^i}{Y_i} \quad \omega_i^L = (1+T_i^L+T_F^L)\frac{W_iL_i}{Y_i} \quad \omega_i^C = \frac{C_i}{Y_i}$$

$$\omega_i^E = (1+T_i^E+T_F^E)\frac{E_i}{Y_i} \quad \omega_i^{E*} = (1+T_i^E+T_F^E)\frac{E_i^*}{Y_i} \quad \omega_{FromFi}^G = \frac{G_{FromF}^i}{Y_i} \quad \omega_i^G = \frac{G_i}{Y_i}$$

2.2. *Linearization*

Table 2 contains the log-linearized model[4]. Log-linearization around an initial equilibrium is commonly applied for economic analysis of (small) tax reforms. The regional budget of the reforming region is exogenous as the tax reform is budget neutral ($\tilde{G}_j = 0$). The domestic endowments for capital and energy are exogenous for all regions ($\tilde{K}_i^* = \tilde{E}_i^* = 0$). Equations (18) and (19) give the factor demand equations for energy and capital. Elasticities ε^*_{ab} $(a, b = L_i, K_i, E_i)$ represent the price elasticities of factor demand conditional on employment. As empirical evidence suggests a positive uncompensated wage elasticity ($\eta_{L_iL_i}$), higher after-tax wage rates (W_i) boost employment (22) (Hausman, 1985).

3. WELFARE

As shown in de Mooij and Bovenberg (1998), the marginal excess burden ($\tilde{\beta}$) measures the welfare effects of a regional environmental tax reform. It is defined as the compensating variation (CV) divided by the output (30). The compensating variation is the additional transfer that keeps the household at its initial utility level. A positive excess burden indicates a welfare loss.

Equation (29) disentangles the welfare change into the effects of the factor market distortions. The θs stand for tax distortions or willingness to pay for environment or public goods. The first term shows that, with positive labor taxes, employment yields a welfare-gain. The labor taxes imply a wedge between the marginal social benefit of employment and the marginal social opportunity cost. The workers are not only compensated for giving up their leisure, but employment also yields public revenues. Similarly, the second term shows a wedge between the marginal social benefit and cost of capital demand. Hence, higher capital demand raises welfare. The third term represents the environmental factor. If total taxes on pollution ($\theta_j^E + \theta_{Fj}^E$) are larger than the marginal environmental damage (θ_{Ej}^P) then higher pollution increases welfare. The fourth term reflects the effect of the federal public good. If $\theta_j^G \omega_{Fj}^G \tilde{G}_F^j > \omega_{ToFj}^G \tilde{G}_{ToF}^j$, the relative increase in the supply of the federal public good is larger than the increase in the federal tax revenues paid by region j. In this case, the welfare of region j improves.

$$\tilde{\beta}_j = -\left[(\theta_j^L + \theta_F^L)\omega_j^L \tilde{L}_j + (\theta_j^K + \theta_{Fj}^K)\omega_j^K \tilde{K}_j + \left((\theta_j^E + \theta_{Fj}^E) - \theta_{Ej}^P\right)\omega_j^E \tilde{E}_j + \left(\theta_j^G \omega_{Fj}^G \tilde{G}_F - \omega_{ToFj}^G \tilde{G}_{ToF}^j\right)\right] \quad (29)$$

with $\tilde{\beta}_j = \frac{CV_j}{Y_j}$ (30) and $\theta_{Ej}^P = \frac{1}{1+T_j^E+T_F^E}\frac{U_M(-M_E)}{\lambda_j}$ (31) and $\theta_i^G = \frac{U_{G_F^i}}{\lambda_i}$ (32)

$$\tilde{\beta}_j = \underbrace{\theta_{Ej}^P \omega_j^E \tilde{E}_j}_{\text{environmental}} - \underbrace{(1-\theta_j^L-\theta_{Fj}^L)\omega_j^L \tilde{W}_j}_{\text{private non-environmental}} - \underbrace{\theta_j^G \omega_{Fj}^G \tilde{G}_F}_{\text{federal public non-environmental}} \quad (33)$$

$$\tilde{\beta}_{-j} = \underbrace{-\theta_{-j}^G \omega_{F-j}^G \tilde{G}_F}_{\text{federal public non-environmental}} \quad (34)$$

Equation (33) represents an alternative notation for the marginal excess burden in the reforming region. It consists of three components: the environmental welfare, the private non-environmental welfare, and the federal public non-environmental welfare. The regional budget does not change in any of the regions ($\hat{G}_i = 0$).

The regional tax reform in j does not affect the factor markets and the contributions to the federal level of the non-reforming regions. The tax reform in region j influences the welfare of the non-reforming regions only through the supply of federal public good (34).

(a) Environmental welfare

The first term of equation (33) expresses the change in environmental welfare in region j. θ_{Ej}^{P} represents the marginal social damage from pollution. An environmental tax reform typically reduces the demand for energy.

(b) Private non-environmental welfare

The private non-environmental welfare is related to the efficiency of the tax system as a revenue-raising device. An efficient tax system implies a lower tax burden on its agents. This boosts the after-tax wages and, hence, welfare.

A higher local energy tax decreases the energy demand, as energy supply is infinitely elastic. Similarly, the energy-poor economy attracts less capital. The marginal productivities of capital and energy remain equal to the world market price, but the marginal productivity of labor decreases. It is said that the incidence of the local energy tax falls on the immobile factor, labor. Similarly, the tax incidence of the local capital tax falls also on the immobile factor. The incidences of the tax that is increased (i.e. the local energy tax) and the taxes that are reduced (i.e. the local labor tax or local capital tax) are borne by immobile labor.

With zero local non-labor taxes ($\theta_j^E = \theta_j^K = 0$), taxes are equally efficient instruments to raise revenues. The local tax system is optimal from a non-environmental point of view. A marginal change in the local tax system does not yield any first-order effect on private welfare.

The capital and energy taxes do not only distort the labor market, but also distort the markets for capital and energy. With initially positive local non-labor taxes ($\theta_j^E > 0, \theta_j^K > 0$), the regional government foregoes energy tax revenues and capital tax revenues, due to the erosion of the energy tax base and the capital tax base. From a non-environmental point of view, the explicit labor tax is a more efficient instrument for raising public revenues as it distorts only the labor market. As in de Mooij and Bovenberg (1998), we call these two tax erosion effects, respectively, the tax burden effect and the negative tax shifting effect. Under particular conditions, however, the tax reform may expand the capital tax base, creating a private welfare benefit, the positive tax shifting effect.

Whether the tax reform reduces or expands the capital tax base depends on the recycling of the excess tax revenues. Tax recycling counteracts the decrease in capital, labor and energy demand, but the offsetting effect depends on the choice between a local labor tax cut and a local capital tax cut. As capital is perfectly mobile, the optimal capital tax is zero. The optimal tax for immobile labor, however, is positive. In the real world, with positive distorting taxes on labor and capital, one can say that capital is overtaxed and labor is undertaxed.

A local labor tax cut favors the undertaxed factor. The tax recycling has only a limited effect as labor supply is relatively inelastic compared to capital. The labor demand slightly increases and the economy in region j attracts only slightly more capital and energy. This counteracts but does not typically offset the previous erosion of capital and energy tax bases. With initially positive energy and capital taxes, the economy of region j suffers from a tax burden effect and a negative tax shifting effect. These effects lower the regional wages and therefore also the private non-environmental welfare. The tax burden effect and the negative tax shifting effect are the private costs for a cleaner environment.

If region j reduces the local tax on capital, it favors the overtaxed factor. The capital tax cut counteracts the previous decrease in capital demand due to the higher energy tax. If the counteraction does not completely offset the capital tax base erosion we still find a negative tax shifting effect. But, under some conditions, the capital tax base erosion is overcompensated and the environmental tax reform expands the local capital tax base. With an initially positive local capital tax, we get a positive tax shifting effect. The capital expansion also boosts the demand for energy and labor. This higher demand counteracts but, typically, does not completely offset the tax base erosion caused by higher local energy taxes. The environmental benefit and tax burden effect remain. The private non-environmental welfare improves if the positive tax shifting effect dominates the tax burden effect. If an improvement in environmental quality goes together with a higher private non-environmental welfare, we find a double dividend.

(c) Federal Public non- environmental welfare

The federal public non-environmental welfare is present in equation (33) for the reforming region j and in equation (34) for the non-reforming regions. θ_j^G is the willingness to pay for the federal public good. The regional tax reform changes the tax bases of the federal taxes in the reforming region.

Section 4 shows that the magnitude and sign of change in public non-environmental welfare depends on the environmental goal, the way of tax recycling of the excess tax revenues, the local and federal share in the overall tax rate, and the number of regions. A positive vertical tax externality increases the federal budget. Region j exports part of its non-environmental welfare gain to the non-reforming regions. Similarly, a negative vertical tax externality decreases the federal budget. The non-reforming regions pay for the environmental quality in the reforming region.

4. ENVIRONMENTAL TAXATION AND TAX RECYCLING

In this section we analyze the welfare effects for tax reforms recycling the tax revenues through local labor or capital taxes. Section 4.1 explains the general equilibrium elasticities in Table 4 and Table 5. Section 4.2 calculates the welfare effects when the regional government recycles the excess tax revenues through the local labor tax. Section 4.3 does the same for the local capital tax. The reduced-form coefficients for wage, energy demand, and federal budget in Table 4 and Table 5 correspond, respectively, with the private welfare, the environmental dividend and the vertical tax externality. Table 6 summarizes the welfare effects of both scenarios.

4.1. General Equilibrium Elasticities

Table 3 lists the general equilibrium elasticities. $\Gamma_{E_jE_j}$ and $\Gamma_{K_jE_j}$ represent the effects on, the energy/labor and capital/labor ratios when the government cuts the local labor tax. In the case of a capital tax cut, these ratios are given by, respectively, $\Gamma_{E_jE_j} - \Gamma_{K_jE_j}$ and $\Gamma_{K_jK_j} - \Gamma_{E_jK_j}$.

$\Gamma_{E_jE_j}$ reflects the effect on the energy/labor ratio with a higher energy price ($\varepsilon^*_{E_iE_i}$) and a lower labor price ($\varepsilon^*_{E_iL_i}$). The higher energy price induces input substitution away from energy towards labor. Moreover, output declines as the regional tax reform shifts the tax burden from the relatively inelastic factor towards the infinitely elastic factor. The negative output effect reinforces the substitution effect and the general equilibrium elasticity is unambiguously positive (i.e. $\Gamma_{E_jE_j} > 0$). A high elasticity corresponds with a strong decline in pollution. From a non-environmental point of view the regional and federal governments forego tax revenues, causing tax burden effects.

$\Gamma_{K_jE_j}$ measures the capital/labor ratio effect of a higher energy price ($\varepsilon^*_{K_iE_i}$) and a lower labor price ($\varepsilon^*_{K_iL_i}$). Two counteracting effects can be observed. On the one hand, higher environmental tax substitutes capital for energy. On the other hand, output declines, decreasing the capital demand. In the normal case, the adverse output effect dominates the positive substitution effect ($\Gamma_{K_jE_j} > 0$ and $\Gamma_{E_jK_j} > 0$), giving a negative tax shifting effect. In the exceptional case, the substitution effect dominates the adverse output effect ($\Gamma_{K_jE_j} < 0$ and $\Gamma_{E_jK_j} < 0$), leading to a positive tax shifting effect.

Table 3: General Equilibrium Elasticities

$\Gamma_{E_iE_i} = \varepsilon^*_{E_iE_i} - \frac{\omega_i^E}{\omega_i^L}\varepsilon^*_{E_iL_i}$	(35)	$\Gamma_{K_iK_i} = \varepsilon^*_{K_iK_i} - \frac{\omega_i^K}{\omega_i^L}\varepsilon^*_{K_iL_i}$	(36)	$\varepsilon^*_{E_iE_i} = -\frac{d\frac{E_i}{L_i} \Big/ \frac{E_i}{L_i}}{\frac{d(1+T_i^E+T_F^E)}{1+T_i^E+T_F^E}}$	(37)	$\varepsilon^*_{E_iL_i} = -\frac{d\frac{E_i}{L_i} \Big/ \frac{E_i}{L_i}}{\frac{d(W_i(1+T_i^L+T_F^L))}{W_i(1+T_i^L+T_F^L)}}$	(38)
$\Gamma_{E_iK_i} = \varepsilon^*_{E_iK_i} - \frac{\omega_i^K}{\omega_i^L}\varepsilon^*_{E_iL_i}$	(39)	$\Gamma_{E_iE_i} - \Gamma_{K_iE_i} = \varepsilon^*_{E_iE_i} - \frac{\omega_i^E}{\omega_i^K}\varepsilon^*_{E_iK_i}$	(40)	$\varepsilon^*_{E_iK_i} = -\frac{d\frac{E_i}{L_i} \Big/ \frac{E_i}{L_i}}{\frac{d(1+T_i^K+T_F^K)}{1+T_i^K+T_F^K}}$	(41)	$\varepsilon^*_{K_iE_i} = -\frac{d\frac{K_i}{L_i} \Big/ \frac{K_i}{L_i}}{\frac{d(1+T_i^E+T_F^E)}{1+T_i^E+T_F^E}}$	(42)
$\Gamma_{K_iE_i} = \varepsilon^*_{K_iE_i} - \frac{\omega_i^E}{\omega_i^L}\varepsilon^*_{K_iL_i}$	(43)	$\Gamma_{K_iK_i} - \Gamma_{E_iK_i} = \varepsilon^*_{K_iK_i} - \frac{\omega_i^K}{\omega_i^E}\varepsilon^*_{K_iE_i}$	(44)	$\varepsilon^*_{K_iK_i} = -\frac{d\frac{K_i}{L_i} \Big/ \frac{K_i}{L_i}}{\frac{d(1+T_i^K+T_F^K)}{1+T_i^K+T_F^K}}$	(45)	$\varepsilon^*_{K_iL_i} = -\frac{d\frac{K_i}{L_i} \Big/ \frac{K_i}{L_i}}{\frac{d(W_i(1+T_i^L+T_F^L))}{W_i(1+T_i^L+T_F^L)}}$	(46)

With $\omega_i^E \Gamma_{E_iK_i} = \omega_i^K \Gamma_{K_iE_i}$

$\Gamma_{E_jE_j} - \Gamma_{K_jE_j}$ measures the effect on the energy/labor ratio when energy price increases ($\varepsilon^*_{E_iE_i}$) and capital price decreases ($\varepsilon^*_{E_iK_i}$). In the normal case, the tax reform leads to a decrease in energy demand ($\Gamma_{E_jE_j} - \Gamma_{K_jE_j} > 0$). The tax burden effect decreases private welfare. In the exceptional case, the regional tax reform increases the energy/labor ratio ($\Gamma_{E_jE_j} - \Gamma_{K_jE_j} < 0$). Here, the positive output effect dominates the negative substitution effect. De Mooij and Bovenberg (1998) explain that this happens when capital is a better substitute for labor than energy.

$\Gamma_{K_jK_j} - \Gamma_{E_jK_j}$ represents the effect on the capital/labor ratio with a lower capital price ($\varepsilon^*_{K_iK_i}$) and a higher energy price ($\varepsilon^*_{K_iE_i}$). The regional tax reform reduces the tax burden on capital in the normal case ($\Gamma_{K_jK_j} - \Gamma_{E_jK_j} \succ 0$). The capital tax base expands, inducing a positive tax shifting effect. In the exceptional case, the capital tax base erodes ($\Gamma_{K_jK_j} - \Gamma_{E_jK_j} \prec 0$), causing a negative tax shifting effect. Here, the negative output effect dominates the substitution effect. This happens when energy is a much better substitute for labor than capital. The regional tax reform shifts the tax burden from the relative inelastic factor (capital) towards the elastic factor (energy).

4.2. *Reducing Labor taxes*

When initial local taxes on labor and capital are zero, the regional tax reform does not affect the private welfare (47). With positive initial taxes, the tax reform lowers the private welfare in the normal case ($\Gamma_{E_iE_i} \succ 0$ and $\Gamma_{E_iK_i} \succ 0$). The higher the initial local taxes, the more the private welfare declines. In the exceptional case ($\Gamma_{E_iE_i} \succ 0$ and $\Gamma_{E_iK_i} \prec 0$), the private welfare improves when the effect of $\Gamma_{E_jK_j}$ dominates $\Gamma_{E_jE_j}$. In the normal case, the tax reform improves the environmental quality (49). Only if $\Gamma_{E_jK_j}$ dominates $\Gamma_{E_jE_j}$ in the exceptional case, does the environment deteriorate with higher environmental taxes. The first and second column of Table 6 show that there is (almost) no scope[5] for a double dividend in the reforming region as private welfare and environmental welfare have an opposite sign.

Table 4: Reduced-form coefficients reducing labor tax: $\tilde{T}_j^L$

		$\tilde{T}_j^E$	
Wage (~Private welfare)	$\Delta_{L_j}\tilde{W}_j$	$-\left(\theta_j^E\Gamma_{E_jE_j} + \theta_j^K\Gamma_{E_jK_j}\right)\omega_j^E$	(47)
Labor	$\Delta_{L_j}\tilde{L}_j$	$-\eta_{L_jL_j}\left(\theta_j^E\Gamma_{E_jE_j} + \theta_j^K\Gamma_{E_jK_j}\right)\omega_j^E$	(48)
Pollution (~Environmental Dividend)	$\Delta_{L_j}\tilde{E}_j$	$-\left(\eta_{L_jL_j}\left(\theta_j^E\Gamma_{E_jE_j} + \theta_j^K\Gamma_{E_jK_j}\right)\omega_j^E + \Delta_{L_j}\Gamma_{E_jE_j}\right)$	(49)
Capital	$\Delta_{L_j}\tilde{K}_j$	$-\left(\eta_{L_jL_j}\left(\theta_j^E\Gamma_{E_jE_j} + \theta_j^K\Gamma_{E_jK_j}\right)\omega_j^E + \Delta_{L_j}\Gamma_{K_jE_j}\right)$	(50)
Output	$\Delta_{L_j}\tilde{Y}_j$	$-\left[\left(\Delta_{L_j} + \eta_{L_jL_j}\theta_j^E\right)\Gamma_{E_jE_j} + \left(\Delta_{L_j} + \eta_{L_jL_j}\theta_j^K\right)\Gamma_{E_jK_j}\right]\omega_j^E$	(51)
Federal Budget (~Vertical Tax Externality)	$\Delta_{L_j}\tilde{G}_F$	$-\frac{1}{N}\frac{1}{\omega_{ToFj}^G}\begin{bmatrix}\left(\left(\theta_{Fj}^L\omega_j^L\left(1+\eta_{L_jL_j}\right) + \theta_{Fj}^K\omega_j^K\eta_{L_jL_j} + \theta_{Fj}^E\omega_j^E\eta_{L_jL_j}\right)\theta_j^E + \theta_{Fj}^E\Delta_{L_j}\right)\Gamma_{E_jE_j} \\ +\left(\left(\theta_{Fj}^L\omega_j^L\left(1+\eta_{L_jL_j}\right) + \theta_{Fj}^K\omega_j^K\eta_{L_jL_j} + \theta_{Fj}^E\omega_j^E\eta_{L_jL_j}\right)\theta_j^K + \theta_{Fj}^K\Delta_{L_j}\right)\Gamma_{E_jK_j}\end{bmatrix}\omega_j^E$	(52)
Consumption	$\Delta_{L_j}\tilde{C}_j$	$-\frac{\omega_j^L}{\omega_j^C}(1-\theta_j^L-\theta_{Fj}^L)\left(1+\eta_{L_jL_j}\right)\left(\theta_j^E\Gamma_{E_jE_j} + \theta_j^K\Gamma_{E_jK_j}\right)\omega_j^E$	(53)
		$\Delta_{L_j} = \left(1-\theta_j^L\right)\omega_j^L - \eta_{L_jL_j}\left(\theta_j^E\omega_j^E + \theta_j^L\omega_j^L + \theta_j^K\omega_j^K\right) \succ 0$	

In the normal case, the federal budget unambiguously decreases after a tax reform (52). The tax reform decreases welfare in the non-reforming regions. The reforming region exports a part of its non-environmental efficiency costs to the other regions. In the exceptional case, however, the federal budget may increase or decrease, depending on general equilibrium elasticities and initial local and federal taxes.

4.3. Reducing capital taxes

The private welfare does not change if the initial local capital and energy taxes are equal to zero (54). In the normal case, the tax burden effect ($\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \succ 0$) and the positive tax shifting effect ($\Gamma_{K_iK_i} - \Gamma_{E_iK_i} \succ 0$) counteract each other. Private welfare may improve or deteriorate. If $\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \succ 0 / \Gamma_{K_iK_i} - \Gamma_{E_iK_i} \prec 0$, private welfare unambiguously deteriorates, whereas if $\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \prec 0 / \Gamma_{K_iK_i} - \Gamma_{E_iK_i} \succ 0$, private welfare unambiguously improves.

Table 5: Reduced-form coefficients reducing capital tax: $\hat{T}_i^K$

		$\hat{T}_j^E$	
Wage (~Private welfare)	$\Delta_{K_j}\hat{W}_j$	$-\left(\theta_j^E\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right) - \theta_j^K\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\right)\omega_j^E$	(54)
Labor	$\Delta_{K_j}\hat{L}_j$	$-\eta_{L_jL_j}\left(\theta_j^E\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right) - \theta_j^K\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\right)\omega_j^E$	(55)
Pollution (~Environmental Dividend)	$\Delta_{K_j}\hat{E}_j$	$-\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right)\Delta_{K_j} - \left(\omega_j^E\eta_{L_jL_j} + \omega_j^L\Gamma_{K_jE_j}\right)\left(\theta_j^E\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right) - \theta_j^K\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\right)$	(56)
Capital	$\Delta_{K_j}\hat{K}_j$	$-\omega_j^E\left(\eta_{L_jL_j} + \frac{\omega_j^L}{\omega_j^K}\Gamma_{K_jK_j}\right)\left(\theta_j^E\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right) - \theta_j^K\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\right) + \frac{\omega_j^E}{\omega_j^K}\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\Delta_{K_j}$	(57)
Output	$\Delta_{K_j}\hat{Y}_j$	$-\omega_j^E\left(\eta_{L_jL_j} + \omega_j^L\left(\Gamma_{K_jE_j} + \Gamma_{K_jK_j}\right)\right)\left(\theta_j^E\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right) - \theta_j^K\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\right)$	(58)
Federal Budget (~Vertical Tax Externality)	$\Delta_{K_j}\hat{G}_F$	$\frac{1}{N}\frac{1}{\omega_{ToFj}^G}\left\{\begin{array}{l}\left[\begin{array}{l}\eta_{L_jL_j}\left(\omega_j^L\left(\theta_{Fj}^L\theta_j^K - \theta_{Fj}^K\theta_j^L\right) + \omega_j^E\left(\theta_{Fj}^E\theta_j^K - \theta_{Fj}^K\theta_j^E\right)\right)\\ +\omega_j^L\left(\theta_{Fj}^K - \theta_{Fj}^K\theta_j^L + \theta_{Fj}^L\theta_j^K\right) + \left[\theta_{Fj}^E\theta_j^K - \theta_{Fj}^K\theta_j^E\right]\omega_j^L\Gamma_{K_jE_j}\end{array}\right]\omega_j^E\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\\ -\left[\begin{array}{l}\eta_{L_jL_j}\left(\omega_j^L\left(\theta_{Fj}^L\theta_j^E - \theta_{Fj}^E\theta_j^L\right) + \omega_j^K\left(\theta_{Fj}^K\theta_j^E - \theta_{Fj}^E\theta_j^K\right)\right)\\ +\omega_j^L\left(\theta_{Fj}^E - \theta_{Fj}^E\theta_j^L + \theta_{Fj}^L\theta_j^E\right) + \left[\theta_{Fj}^K\theta_j^E - \theta_{Fj}^E\theta_j^K\right]\omega_j^L\Gamma_{K_jK_j}\end{array}\right]\omega_j^E\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right)\end{array}\right\}$	(59)
Consumption	$\Delta_{K_j}\hat{C}_j$	$-\frac{\omega_j^E\omega_j^L}{\omega_j^C}(1 - \theta_j^L - \theta_{Fj}^L)(1 + \eta_{L_jL_j})\left(\theta_j^E\left(\Gamma_{E_jE_j} - \Gamma_{K_jE_j}\right) - \theta_j^K\left(\Gamma_{K_jK_j} - \Gamma_{E_jK_j}\right)\right)$	(60)
		$\Delta_{K_j} = \left(\omega_j^L(1 - \theta_j^L) - \omega_j^L\left(\theta_j^E\Gamma_{K_jE_j} + \theta_j^K\Gamma_{K_jK_j}\right)\right) - \eta_{L_jL_j}\left(\omega_j^L\theta_j^L + \theta_j^E\omega_j^E + \theta_j^K\omega_j^K\right) \succ 0$	

A double dividend appears when the positive tax shifting effect ($\Gamma_{K_jK_j} - \Gamma_{E_jK_j}$) dominates the tax burden effect ($\Gamma_{E_jE_j} - \Gamma_{K_jE_j}$) for the private welfare (54) but not for environmental quality (56). A double dividend never appears in the exceptional cases: the private welfare either improves at the expense of the environment or a better environment deteriorates the private welfare.

Equation 59 shows that the federal tax revenues depend on general equilibrium elasticities, initial local and federal taxes, and the relative importance of the reforming region in the federal state. In the normal case, the regional tax reform has an ambiguous effect on the federal budget. It may increase or decrease. With $\Gamma_{E_jE_j} - \Gamma_{K_jE_j} \succ 0$ and $\Gamma_{K_jK_j} - \Gamma_{E_jK_j} \prec 0$, we get a negative tax externality. The reforming region partially exports its costs for a cleaner environment to the other regions. It tends to oversupply environmental quality. If $\Gamma_{E_jE_j} - \Gamma_{K_jE_j} \prec 0$ and $\Gamma_{K_jK_j} - \Gamma_{E_jK_j} \succ 0$, the reforming region exports a part of its positive private welfare to the other regions. The reforming region is inclined to allow for too much pollution.

The last three columns of Table 6 summarize the welfare effects for the normal case (i.e. $\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \succ 0$ and $\Gamma_{K_iK_i} - \Gamma_{E_iK_i} \succ 0$) and two exceptional cases (i.e. $\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \prec 0 / \Gamma_{K_iK_i} - \Gamma_{E_iK_i} \succ 0$ and $\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \succ 0 / \Gamma_{K_iK_i} - \Gamma_{E_iK_i} \prec 0$). The exceptional case $\Gamma_{E_jE_j} - \Gamma_{K_jE_j} \prec 0 / \Gamma_{K_jK_j} - \Gamma_{E_jK_j} \prec 0$ does not exist.

Table 6: Welfare effects in region j reducing $\tilde{T}_j^L$ or reducing $\tilde{T}_j^K$

	Reducing $\tilde{T}_j^L$		Reducing $\tilde{T}_j^K$		
	$\Gamma_{E_iE_i} \succ 0$ (normal) $\Gamma_{E_iK_i} \succ 0$ (normal)	$\Gamma_{E_iE_i} \succ 0$ (normal) $\Gamma_{E_iK_i} \prec 0$ (exceptional)	$\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \succ 0$ (normal) $\Gamma_{K_iK_i} - \Gamma_{E_iK_i} \succ 0$ (normal)	$\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \succ 0$ (normal) $\Gamma_{K_iK_i} - \Gamma_{E_iK_i} \prec 0$ (exceptional)	$\Gamma_{E_iE_i} - \Gamma_{K_iE_i} \prec 0$ (exceptional) $\Gamma_{K_iK_i} - \Gamma_{E_iK_i} \succ 0$ (normal)
$\theta_i^E = 0$ and $\theta_i^K = 0$	Private welfare (=) Environmental (+) Tax externality (-)	Private welfare (=) Environmental (+) Tax externality (+/-)	Private welfare (=) Environmental (+) Tax externality (+/-)	Private welfare (=) Environmental (+) Tax externality (-)	Private welfare (=) Environmental (-) Tax externality (+)
$\theta_i^E \succ 0$ and $\theta_i^K = 0$	Private welfare (-) Environmental (+) Tax externality (-)	Private welfare (-) Environmental (+) Tax externality (+/-)	Private welfare (-) Environmental (+) Tax externality (+/-)	Private welfare (-) Environmental (+) Tax externality (-)	Private welfare (+) Environmental (-) Tax externality (+)
$\theta_i^E = 0$ and $\theta_i^K \succ 0$	Private welfare (-) Environmental (+) Tax externality (-)	Private welfare (+) Environmental (+/-) Tax externality (+/-)	Private welfare (+) Environmental (+/-) Tax externality (+/-)	Private welfare (-) Environmental (+) Tax externality (-)	Private welfare (+) Environmental (-) Tax externality (+)
$\theta_i^E \geq 0$ and $\theta_i^K \geq 0$	Private welfare (-) Environmental (+) Tax externality (-)	Private welfare (+/-) Environmental (+/-) Tax externality (+/-)	Private welfare (+/-) Environmental (+/-) Tax externality (+/-)	Private welfare (-) Environmental (+) Tax externality (-)	Private welfare (+) Environmental (-) Tax externality (+)

5. SIMULATIONS

We illustrate the theoretical results with simulations for a small federal state (e.g. Belgium) and a large federal state (e.g. United States). We raise after-tax energy prices by 10%. We assume that the supply of capital is infinitely elastic. In the real world the supply of capital is more elastic in the long run than in the short run. Therefore, these simulations can be interpreted as the long-run consequences of environmental tax reforms. The shares, taxes, and elasticities correspond roughly to most Western countries (see de Mooij and Bovenberg, 1998). These economies are characterized by a large share of labor income in GDP and large labor and capital taxes as compared to energy taxes. The labor income tax on a before-tax basis is 50% ($T^L = 1$). The capital income tax is set at one third for mobile capital ($T^K = 0.5$). The energy tax is set at about 10% ($T^E = 0.1$).

The debate on the substitutability/complementarity between capital and energy calls for sensitivity analysis on the cross price elasticity of capital and energy demand. Therefore, we run the model three times. The base run uses $\varepsilon^*_{K_iE_i} = -0.02$ and $\varepsilon^*_{E_iK_i} = -0.04$. In the second run we assume that K_i and E_i are better substitutes ($\varepsilon^*_{K_iE_i} = -0.1$ and $\varepsilon^*_{E_iK_i} = -0.2$). The third run assumes that K_i and E_i are poorer substitutes ($\varepsilon^*_{K_iE_i} = 0.06$ and $\varepsilon^*_{E_iK_i} = 0.12$). We assume that the marginal utility of the federal local public goods (61) and the marginal utility of environmental quality (62) equal the marginal utility of consumption in initial equilibrium, i.e. both public goods are provided at efficient level.

$$U_{G^i_{FromF}} = \lambda_i \qquad (61)$$

$$U_M(-M_E) = \lambda_i \qquad (62)$$

Belgium and the United States differ in two aspects. First, we assume that Belgium consists of two identical regions[6], whereas the US has 50 identical states. We consider them all to be small open economies[7]. Second, in the United States, the lower government levels[8] are responsible for about half of the total energy taxation. We estimate that the state's tax shares in the US are 20%, 20% and 50% for respectively capital tax, labor tax and energy tax[9]. In Belgium, the local tax shares are 20% for capital and 10% for both labor and pollution[10].

5.1. Small federal state: Belgium

The base run with a local labor tax cut (first column Table 7) shows a positive environmental dividend in the reforming region with a decline of 6.47% in energy demand. Wage and employment decrease respectively with 0.02% and 0.01%, causing a negative non-environmental private welfare. There is no double dividend, but rather a trade-off between private and environmental welfare. Compared to labor, energy seems to be overtaxed from a non-environmental point of view. Moreover, regional environmental policy decreases the federal budget with 0.11%, causing a negative vertical tax externality. The overall welfare in the reforming region increases with 0.54%. This is a trade-off of the private welfare, the environmental dividend, and the vertical externality. The non-reforming region, however, suffers from a negative environmental tax externality and its welfare decreases by 0.04%.

In the case of a local capital tax cut (second column in Table 7), pollution decreases by 5.76% and capital demand is 4.32% higher. Wage and employment increase by 0.08% and 0.02%, respectively. The positive tax shifting effect dominates the negative tax burden effect and we observe a double dividend. This suggests that in most Western countries capital is overtaxed compared to energy. Moreover, the tax reform brings about a positive vertical tax externality as the federal budget increases by 0.28%. The overall welfare in the reforming region and non-reforming regions improve by 0.66% and 0.11%, respectively.

When capital and pollution are better substitutes (third and fourth column of Table 7), substituting energy taxes for distorting taxes on labor or capital becomes more favorable from a non-environmental point of view. For a local labor tax cut, wage, employment and federal budget decrease less than in the base run. More capital is used after the tax reform thanks to the easier substitution between capital and energy. In the case of a local capital tax cut, wage, employment, capital demand and federal budget increase more than in the corresponding base run. The better substitution boosts the economy from a non-environmental point of view.

Table 7: Effects of an increase in after-tax energy prices by 10% in Belgium

	Base run $\varepsilon^*_{K_iE_i}=-0.02$ and $\varepsilon^*_{E_iK_i}=-0.04$		K_i/E_i better substitutes $\varepsilon^*_{K_iE_i}=-0.1$ and $\varepsilon^*_{E_iK_i}=-0.2$		K_i/E_i poorer substitutes $\varepsilon^*_{K_iE_i}=0.06$ and $\varepsilon^*_{E_iK_i}=0.12$	
	Lower T_i^L	Lower T_i^K	Lower T_i^L	Lower T_i^K	Lower T_i^L	Lower T_i^K
Wage	-0.02	0.08	-0.002	0.10	-0.04	0.06
Employment	-0.01	0.02	-0.0009	0.02	-0.02	0.01
Pollution	-6.47	-5.76	-6.46	-6.52	-6.47	-4.98
Capital	-0.77	4.32	0.04	5.17	-1.57	3.46
Output	-0.75	0.07	-0.58	0.08	-0.91	0.06
Federal Budget	-0.11	0.28	-0.05	0.34	-0.18	0.22
Consumption	-0.01	0.06	-0.001	0.07	-0.02	0.04
Welfare in region j	0.539	0.658	0.569	0.755	0.509	0.560
Welfare in region –j	-0.042	0.107	-0.018	0.130	-0.067	0.085

Poor substitution between capital and pollution (fifth and sixth column in Table 7) exacerbates the loss in wage, employment, capital demand and federal budget in case of a labor tax cut. With a capital tax cut, poor substitution curtails the gain in wage, employment, capital, and federal budget. The overall welfare in the reforming and the non-reforming region is better off when capital and energy are better substitutes. Similarly, their welfare decreases if capital and pollution are poorer substitutes. A better substitution of capital and energy favors a regional environmental tax reform, while a poorer substitution between capital and energy limits the scope for cheap environmental improvement.

5.2. *Large federal state: United States*

The results for the US in Table 8 are similar to those for Belgium. The environmental gain is similar. With a local labor tax cut, the regional tax reform deteriorates private and federal public non-environmental welfare. A capital tax cut boosts private welfare and federal budget. Better substitution between capital and pollution favors a cheap improvement of environmental quality. Poorer substitution worsens welfare.

Differences between American and Belgian results are due to the higher local share in the overall energy tax and the higher number of regions in the US. First, a high initial local environmental tax rate reinforces the tax burden effect on the regional level. With a labor tax cut, the wage and employment decrease more in the US than in Belgium. With a capital tax cut, the tax reform boosts the American wages and employment less than the Belgian. Second, as the number of regions is much higher in the US, the federal budget is less sensible to the policy of a single region. A regional environmental tax reform in the US imposes a relatively smaller vertical tax externality.

Curiously, the welfare improvement in the reforming region in the US is higher than in Belgium for a labor tax cut. This is due to the fact that the provision of federal local public goods decreases relatively less in the US. In the simulation, this effect outweighs the larger tax burden effect. Similarly, for a capital tax cut the welfare increase in the reforming region is smaller in the US due to the lower positive vertical tax effect and the larger tax burden.

Table 8: Effects of an increase in after-tax energy prices by 10% for the US.

	Base run $\varepsilon^*_{K_iE_i}=-0.02$ $\varepsilon^*_{E_iK_i}=-0.04$		K_i/E_i better substitutes $\varepsilon^*_{K_iE_i}=-0.1$ $\varepsilon^*_{E_iK_i}=-0.2$		K_i/E_i poorer substitutes $\varepsilon^*_{K_iE_i}=0.06$ $\varepsilon^*_{E_iK_i}=0.12$	
	Lower T_i^L	Lower T_i^K	Lower T_i^L	Lower T_i^K	Lower T_i^L	Lower T_i^K
Wage	-0.06	0.05	-0.04	0.06	-0.08	0.04
Employment	-0.03	0.01	-0.02	0.01	-0.03	0.007
Pollution	-6.48	-5.74	-6.48	-6.51	-6.49	-4.95
Capital	-0.78	4.21	0.02	5.06	-1.59	3.37
Output	-0.76	0.04	-0.60	0.05	-0.93	0.04
Federal Budget	-0.004	0.01	-0.002	0.02	-0.007	0.01
Consumption	-0.04	0.03	-0.03	0.04	-0.05	0.03
Welfare in region j	0.567	0.543	0.573	0.619	0.560	0.466
Welfare in regions -j	-0.0015	0.004	-0.0005	0.0052	-0.0025	0.0034

6. CONCLUSIONS

Regions rarely take into account the effects of their policy on the budgets of the other government levels. A regional environmental tax reform can cause positive or negative vertical tax externalities to the federal government. This vertical tax externality influences the welfare of the neighboring regions through the supply of federal public goods. In this paper we show that the vertical externality depends on the improvement in environmental quality, the way the excess taxes are recycled, the local and federal share in the overall tax rate, and the number of regions.

First, higher local energy taxes generally lead to higher environmental quality. The environmental tax reform erodes the tax base of both local and federal energy taxes, causing a tax burden effect on regional and federal levels. High local energy taxes enforce the negative tax burden effect. The simulations for Belgium and the US show that the regional economy responds better to a budget-neutral tax reform when the local energy tax is low. With positive federal energy taxes, the tax burden effect is a cost to the federal budget. Greater environmental progress leads to a more severe tax burden.

Second, the regional tax reform may boost or erode the tax base of local and federal capital taxes. This depends on the way the excess energy tax revenues are recycled. A negative federal tax shifting effect exacerbates the negative tax burden effect, whereas a positive tax shifting effect counteracts or even offsets the tax burden effect. With positive federal capital taxes, the tax shifting effect is a cost or benefit to the federal level.

Third, when the positive tax shifting effect dominates the negative tax burden effect at the regional level, the wages increase, leading to higher federal labor tax revenues. Decreasing wages entails a cost for the federal budget.

Fourth, the federal budget responds better when the share of energy in the total federal tax revenues is low. Obviously, the effect of a regional tax reform also depends on the relative share of the reforming region in the federal state. The impact of a US state on the federal level is smaller than a Belgian region.

With a negative tax externality, the reforming region partially exports its costs for cleaner environment to the other government level and, hence, to the other regions. The reforming region tends to oversupply environmental quality. With a positive tax externality, the reforming region exports a part of its positive private welfare to the other regions. The reforming region is inclined to allow for too much pollution

This conclusion has strong similarities with the concept of double marginalization. Tirole (1998) explains that double marginalization arises when multiple firms at different places in a supply chain have market power. They all use their market power to receive a positive margin on their product. If these firms are vertically integrated, the total margin is lower than the sum of margins in the disintegrated case. Future research should investigate whether this argument holds for a federal state too, where serial governments (e.g. local and federal government) may set their taxes or environmental quality too high.

7. REFERENCES

- De Mooij, R.A. and A.L. Bovenberg. (1998). "Environmental Taxes, International Capital Mobility and Inefficient Tax Systems: Tax Burden vs. Tax Shifting." *International Tax and Public Finance* 5, 7-39.

- Goulder, L.H. (1995). "Environmental taxation and the double dividend: A reader's guide." *International Tax and Public Finance* 2, 155-182.

- Hausman, J.A. (1985). "Taxes and Labour supply." In A.J. Auerbach and M.S. Feldstein (eds.), *Handbook of Public Economics I*. Amsterdam: Elsevier.

- Keen, M. (1998). "Vertical Tax Externalities in the Theory of Fiscal Federalism." *International Monetary Fund Staff Papers* 45, 454-485

- Oates, W.E. and R.M. Schwab. (1988). "Economic competition among jurisdictions: Efficiency enhancing or distortion inducing?" *Journal of Public Economics 35*, 333-354.

- Tirole, J. (1988). *The Theory of Industrial Organization*. Cambridge, Mass.: The MIT Press.

8. ENDNOTES

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2 We do not compute a Nash equilibrium. The reforming region is represented by j. All regions are represented by $I = \{1,...,i,...,N\}$ and $j \in I$. $-j$ represents the N-1 non-reforming regions.

3 The model is also valid when energy is generalized to a polluting input factor.

4 All variables are now denoted as $\tilde{Z}$, representing $d \ln Z$ or $\frac{dZ}{Z}$, except for the tax ratios where $\tilde{T}_i^E$ denotes $\frac{dT_i^E}{1+T_i^E+T_F^E}$.

5 Only in the very specific case if $\Gamma_{E_j K_j}$ dominates $\Gamma_{E_j E_j}$ in equation 47, but does not dominate in equation 49 is there a double dividend with a very small improvement of private welfare and environmental quality.

6 The two regions in the model are Flanders and Wallonia/Brussels. In reality, Belgium consists of three heterogeneous regions Flanders, Wallonia and Brussels Capital-Region, the last being a much smaller region.

7 Although the United States as a whole are definitely not a small open economy, it is a reasonable assumption to treat most states like small open economies. Only four states have more than 13 million people: California, Florida, New York and Texas.

8 States, provinces, municipalities

9 US Census Bureau, 2000

10 Anno 2005