Optimal Taxation and Environmental Policy in a Decentralized Economic Federation with Environmental and Labor Market Externalities

Tomas Sjögren*

Department of Economics, Umeå University,

901 87 Umeå, Sweden

Abstract

This paper concerns optimal taxation and environmental policy in the presence of transboundary environmental damage and labour market distortions, where the latter gives rise to wage bargaining externalities between countries. I consider a decentralized economic federation where the federal government chooses emission targets to be implemented by the national governments. The results show that the labour market externality will influence the target levels for emissions chosen by the central government. I then proceed to characterize the optimal tax policy at the national level. The decentralized federation structure produces incentives for the national governments to use the tax policy to influence the policies chosen by the federal level. It is shown how these objectives interact with the additional objective to minimize the distortion on the national labour market.

Key words: Transboundary Externalities, Labour Market Distortions, Economic Federation, Optimal Taxation.

JEL Classification: H23, J51, H77, H21.

---

* The author would like to thank Thomas Aronsson and two anonymous referees for helpful comments and suggestions. A research grant from the Jan Wallander, Tom Hedelius´ and Tore Browaldhs Foundation is gratefully acknowledged.

1. Introduction

There is, today, a relatively large literature which explores the connection between labour market distortions and environmental policy. This reflects that environmental policy may influence the outcome on the labour market, and if the latter is characterized by imperfect competition, the welfare effects that originate from the labour market may be significant. One strand of this literature analyzes how labour market distortions operate simultaneously with environmental externalities, and how environmental tax reforms may improve welfare in the presence of unemployment.[1] Another characterizes the environmental policy in the context of an optimal tax and expenditure structure.[2] In this paper, I follow the second line of research by considering environmental policy as part of an optimal tax and expenditure problem.

The design of environmental and fiscal policy typically depends on the context within which these decisions are made. Earlier studies of environmental policy and labour market distortions have dealt with unified economies in which there is no distinction between different levels in the public sector. This is somewhat surprising, considering that countries, or unions of countries, have a multi-level decision structure, where different levels of governments choose different policy instruments. Compared with a unified country, the multi-level decision structure may have important implications for the design of policies because different government levels may (i) have different objectives and (ii) may have access to different policy instruments. Usually, (i) is interpreted to mean that local governments are only concerned with domestic welfare whereas the federal level is concerned with the welfare in all localities. In the presence of transboundary environmental externalities, this means that environmental policies (e.g. emission targets) should be determined at the federal level, whereas the implementation of these policies can be left to the local governments. A possible example is the European Union (EU), where emission targets for e.g. greenhouse gases are determined at the European level, whereas the implementation is left to the member countries. As for (ii), it is related to the argument that some federal structures, such as EU, can be characterized as decentralized federations because the federal government is weak relative to the lower-level (national) governments. This is usually interpreted to mean that the federal government only has access to a restricted set of policy instruments, and that the national governments act as first-movers vis-à-vis the federal government.[3] The weak federation structure contrasts to the approach used in most earlier studies on economic federations,

[1] See, for example, Bovenberg and de Mooij (1994), Bovenberg and Goulder (1998), Bovenberg and van der Ploeg (1998), Parry et al (1999), and Koskela, Schöb and Sinn (2001).
[2] See, e.g., Bovenberg and van der Ploeg (1996) and Aronsson (2005).
[3] See, e.g. Caplan and Silva (1999).

where it is the federal government which acts as a first-mover towards the local governments. The weak federation structure will have important implications for how the lower-level governments design their policies since these can be used to influence the federal government. This means that in a weak federation, there will be additional motives underlying the environmental and fiscal policies chosen by a lower-level government. In spite of the fact that decentralized federation approach is practically relevant because it may be a good approximation of the decision structure within EU, there are only a few earlier studies which have analyzed environmental policies in the context of a decentralized economic federation.[4]

The discussion above implies that if there exists other externalities between countries, in addition to those attributable to the environment, then the federal level in a decentralized federation may lack the proper policy instruments to fully internalize these other inefficiencies. One source which may generate additional externalities between countries is the labour market. If the labour markets between countries are connected, e.g. due to (potential) firm mobility, then the wage observed in one country will influence the wages in the other countries.[5] If there is imperfect competition on the labour market, this mechanism will give rise to a wage bargaining externality between the countries. In this paper the externality arises because the firms use the threat of moving abroad as a tool to moderate wage claims. The credibility of the threat depends on how large the potential outside profit is which, in turn, depends on the wage level in the other countries. As such, any policy undertaken by the government in one country which affects the domestic wage will also indirectly influence the bargained wage in the other countries. Although the individual countries are not likely to coordinate their fiscal policies, the federal level (most likely) recognizes the wage bargaining externality and wants to internalize it. Then, even if the federal level lacks the proper policy instruments to do this (which clearly is the case if the federal level only determines emission targets), the federal level may, nevertheless, let its policy instrument(s) be influenced by the wage bargaining externality. This will, in turn, have implications for the fiscal policies implemented by the national governments. To my knowledge, this link has not been explored in the previous literature.

The purpose of this paper is, therefore, to analyze fiscal policy in the presence of environmental and labour market externalities within a decentralized federation structure. I assume that the environmental damage, which is transboundary, is caused by the use of a ´dirty´ input in the production. The federation consists of two countries and two levels of

[4] See Silva and Caplan (1997), Caplan et al (2000), Aronsson et al (2006) and Persson (2008).

[5] See Aronsson and Sjögren (2004a).

governments, where the federal level determines environmental targets to be implemented by the national governments. On the national level, the governments raise tax revenue to finance the provision of a national public good. Each national government's problem is solved within a two-type framework[6] where the set of available policy instruments includes a nonlinear labour income tax, a commodity tax, a tax on factor inputs and a profit tax. On the labour market, trade unions influence wage formation, and this distorts the allocation of labour between two production sectors, and it also gives rise to a wage bargaining externality between countries. I characterize the optimal policy at the federal level and show how the wage bargaining externality will influence the emission targets chosen by the federal government. I then proceed to characterize the optimal tax policy at the national level.

The attempt to combine decentralized fiscal federalism with environmental externalities in the presence of unemployment is particularly interesting from a European perspective. There are several reasons for this. First, earlier theoretical work often uses the European Union as an example of a decentralized federation because of the relative weakness of the supranational structure in EU vis-à-vis the member countries. Second, the European Union plays an important role for environmental policy as it decides upon targets for environmental damage which are then to be implemented at the national level. Third, several European countries have experienced high unemployment levels for a number of years, possibly due to the influence of trade unions on wage formation. The first two points are often used to motivate studies dealing with redistribution in economic federations with decentralized leadership while the last point is used to motivate theoretical analyses of environmental policy in economies with unemployment. As such, this study brings these ideas together and to my knowledge, this has not been done before.

This paper is primarily related to three fields; (i) optimal nonlinear taxation in the presence of labour market distortions, (ii) environmental policy under optimal nonlinear taxation and (iii) environmental policy in decentralized economic federations. Previous studies on optimal nonlinear taxation in the presence of labour market distortions have focused on a variety of issues. Fuest and Huber (1997), and Aronsson and Sjögren (2004b) analyze the effects of labour-tax progression on employment and welfare. The contribution of both papers is to characterize the determinants of tax progression. In the former study, the welfare maximizing degree of tax progression is influenced by the wage elasticity of labour demand and the distribution of bargaining power, whereas in the latter study, it is shown that the argument for

[6] See Stern (1982) and Stiglitz (1982).

progressive income taxation depends on whether the hours of work are chosen by the individual workers or by the union. Other studies are Marceau and Boadway (1994) and Aronsson and Sjögren (2003), both of which incorporate a two-type model into a framework where there is unemployment in equilibrium.

Earlier studies dealing with environmental policy under optimal nonlinear taxation are commonly based on the assumption that the labour market is competitive.[7] One exception is Aronsson (2005) who analyzes environmental policy in the presence of a labour market distortion caused by union-firm wage bargaining. The policy instruments are a general income tax function and linear commodity taxes, and his main contribution is to characterize how the interaction between the labor market distortion and the environmental damage influences the optimal tax policy.

This paper is also related to the literature on environmental policy in the context of decentralized federations. To my knowledge, there are very few studies which have addressed this issue. Silva and Caplan (1997), and Caplan and Silva (1999) analyze different kinds of transboundary environmental problems and associated policies to solve them. They consider a federal structure involving one federal level and several lower level governments, where the policy instruments differ between levels. They characterize the environmental policy outcomes depending on whether the federation is centralized or decentralized, and depending on how the control over policy instruments is distributed between the two levels of government. In Aronsson et al (2006), the federal government chooses environmental targets to be implemented by the national governments. The national governments will then use their policy instruments to influence the emission target. It is shown that this provides an argument for using distortionary labor income taxation and that the commodity tax does will no longer satisfy the additivity property.

Compared with the papers discussed above, this paper contributes to the literature in primarily two ways. The first is by characterizing environmental and tax policy in the presence of labour market distortions within the context of a decentralized economic federation. This makes it possible to analyze how the tax structure at the national level is affected by the national government's incentive to influence both the labour market distortion and the central government's policies. In particular, it is possible to study how these different motives behind taxation interact when it comes to designing the (national government's) optimal tax policy. The second contribution is to explicitly incorporate the wage bargaining

[7] See, e.g. Pirttilä and Tuomala (1997), Cremer et al (2001) and Cremer and Gahvari (2001).

externality mentioned above into the framework of a federation and analyze how this feature affects the central government's policy decisions. In particular, it means that since the central government lacks a direct instrument by which to internalize the wage bargaining externality, the presence of this externality will affect the central government's choices of emission targets.

The outline of the paper is as follows. In section 2, I present the outcome of private decisions and characterize the equilibrium. Section 3 concerns optimal policy, both by the central government and the national governments. The paper is summarized in section 4.

2. The Model

Consider an economic federation which is made up of two identical member countries[8] and a federal government. Each member country consists of four types of decision makers; consumers, firms, trade unions and a national government. Each country produces two goods, *c* and *x*, which are traded on the world market at a fixed price.

2.1 The Consumers

The consumers' preferences can be described by the following utility function

$$U = u(c, x, z) + \Theta(G) + \varphi(D) + \Gamma(D^*) \tag{1}$$

where c and x are consumption goods, and z is leisure which is defined as $z = h - l$, where h is a fixed time endowment and l the hours of work. The term G is a national public good, D is environmental damage generated within the country and D^* is environmental damage coming from the other country (in what follows, all variables indexed by "*" refer to the other country). The function $\varphi(D)$ captures the utility loss of domestically generated environmental damage whereas $\Gamma(D^*)$ captures the utility loss of foreign environmental damage. The functions $u(c, x, z)$ and $\Theta(G)$ are increasing in their respective arguments, whereas $\varphi(D)$ and $\Gamma(D^*)$ are decreasing in D and D^*, respectively.

[8] The number of countries making up the federation is of no importance. All results derived below carry over to a framework with more than two member countries.

Each country is made up of three types of consumers; a firm-owner and two types of workers, where the latter differ in terms of their productivity on the labour market. The private goods are produced in two separate production sectors using two separate technologies, and the productivity difference between the workers shows up in the production of good *x*. This difference is reflected in a productivity indicator which will be part of the production function for good *x* to be described below. A worker of type 1, has low productivity, indicated by a^1, while a type 2 worker has high productivity, indicated by a^2, where $a^2 > a^1$. These productivity levels will influence the before-tax wage rate, w^i, which ability type *i*, $i = 1, 2$, receives if he/she is employed in sector *x*. I assume that $w^2 > w^1$. There are M^i workers of type *i*, out of which N^i are employed in sector *x* while $M^i - N^i$ are employed in sector *c*. In the latter sector, both types of workers have the same productivity. This means that all workers who are employed in that sector receive the same before-tax wage, w^c.

The maximization problem facing a worker who receives the wage w^k, $k = 1, 2, c$, can be solved in two stages. First, the utility maximization problem is solved conditional on the hours of work. This involves maximizing equation (1) w.r.t. c^k and x^k subject to $b^k = c^k + qx^k$, where b^k is treated as a fixed post-tax income. Good *c* is a numeraire good and its price is normalized to one, whereas the consumer price of good *x* is given by $q = p + t$, where *p* is a fixed world market producer price and *t* a commodity tax. Solving this problem produces the following conditional demand and indirect utility functions

$$c^k = c\left(q, b^k, z^k\right) \tag{2}$$

$$x^k = x\left(q, b^k, z^k\right) \tag{3}$$

$$V^k = v\left(q, b^k, z^k\right) + \Theta\left(G\right) + \varphi\left(D\right) + \Gamma\left(D^*\right) \tag{4}$$

In the second stage, the hours of work are derived by maximizing the conditional indirect utility function with respect to l^k subject to the budget constraint $b^k = I^k - T\left(I^k\right)$, where $I^k = w^k l^k$ is gross income and $T\left(I^k\right)$ is the income tax function. The first-order condition for this problem is written

$$\left(1-T_I^k\right)w^k V_b^k - V_z^k = 0 \tag{5}$$

where $V_b^k = \partial V^k / \partial b^k$ and $V_z^k = \partial V^k / \partial z^k$, and where $T_I^k = \partial T^k / \partial I^k$ is the marginal income tax rate. Conditional on the income tax schedule, this first-order condition implicitly defines the labour supply as a function of the pre-tax wage rate and as a function of the parameters of the income tax function (for notational convenience, these parameters are suppressed); $l^k = l\left(w^k\right)$.

Turning to the firm-owners, I normalize their number to one. The firm-owner does not work, which means that his/her budget constraint is written $b^f = c^f + qx^f$, where b^f is the firm-owner's post-tax income, and where the superindex f refers to the firm-owner. The solution to the firm-owner's problem of choosing c^f and x^f to maximize the utility produces the following conditional demand and indirect utility functions

$$c^f = c\left(q, b^f\right) \tag{6}$$

$$x^f = x\left(q, b^f\right) \tag{7}$$

$$V^f = v\left(q, b^f\right) + \Theta\left(G\right) + \varphi\left(D\right) + \Gamma\left(D^*\right) \tag{8}$$

Post-tax income is given by $b^f = \left(1-s\right)\Pi$, where Π is the gross profit and s a profit tax paid by the firm.

The presence of a nonworking household which receives all profit income is a strong assumption. An alternative would be to assume that all agents in the economy own shares in the firm and thereby also receive the profit income. However, this would introduce distributional concerns into the model which would complicate the mathematical equations to be derived below without providing any new insight into the incentives influencing policy in the presence of environmental externalities and imperfect competition in the labour market. Therefore, to avoid this, I make the assumption that the profit accrues to one single firm-owner.

2.2 Production

Production takes place in two separate sectors, each made up of identical competitive firms. The number of firms in each sector is normalized to one. In sector *x*, the production function is written $F\left(a^1L^1, a^2L^2, E\right)$, where L^i is total employment of ability type *i* and *E* is an environmentally 'dirty' input, henceforth referred to as energy. Total employment is measured as the hours of work per employee, l^i, times the number of employed workers, N^i. The production function is increasing and concave in each argument, and the production is characterized by decreasing returns to scale.[9] The two types of labour are weak substitutes in production whereas energy is complementary in production with both types of labour. The firm's objective is to choose L^i and E to maximize the profit

$$\Pi = pF\left(a^1L^1, a^2L^2, E\right) - w^1L^1 - w^2L^2 - \theta E \tag{9}$$

where θ is the price of energy. It is assumed that the supply of energy is infinitely elastic. This means that, without loss of generality, the marginal cost of producing energy can be normalized to zero, so that the energy price paid by the firm equals the energy tax. This simplification is not important for the qualitative results to be derived below.

Profit maximization means choosing L^i and E such that $w^i = a^i p\left(\partial F / \partial L^i\right)$ and $\theta = p\left(\partial F / \partial E\right)$. These first-order conditions implicitly define the following factor demand and profit functions

$$L^i = L^i\left(w^1, w^2, \theta\right), \qquad E = E\left(w^1, w^2, \theta\right), \qquad \Pi = \Pi\left(w^1, w^2, \theta\right) \tag{10}$$

where the exogenous terms a^1 and a^2 have been suppressed. It is assumed that the profit is taxed at the firm level at the rate *s*, which means that the net profit is given by $(1-s)\Pi$.

The numeraire good is produced in a separate sector, *c*, with a linear technology which uses labour as the only production factor. In sector *c*, type 1 and type 2 workers have the same

[9] The reason for assuming decreasing returns to scale is that the labour market is dominated by trade unions, and to be able to characterize the wage bargain between the union and the firm, the labour demand function needs to be well-defined.

productivity[10], which means that both ability types receive the same constant wage rate, w^c. It is assumed that sector *c* is a low-paid sector which means that $w^c < w^i$, for $i = 1,2$, always holds.

2.3 The Labour Market

As mentioned above, each country is made up of two production sectors. In sector *x*, the wage is determined in a bargain between the firm and two type specific trade unions whereas in sector *c*, the labour market functions competitively in the sense that the demand and the supply of labour are equalized.

In sector *x*, each ability type is organized by an ability-specific trade union.[11] The wage formation process is decentralized in the sense that both the firm and the two trade unions treat the policy instruments of the government, as well as the output price and the wage in the competitive sector, as exogenous. The wage rates w^1 and w^2 are determined simultaneously in two separate negotiations, and in each bargain the other wage rate is treated as exogenous. To characterize the bargaining outcomes, it is necessary to make an assumption of what the union objective functions look like. Following Oswald (1993), it is assumed that the workers of both types can be ranked according to exogenous seniority rules and that the decisive union member of ability-type *i* is the worker with median seniority. The objective of the median union member in each trade union is to achieve the highest possible private utility, conditional on that he/she remains employed in sector *x*. This means that the objective of union *i* is to maximize

$$V^i = v\left[q, w^i l^i - T\left(w^i l^i\right), h - l^i\right] + \Theta\left(G\right) + \varphi\left(D\right) + \Gamma\left(D^*\right) \tag{11}$$

[10] The reason for using such a simple technology in the production of the numeraire good is analytical convenience. A more general formulation would complicate the calculations without providing any novel results.

[11] In practice, union membership reflects a variety of factors such as ability, industry and occupation. In this model, I have chosen to organize the workers on the basis of their ability, since I do not distinguish between different parts of the production sector. Another possibility would be to assume that both ability types are organized by the same type of union. As long as the wage rates chosen by such a union reflects ability in the sense that higher ability means a higher wage, the description of how the workers are organized into unions does not affect the results to be derived below.

subject to $l^i = l\left(w^i\right)$. If no contract is signed between the union and the firm, the union members will leave sector *x* and seek employment in sector *c*. This means that each union member's fall-back utility is given by

$$V^c = v\left[q, w^c l^c - T\left(w^c l^c\right), h - l^c\right] + \Theta(G) + \varphi(D) + \Gamma\left(D^*\right) \tag{12}$$

where $l^c = l\left(w^c\right)$. As for the firm, it has the option to move the production abroad, in which case the fall-back gross profit is given by $\Pi^* = \Pi\left(w^{1*}, w^{2*}, \theta^*\right)$. The move abroad is associated with a fixed moving cost, *q*, which means that the net fall-back profit is given by $\left(1-s^*\right)\Pi^* - q$.

By defining $V^i - V^c$ and $(1-s)\Pi - \left(1-s^*\right)\Pi^* + q$ to be union *i*'s and the firm's respective rents from the bargain, the outcome of the bargain will be the wage that maximizes the following Nash product

$$\Omega^i = \left(v^i - v^c\right)^{\beta^i}\left[(1-s)\Pi - \left(1-s^*\right)\Pi^* + q\right]^{1-\beta^i} \tag{13}$$

where β^i is trade union i's bargaining power vis-a-vis the firm. Since the firm bargains with the two trade unions simultaneously, the first-order conditions for w^i, $i = 1,2$, can be written as

$$\frac{\partial \Omega^i}{\partial w^i} = \beta^i\left(1 - T_I^i\right) l^i v_b^i \left[(1-s)\Pi - \left(1-s^*\right)\Pi^* + q\right] - \left(1-\beta^i\right)(1-s) L^i\left(v^i - v^c\right) = 0 \tag{14}$$

where equation (5) and Hotelling's lemma have been used to simplify the first-order condition. It is assumed that the second order-condition $\partial\Omega^i / \partial w^i < 0$ is fulfilled for $i = 1,2$, and for the analysis below, observe that conditional on w^2, the bargained wage w^1 is decreasing in Π^*, and vice versa. This basically reflects that if the firm's outside option is improved, the firm may be tougher in the wage negotiations.

To simplify the analysis below, it will be convenient to write equation (14) such that the wage rates become functions of variables that are directly affected by the national government's policy instruments. As will be shown below, the problem facing the national government will be written such that b^f, b^k and l^k are interpretable as decision variables for the national government (via which the tax and expenditure policies can be derived). Therefore, to derive wage equations that are functions of b^f, b^k and l^k (instead of s, T^k and T_I^k), note that $b^f = (1-s)\Pi$ and that equation (5) implies $\left(1-T_I^k\right)v_b^k = v_z^k / w^k$. Substituting these expressions into equation (14) produces the following modified first-order condition for w^i

$$\frac{\partial\tilde{\Omega}^i}{\partial w^i} = \frac{\beta^i l^i v_z^i}{w^i}\left[b^f - \left(1-s^*\right)\Pi^* + q\right] - \left(1-\beta^i\right)\left(1-s\right)L^i\left(v^i - v^c\right) = 0 \tag{15}$$

In accordance with the assumption that the bargaining parties obey the second-order sufficient conditions for a maximum, it will be assumed that $\partial\tilde{\Omega}^i / \partial w^i < 0$. By observing that v^i is a function of b^i, z^i and q, equation (15) implies that the wage rate w^i can be written as a function

$$w^i = w^i\left(b^f, b^1, b^2, b^c, l^1, l^2, l^c, \theta, t, \left(1-s^*\right)\Pi^*\right) \tag{16}$$

for $i = 1, 2$, where the notation of fixed terms are omitted.

It is assumed that the workers who do not become employed in sector x leave that sector and seek employment in sector c. Since the labour market functions competitively in sector c, everyone will find a job there. Hence, there will be no unemployment in this model. Rather, the effect of trade unions is to push up the wage rates in sector x above that in sector c, meaning that the allocation of labour between the two sectors becomes inefficient.

3. Optimal Policy

The environmental damage facing the residents in each country is generated by the use of energy in the production. This means that the environmental damages are given by $D = E$ and $D^* = E^*$, respectively. Within the federation, it is the central government that determines emission targets for D and D^*, and these targets are then to be implemented by the individual countries.

The wage formation process produces an additional externality. This externality is a consequence of the assumption that the firm uses the threat of moving production abroad as a tool to moderate wage claims. The credibility of this threat depends on the size of the outside profit; the larger the outside profit, the stronger will be the firm's bargaining position vis-à-vis the trade union. This has an important implication for fiscal policy: any (tax) policy which affects the domestic profit level will also affect the outcome of the wage bargain in the other country. As long as the fiscal policy is not coordinated between the national governments, this mechanism will imply that there is an uninternalized international wage bargaining externality in equilibrium. Although each national government does not take into account that its policy affects the other country, the federal government does. It will, therefore, incorporate the international wage bargaining externality into its decision problem.

It is assumed that the order of decision-making is such that the public policies at both the federal and the national level is determined before the private agents make their decisions. As such, the federal government acts as a Stackelberg leader vis-a-vis the private agents in both countries whereas the national government acts as a Stackelberg leader vis-a-vis the domestic private agents. In addition, the federal government treats the policies chosen by the national governments as exogenous, but for two exceptions (see below). Each national government, in turn, treats the policy of the other national government as exogenous, whereas both national governments act as first movers vis-a-vis the federal government (the latter is a consequence of the assumption that the federation is decentralized).

To be able to characterize the policy determined within the federation, I will first describe the problem (without solving it) facing the national government because this is needed to understand the problem facing the federal government. Next, I solve the federal government's problem and this solution is then used to derive reaction functions for the policy instruments chosen at the federal level. These reaction functions are then incorporated into each national government's problem, after which I solve this problem and characterize the optimal solution at the national level.

3.1 The National Government

Each government has a utilitarian objective function. This means that the objective of the national government is to maximize the sum of utilities inside the country, i.e.

$$W = \sum_n N^n V^n \tag{17}$$

where $n = 1, 2, c, f$, $N^c = \sum_i \left(M^i - N^i\right)$ and $N^f = 1$. Each national government collects tax revenues via the profit tax, the labour income tax, the commodity tax and the energy tax. These revenues are used to finance redistribution and the expenditure on a national public good, *G*. It is assumed that good *x* can be converted to the public good without cost and on a one-to-one basis. This means that the national government purchases *G* units of good *x* on the market. Each national government's budget constraint can then be written as

$$\sum_k N^k T^k + s\Pi + \theta E + t\sum_n N^n x^n - pG = 0 \tag{18}$$

Note that by choosing the parameters of the income tax function $T\left(I^k\right)$, the national government can induce any desired combination of b^k and l^k. As such, this means b^k and l^k, and the parameters of $T\left(I^k\right)$, constitute two equivalent sets of policy instruments and in this paper, it is more convenient to use b^k and l^k instead of the parameters of the tax function as decision variables of the government. Similarly, also b^f and *s* constitute two equivalent policy instruments, and I will use the former as a decision variable of the national government. This means that the national government's problem will be written in terms of the following vector of decision variables; $\left(b^f, b^k, l^k, \theta, t, G\right)$. By combining equation (18) with $b^k = w^k l^k - T\left(w^k l^k\right)$ and $b^f = (1-s)\Pi$, and by using equation (9) together with $L^k = N^k l^k$, the budget constraint can be rewritten in terms of the national government's decision variables

$$pF\left(a^1 L^1, a^2 L^2, E\right) + w^c N^c l^c + t\sum_n N^n x^n - \sum_n N^n b^n - pG = 0 \tag{19}$$

The informational assumptions are conventional. The government can observe an individual's gross income, I^k, but not his/her ability type. This means that the government must choose the policy such that a high-ability type does not wish to behave as a low-ability type and vice versa. Since the government has a desire to redistribute towards low-income groups, it has become the convention in the literature to focus on the case where the high-ability type may mimic the gross income of the low-ability type. For a type 2 worker to have the same gross income as type 1, he/she must determine his/her labour input such that $\hat{l}^2 = \phi l^1$, where $\phi = w^1 / w^2$ is the wage ratio, and where "^" denotes a variable associated with the mimicker. This means that the self-selection constraint that may bind is written $V^2 \geq \hat{V}^2$, where

$$\hat{V}^2 = v\left(q, b^1, h - \hat{l}^2\right) + \Theta\left(G\right) + \varphi\left(D\right) + \Gamma\left(D^*\right) \tag{20}$$

Furthermore, since workers who are not employed in sector *x* become employed in sector *c*, where they earn the gross income $w^c l^c$, there are potentially two more self-selection constraints that may bind

$$v\left(q, b^2, h - l^2\right) \geq v\left(q, b^c, h - w^c l^c / w^2\right) \tag{21}$$

$$v\left(q, b^1, h - l^1\right) \geq v\left(q, b^c, h - w^c l^c / w^1\right) \tag{22}$$

However, it will be assumed that the wage in the low-paid sector is sufficiently low never to make mimicking of this type an attractive choice. This means that the potential self-selection constraints in (21) and (22) will not be binding.

Finally, the government also recognizes that the gross wage for ability type $i = 1, 2$, is determined by equation (16).

3.2 The Federal Government

The federal government aims to maximize the sum of utilities over both countries.[12] The constraints facing the federal government are the behavioural equations of the private sector in each country, and the environmental damage functions $D = E$ and $D^* = E^*$. These equalities imply that there is a one-to-one relationship between the use of energy and the environmental damage. It is also assumed that the federal government recognizes, and takes

[12] An alternative, and possibly more realistic approach within an EU context, would be to model the federal policy as the outcome of a bargain between the member countries. Although the first-order conditions defining the optimal policy at the federal level would become more complex, one can show that the qualitative results derived in this paper would still remain.

into account, the self-selection constraint in each country. The direct decision variables are the emission targets D and D^* (and hence also E and E^*). To solve the federal government's problem, I need to make two assumptions. These regard (i) how the federal government expects the national governments to implement the emission targets and (ii) how the federal government expects the national governments to respond to a change in tax revenue. Assumption (i) is needed to determine a trade-off at the federal level between the benefits of lower emissions and the welfare costs, in terms of reduced private consumption, associated with these reductions. In principle, each national government could use any policy instrument, or combination of policy instruments, to implement the emission target. As such, there are many possible responses at the national level but I have to choose one of them in order to be able to solve the federal government's problem. Therefore, I choose the most direct link, which is to say that the federal government expects each emission target to be implemented at the national level via the policy instrument which directly influences emissions, namely the production tax, θ. As for (ii), I assume that the central government expects that a change in tax revenue will be met by a corresponding change in the provision of the local public good,[13] G. All other national decision variables are treated as exogenous by the federal government.

The Lagrangian corresponding to the federal government's problem is written (the superindex "F" refers to the federal government)

$$
\begin{aligned}
Z^F &= W + W^* + \lambda^F\left(V^2 - \hat{V}^2\right) + \lambda^{F*}\left(V^{2*} - \hat{V}^{2*}\right) + \mu^F\left(D - E\right) + \mu^{F*}\left(D^* - E^*\right) \\
&+ \gamma^F\left[pF + w^c N^c l^c + t\sum_n N^n x^n - \sum_n N^n b^n - pG\right] \\
&+ \gamma^{F*}\left[pF^* + w^{c*} N^{c*} l^{c*} + t^*\sum_n N^{n*} x^{n*} - \sum_n N^{n*} b^{n*} - pG^*\right] \\
&+ \sum_i \rho^{Fi}\left[w^i - w^i\left(b^f, b^1, b^2, b^c, l^1, l^2, l^c, \theta^F, t, \Pi^*\right)\right] \\
&+ \sum_i \rho^{Fi*}\left[w^{i*} - w^{i*}\left(b^{f*}, b^{1*}, b^{2*}, b^{c*}, l^{1*}, l^{2*}, l^{c*}, \theta^{F*}, t^*, \Pi\right)\right]
\end{aligned}
\qquad (23)
$$

where λ^F, λ^{F*}, γ^F, γ^{F*}, μ^F and μ^{F*} are Lagrange multipliers associated with the self-selection constraints, the national budget constraints and the environmental damages,

[13] Assumption (i) is in line with Aronsson et al (2006), whereas assumption (ii) is common in the literature on fiscal federalism.

respectively. The constraints associated with the Lagrange multipliers ρ^{Fi} and ρ^{Fi*} represent the wage equations for type 1 and type 2 workers in the two countries.

The formulation in equation (23) is convenient as it makes it possible to identify the determinants of the shadow prices that the federal government attaches to the national budget constraints and the labour market imperfections. The additional (and artificial) decision variables corresponding to these constraints are *G*, G^*, w^i and w^{i*}. In addition to choosing *D*, D^*, *G*, G^*, w^i and w^{i*}, assumption (i) implies that also the energy tax will be viewed as decision variable by the federal government. To separate the federal government's preferred choice of the energy tax from that of the national government, I label the federal government's preferred choice with the superindex "*F*", i.e. θ^F. In equilibrium, the federal government's preferred choice will coincide with that actually chosen by the national government. The first-order conditions are presented in the Appendix.

To characterize the emission target for *D*, observe that it is implicitly determined by the first-order condition for the federal government's "choice" of the energy tax. The first-order condition for θ^F can be written as

$$\theta^F = \frac{\mu^F}{\gamma^F} - \sum_i \frac{\Phi^{Fi}}{l^i} \frac{\partial L^i / \partial \theta}{\partial E / \partial \theta} + \sum_i \frac{\rho^{Fi}}{\gamma^F} \frac{\partial w^i / \partial \theta}{\partial E / \partial \theta} \tag{24}$$

where

$$\Phi^{Fi} = \frac{V^i - V^c}{\gamma^F} + \left[T^i - T^c + t\left(x^i - x^c \right) \right] \tag{25}$$

The term Φ^{Fi} measures the welfare effect that will arise if a worker of type $i = 1, 2$ goes from working in sector *c* to working in sector *x*. This welfare effect is made up of two parts. First, each worker who goes from being employed in sector *c* to be employed in sector *x* experiences a direct utility gain equal to $V^i - V^c$. Second, the net effect on the tax revenue is given by the terms inside the square brackets. Since workers of both types have a higher gross income in sector *x* than in sector *c*, the tax revenue effect is likely to be positive, in which case Φ^{Fi} is positive.

To interpret equation (24), observe first that anything that works in the direction of increasing (decreasing) θ^F, will induce the federal government to set a tighter (less tight) emission target for *D*. Equation (24) shows that three factors influence θ^F, and hence *D*. The first is μ^F / γ^F, which appears in the tax formula as a corrective measure to internalize the externality. The shadow price, μ^F, is equal to the sum of the marginal disutility of *D* over all agents in both countries

$$\mu^F = -\sum_n N^n V_D^n - \sum_n N^{n*} V_D^{n*} \tag{26}$$

The remaining two terms in equation (24) are directly linked to the imperfection on the labour market. The middle term, which is negative as long as $\partial L^i / \partial\theta < 0$ and $\partial E / \partial\theta < 0$, captures that a tighter emission target (which means that θ^F is higher) has a direct and negative effect on the level of employment. This provides the federal government with an incentive to set the emission target less tight. The last term on the right hand side of equation (24) reflects that the energy tax indirectly affects welfare via the wage rates w^1 and w^2. Since the shadow price associated with the labour market distortion for ability type *i*, ρ^{Fi}, (most likely) will be positive, the sign of the last term in (24) depends on whether $\partial w^i / \partial\theta$ is positive or negative. If $\partial w^i / \partial\theta > 0$, the final term in (24) is negative which means that the indirect effect via the wages will induce the federal government to set the emission target less tight. The argument goes in the opposite direction if $\partial w^i / \partial\theta < 0$.

Since the shadow price associated with the labour market imperfection plays an important role for the federal government's policy, it is instructive to see how it is determined. In the Appendix, I show that for ability type *j*, $j = 1,2$, ρ^{Fj} / γ^F can be written as

$$\frac{\rho^{Fj}}{\gamma^F} = -\sum_i \frac{\Phi^{Fi}}{l^i}\frac{\partial L^i}{\partial w^j} - \left(\theta^F - \frac{\mu^F}{\gamma^F}\right)\frac{\partial E}{\partial w^j} - \frac{\lambda^F}{\gamma^F}\frac{\partial \phi}{\partial w^j} l^1 \hat{V}_z^2 + \sum_i \frac{\rho^{Fi*}}{\gamma^F}\frac{\partial w^{i*}}{\partial \Pi}\frac{\partial \Pi}{\partial w^j} \tag{27}$$

Equation (27) shows the shadow price of a (small) increase in w^j is made up of four parts. The first term on the right hand side of equation (27) is the direct welfare cost of a higher wage which follows because the level of employment in sector *x* is reduced. Turning to the second term on the right hand, note that it is nonzero if the environmental tax deviates from the shadow price of the environmental externality. This reflects that if θ^F is set below μ^F / γ^F, then the environmental externality is not fully internalized. In that case a higher wage, which has a negative effect on the use of energy, helps to reduce the use of energy towards the preferred level. This is welfare improving and contributes to reduce ρ^{Fi} / γ^{F}. If, on the other hand, $\theta^{F} > \mu^{F} / \gamma^{F}$, the opposite argument applies. The third term on the right hand side reflects the self-selection constraint. Since $\partial \phi / \partial w^{1} > 0$ it follows that a higher wage for the low-ability type will relax the self-selection constraint, which is welfare improving and contributes to reduce ρ^{Fi} / γ^{F}. On the other hand, since $\partial \phi / \partial w^{2} < 0$, the opposite argument applies for w^{2}. The final term on the right hand side of equation (27) appears as a consequence of the international wage bargaining externality. To interpret this term, observe that an increase in the domestic wage, w^{j}, which has a negative effect on the domestic profit level, will push up the wage rates in the other country. This is due to the wage bargaining mechanism where the domestic profit level constitutes the fall-back profit for the firm in the other country. If the domestic profit level is reduced, the bargaining power of the firm in the other country is eroded which leads to higher wages, and reduced welfare in that country. Hence, the wage bargaining externality reinforces the welfare cost associated with high domestic wage rates.

Since ρ^{Fi} / γ^{F} is part of the third term on the right hand side of equation (24), the international wage bargaining externality will influence the federal government's choice of emission target. The following result is now readily available;

Proposition 1: *If* $\partial w^{i} / \partial \theta > 0$ ($\partial w^{i} / \partial \theta < 0$), *the international wage bargaining externality will induce the federal government to set the emission target less tight* (*tighter) than otherwise.*

The result in Proposition 1 is potentially important because if the international wage bargaining externality is significant, then it may have a non-negligible impact on the design of the environmental target. A consequence of this argument is that even if the environmental targets are determined at the federal level, meaning that environmental damages in all localities are internalized in the decision making process, the environmental target may nevertheless deviate significantly from a first-best level.

Finally, observe that by combining the first-order conditions that define the federal government's optimal policy, we can derive the following reaction functions for the environmental target levels

$$\bar{D} = \alpha\left(b^f, b^1, b^2, b^c, l^1, l^2, l^c, t, b^{f*}, b^{1*}, b^{2*}, b^{c*}, l^{1*}, l^{2*}, l^{c*}, t^*\right) \tag{28}$$

$$\bar{D}^* = \alpha^*\left(b^f, b^1, b^2, b^c, l^1, l^2, l^c, t, b^{f*}, b^{1*}, b^{2*}, b^{c*}, l^{1*}, l^{2*}, l^{c*}, t^*\right) \tag{29}$$

where $b^f = (1-s)\Pi$ and $b^{f*} = (1-s^*)\Pi^*$ have been used to eliminate s and s^*. These reaction functions define the environmental targets as functions of national decision variables.

3.3 The National Government's Optimal Policy

The national government's problem is to maximize the welfare function in equation (17) subject to the budget constraint (19), the self-selection constraint $V^2 \geq \hat{V}^2$ and the wage equation (16) for $i = 1, 2$. In addition, since each national government behaves as a first-mover vis-à-vis the federal government, the former observes, and incorporates into its decision problem, the reaction functions given by equations (28) and (29). Therefore, the Lagrangian corresponding to the national government's problem can be written as

$$\begin{aligned} Z = W &+ \gamma\left[pF + w^c N^c l^c + t\sum_n N^n x^n - \sum_n N^n b^n - pG\right] \\ &+ \lambda\left(V^2 - \hat{V}^2\right) + \mu(D - E) + \sum_i \rho^i\left[w^i - w^i\left(b^f, b^1, b^2, b^c, l^1, l^2, l^c, \theta, t, \Pi^*\right)\right] \\ &+ \kappa\left[\alpha\left(b^f, b^1, b^2, b^c, l^1, l^2, l^c, t, b^{f*}, b^{1*}, b^{2*}, b^{c*}, l^{1*}, l^{2*}, l^{c*}, t^*\right) - D\right] \\ &+ \kappa^*\left[\alpha^*\left(b^f, b^1, b^2, b^c, l^1, l^2, l^c, t, b^{f*}, b^{1*}, b^{2*}, b^{c*}, l^{1*}, l^{2*}, l^{c*}, t^*\right) - D^*\right] \end{aligned} \tag{30}$$

where κ and κ^* are Lagrange multipliers associated with the reaction functions in equation (28) and (29). The first-order conditions are presented in the Appendix.

The national government's policy will depend on the shadow prices appearing in the Lagrangian. As such, it is important to recognize what factors influence their respective signs and sizes. Let us begin by deriving an expression for the term μ / γ which is the shadow price of the environmental externality measured in terms of the federal government's tax revenue. Define $MWP_{Db}^n = -V_D^n / V_b^n$ to be a domestic consumers' marginal willingness to pay for a small reduction in the domestic environmental damage. It is then straightforward to show that μ / γ is given by

$$\frac{\mu}{\gamma} = \sum_n N^n MWP_{Db}^n + \frac{\lambda \hat{V}_b^2}{\gamma}\left(MWP_{Db}^1 - M\hat{W}P_{Db}^2\right) - t\sum_n N^n \frac{\partial \tilde{x}^n}{\partial D} + \sum_n N^n MWP_{Db}^n \sum_i \frac{\rho^i}{\gamma}\frac{\partial w^i}{\partial b^n}$$
$$+\frac{\kappa}{\gamma} - \frac{\kappa}{\gamma}\sum_n MWP_{Db}^n \sum_i \frac{\partial \alpha}{\partial b^n} - \frac{\kappa^*}{\gamma}\sum_n MWP_{Db}^n \sum_i \frac{\partial \alpha^*}{\partial b^n} \quad (31)$$

The first term on the right hand side of equation (31) is the sum of the marginal willingness to pay for a small reduction in the domestic environmental damage, while the second appears because a change in D will affect the self-selection. The third term captures the effect of the externality on the tax revenues. All these terms are well understood from earlier research,[14] and they will not be discussed any further.

Turning to the fourth term in the first row of equation (31), it basically reflects that if $\partial w^i / \partial b^n \neq 0$, then the labour market distortion will, by itself, influence μ / γ. The explanation is that if $\partial w^i / \partial b^n \neq 0$, then the government has a different valuation of increasing b^n than the individual consumer. This, in turn, has implications for μ / γ. If, for example $\partial w^i / \partial b^n > 0$, the government (ceteris paribus) attaches a lower value to an increase in b^n than the individual consumer. Therefore, the level of b^n and, hence the private utility, will be lower than otherwise. To 'compensate' the individual for this 'utility loss', the government can improve the environmental quality. As such, the government will attach a higher value to environmental quality than otherwise. The argument goes in the opposite direction if $\partial w^i / \partial b^n < 0$.

Turning to the second row of equation (31), the first two terms correspond to effects derived in Aronsson et al (2006). To interpret these, observe first that the federal government is likely to set the environmental target for D tighter than the national government would prefer. The reason is, of course, that the federal government recognizes, and takes into account, that an increase in D has a direct, negative effect on the welfare in both countries, whereas the national government only recognizes the effect on domestic welfare. Consequently, the target constraint will be binding (i.e. $\kappa > 0$), in which case κ / γ in equation (31) reflects that the national government is forced to attach a higher value to the domestically environmental damage than it would otherwise have done.

[14] See e.g. Pirttilä and Tuomala (1997).

The second term in the second row of equation (31) appears because the national government acts as a strategic leader towards the federal government. Since $\kappa > 0$, a relaxation of the domestic environmental target will improve the domestic welfare. If $\partial\alpha / \partial b^n < 0$, the strategic leadership effect provides the national government with an incentive to reduce disposable income by letting the consumers pay higher taxes than otherwise. The fact that the environmental constraint is relaxed when the consumers pay higher taxes is interpretable as an extra benefit associated with raising tax revenues which works to decrease γ (where the latter is interpretable as the marginal cost of public funds in utility terms). Consequently, this has a positive effect on μ / γ. The argument goes in the opposite direction if $\partial\alpha / \partial b^n > 0$.

The last term on the second row of equation (31) reflects that the national government also uses its strategic leadership vis-à-vis the federal government to influence the environmental target for the other country. To interpret this effect, note first that κ^*, which is the domestic shadow price of foreign environmental damage, is given by

$$\kappa^* = \sum_n V^n_{D^*} < 0 \tag{32}$$

This reflects that from the domestic government's point of view, it is always welfare improving to tighten the emission target in the other country. Then, if $\partial\alpha^* / \partial b^n < 0$, the national government has an incentive to increase disposable income by letting the consumers pay lower taxes than otherwise. This implies an additional cost of raising tax revenue that works to increase γ which, in turn, has a negative effect on μ / γ. The argument goes in the opposite direction if $\partial\alpha^* / \partial b^n > 0$.

Let us now turn to the shadow price associated with the labour market distortion, ρ^j / γ. In the Appendix, I show that it is given by

$$\frac{\rho^j}{\gamma} = -\sum_i \frac{\Phi^i}{l^i}\frac{\partial L^i}{\partial w^j} - \left(\theta - \frac{\mu}{\gamma}\right)\frac{\partial E}{\partial w^j} - \frac{\lambda}{\gamma}\frac{\partial \phi}{\partial w^j} l^1 \hat{V}^2_z \tag{33}$$

By comparison, it follows that the terms on the right hand side of (33) correspond to, and can be given the same interpretation, as the first three terms on the right hand side of equation (27). Note, however, that the national government's shadow price does not contain the last term in equation (27), which is related to the wage bargaining externality. This means that the national government underestimates the full welfare cost associated with the labour market distortion.

3.3.1 The Energy Tax

Let us now characterize the optimal tax and expenditure policy. Beginning with the energy tax, consider Proposition 2;

Proposition 2: *In the context of the decentralized federation, the energy tax implemented by the national government can be written as*

$$\theta = \frac{\mu}{\gamma} - \sum_i \frac{\Phi^i}{l^i} \frac{\partial L^i / \partial \theta}{\partial E / \partial \theta} + \sum_i \frac{\rho^i}{\gamma} \frac{\partial w^i / \partial \theta}{\partial E / \partial \theta} \quad (34)$$

Proof: See the Appendix.

The difference between equations (25) and (34) refer to the shadow prices of the environmental and labour market externalities. In particular, since the national government does not recognize the interregional wage bargaining externality associated with the labour market distortion, the national government's shadow price associated with the labour market distortion, ρ^i / γ, will underestimate the full negative welfare effect of the labour market distortion. However, since the federal government takes the wage bargaining externality into account when it sets the emission targets, the national government is indirectly forced to recognize the wage bargaining externality because it is incorporated in the shadow price μ / γ (via κ). Since μ / γ appears in the tax formula for θ, it means that the energy tax will be used as an indirect instrument to (partially) internalize the international wage bargaining externality.

For the analysis below, let us substitute equation (34) into equation (33) to obtain the following expression for the national government's shadow price of the wage bargaining externality

$$\frac{\rho^j}{\gamma} = -\sum_i \frac{\Phi^i}{l^i} \frac{\partial L^i}{\partial w^j} + \left(\sum_i \frac{\Phi^i}{l^i} \frac{\partial L^i / \partial \theta}{\partial E / \partial \theta} - \sum_i \frac{\rho^i}{\gamma} \frac{\partial w^i / \partial \theta}{\partial E / \partial \theta} \right) \frac{\partial E}{\partial w^j} - \frac{\lambda}{\gamma} \frac{\partial \phi}{\partial w^j} l^1 \hat{V}_z^2 \tag{35}$$

Equation (35) shows that ρ^j / γ is independent of μ / γ.

3.3.2 The Commodity Tax

Let us continue with the commodity tax. To simplify the analysis, I will use the following short notations;

$$\frac{\partial \tilde{w}^i}{\partial t} = \frac{\partial w^i}{\partial t} + \sum_n x^n \frac{\partial w^i}{\partial b^n}, \qquad \frac{\partial \tilde{\alpha}}{\partial t} = \frac{\partial \alpha}{\partial t} + \sum_n x^n \frac{\partial \alpha}{\partial b^n}, \qquad \frac{\partial \tilde{\alpha}^*}{\partial t} = \frac{\partial \alpha^*}{\partial t} + \sum_n x^n \frac{\partial \alpha^*}{\partial b^n} \tag{36}$$

$$\frac{\partial \tilde{x}^n}{\partial q} = \frac{\partial x^n}{\partial q} + x^n \frac{\partial x^n}{\partial b^n}, \qquad \Delta = \frac{\partial \tilde{x}^f}{\partial q} + \sum_k N^k \frac{\partial \tilde{x}^k}{\partial q} < 0 \tag{37}$$

where the definitions in (36), as well as the first definition in (37), can be viewed as 'compensated' effects of a change in the commodity tax. Now, consider Proposition 3;

Proposition 3: *In the context of the decentralized federation, the commodity tax implemented by the national government can be written as*

$$t = \frac{\lambda \hat{V}_b^2}{\gamma \Delta} \left(x^1 - \hat{x}^2 \right) - \sum_i \frac{\rho^i}{\gamma \Delta} \frac{\partial \tilde{w}^i}{\partial t} - \frac{\kappa}{\gamma \Delta} \frac{\partial \tilde{\alpha}}{\partial t} - \frac{\kappa^*}{\gamma \Delta} \frac{\partial \tilde{\alpha}^*}{\partial t} \tag{38}$$

Proof: See the Appendix.

The important result in equation (38) is that because of the additivity property,[15] the shadow price μ / γ does not appear in the tax formula for the commodity tax. This means that neither the environmental externality, nor the international wage bargaining externality (which is incorporated via μ / γ), will influence the commodity tax structure. Rather, equation (38) shows that the commodity tax consists of four parts which are unrelated to any transboundary externality. The first term on the right hand side of equation (38) is related to self-selection

[15] See Sandmo (1975).

and has been discussed in, e.g. Edwards et al (1994). The second term is directly related to the domestic labour market distortion and if $\partial \tilde{w}^i / \partial t > 0$, this term is negative. It reflects that if the commodity tax increases, then trade union *i* compensates the median union member by opting for a higher wage. Since the increase in the wage has a negative effect on the welfare, the labour market distortion contributes to reduce the commodity tax. This link has been pointed out by Aronsson (2005).

The remaining two terms in equation (38) reflect that the national government uses the commodity tax as an instrument to influence the environmental targets. Beginning with the first, which is associated with the national government's ability to influence the target for domestically generated pollution, it implies that if $\partial \tilde{\alpha} / \partial t < 0$ ($\partial \tilde{\alpha} / \partial t > 0$) then the national government has an incentive to tax commodity *x* less hard (harder) compared to when the national government is unable to act as a strategic leader vis-à-vis the federal government. By doing this, the target on domestic pollution can be relaxed which is welfare improving from the national government's point of view. This link has been discussed in Aronsson et al (2006).

The last term in equation (38) reflects that the commodity tax structure may also influence emission target in the other country. Since it is always welfare improving from the national government's point of view to reduce the emission from the other country, it follows that if $\partial \tilde{\alpha}^* / \partial t < 0$, the national government has an incentive to tax good *x* harder than otherwise because this leads to a tightening of the emission target for the other country.

3.3.3 Labour Income Taxation

The arguments behind the use of energy and commodity taxes also carry over to the incentive structure underlying marginal income taxation. To shorten the tax formulas to be discussed below, let $MRS_{bz}^k = V_z^k / V_b^k$ denote the marginal rate of substitution between leisure and private income for $k = 1, 2, c$, and let $M\hat{R}S_{bz}^2 = \hat{V}_z^2 / \hat{V}_b^2$ denote the marginal rate of substitution for the mimicker. I also use the following short notations

$$\frac{\partial \tilde{x}^k}{\partial z^k} = \frac{\partial x^k}{\partial z^k} - \frac{\partial x^k}{\partial b^k} MRS_{bz}^k, \qquad \frac{\partial \tilde{w}^k}{\partial l^k} = \frac{\partial w^k}{\partial l^k} + \frac{\partial w^k}{\partial b^k} MRS_{bz}^k \tag{39}$$

$$\frac{\partial \tilde{\alpha}}{\partial l^k} = \frac{\partial \alpha}{\partial l^k} + \frac{\partial \alpha}{\partial b^k} MRS_{bz}^k, \qquad \frac{\partial \tilde{\alpha}^*}{\partial l^k} = \frac{\partial \alpha^*}{\partial l^k} + \frac{\partial \alpha^*}{\partial b^k} MRS_{bz}^k \tag{40}$$

for 'compensated' effects on x, w^k, a and α^* in response to an increase in the use of leisure. Consider Proposition 4;

Proposition 4: *In the context of the decentralized federation, the marginal income tax rates implemented by the national government can be written as*

$$T_I^1 = \frac{\lambda \hat{V}_b^2}{\gamma w^1 N^1}\left(MRS_{bz}^1 - \phi M\hat{R}S_{bz}^2\right) + \frac{\Phi^1}{w^1 l^1} + \frac{t}{w^1}\frac{\partial \tilde{x}^1}{\partial z^1} + \Psi^1 \tag{41}$$

$$T_I^2 = \frac{\Phi^2}{w^2 l^2} + \frac{t}{w^2}\frac{\partial \tilde{x}^2}{\partial z^2} + \Psi^2 \tag{42}$$

$$T_I^c = \frac{t}{w^c}\frac{\partial \tilde{x}^c}{\partial z^c} - \frac{\kappa}{\gamma w^c N^c}\frac{\partial \tilde{\alpha}}{\partial l^c} - \frac{\kappa^*}{\gamma w^c N^c}\frac{\partial \tilde{\alpha}^*}{\partial l^c} \tag{43}$$

where

$$\Psi^j = MRS_{bz}^j \sum_i \frac{\rho^i}{\gamma w^j N^j}\frac{\partial \tilde{w}^i}{\partial l^j} - \frac{\kappa}{\gamma w^j N^j}\frac{\partial \tilde{\alpha}}{\partial l^j} - \frac{\kappa^*}{\gamma w^j N^j}\frac{\partial \tilde{\alpha}^*}{\partial l^j} \tag{44}$$

Proposition 4 shows that there are basically four motives for setting a nonzero marginal income tax rate for the low-ability type employed in sector x; (i) relaxing the self-selection constraint, (ii) influencing the hours of work and the wage rate in order to alleviate the labour market distortion, (iii) to compensate the consumer for distortions created by the commodity tax, and (iv) influencing the emission targets chosen by the federal government.

Motive (i) is captured by the first term on the right hand side of equation (41) and one can show that $MRS_{bz}^1 - \phi M\hat{R}S_{bz}^2 > 0$, which means that the presence of self-selection contributes to increase the marginal income tax rate. There is also an indirect self-selection effect, which is ambiguous in sign, because the hours of work will influence the wage ratio. This term is featured in Ψ^1 via ρ^i. These motives for influencing the hours of work of the low-ability type has been highlighted in earlier studies (Stiglitz 1982).

The second term on the right hand side of equation (41) is a direct consequence of the labour market distortion and reflects that for a given labour demand, L^1, the number of type 1 workers employed in sector x can be increased if the hours of work, l^1, is reduced (because

$N^1 = L^1 / l^1$). This has a direct, positive welfare effect and provides the national government with an incentive to tax labour at a higher rate.[16] In addition, the labour market distortion also affects T_I^1 because l^1 will influence the bargained wage w^i (see equation 16). This indirect effect is incorporated in Ψ^1 via ρ^i and provides the government with an incentive to tax labour harder (less hard) if $\partial \tilde{w}^i / \partial l^1 > 0$ ($\partial \tilde{w}^i / \partial l^1 < 0$).

The third term on the right hand side of equation (41) can be interpreted in several ways. On one hand, it can be viewed as a tax base effect. If an increase in leisure has a positive effect on the (compensated) demand for good *x*, which leads to higher revenues from commodity taxation, this tax motive provides the national government with an incentive to increase leisure by implementing a higher marginal income tax rate. On the other hand, $t\left(\partial \tilde{x}^1 / \partial z^1\right) / w^1$ can also be viewed as compensating the consumer for distortions created by the commodity tax. To see this, observe that the government has no direct motive besides externality correction to distort the consumption of good *x*. The components in the tax formula for the commodity tax that appear because of self-selection, labour market distortions and emission targets only appear in equation (37) because the national government lacks direct tax instruments to influence these variables. Therefore, if $t \neq 0$ at the optimum, the government basically uses marginal income taxation (partly) to compensate the consumers for the distortion caused by the commodity tax. If $t > 0$, the national government "compensates" the consumers by stimulating the consumption of good *x*. Then, if $\partial \tilde{x}^1 / \partial z^1 > 0$ ($\partial \tilde{x}^1 / \partial z^1 < 0$) this compensation is achieved by stimulating (reducing) leisure via a higher (lower) marginal income tax rate. The argument goes in the opposite direction if $t < 0$.

The last terms influencing the marginal income tax rate for the low-ability type are related to the emission targets. These terms, which appear in Ψ^1, can be interpreted similarly as the corresponding terms in previous sections. Consequently, if $\partial \tilde{\alpha} / \partial l^1 > 0$ ($\partial \tilde{\alpha} / \partial l^1 < 0$), the marginal tax rate for ability type 1 will be reduced (increased). The explanation is that if the emission target is relaxed (tightened) when l^1 increases, then the national government has an incentive to stimulate (reduce) the hours of work by setting a lower (higher) marginal tax on labour. A similar argument can be used to interpret the last term in equation (44) which is related to the emission target for the other country. As for the marginal income tax rates for the high-ability type and the workers in sector *c*, the terms on the right hand side of equations

[16] This has been pointed out by Aronsson and Sjögren (2004b).

(42) and (43) can be interpreted along similar lines as the corresponding terms in equation (41).

The novelty in Proposition 4 concerns the marginal income tax facing the workers in sector *c*. Equation (43) shows that the national government basically has two motives for setting $T_I^c \neq 0$; compensating the workers for the distortionary commodity tax and influencing the emission targets. Note in particular that the labour market distortion will not explicitly influence the design of T_I^c. This reflects that as long as the workers in sector *c* have made optimal labour supply decisions, a marginal change in their hours of work will have no effect on the bargained wage rates in sector *x*. Another feature is that the self-selection constraint will influence the design of the marginal income tax rate for workers in sector *c*, even though the self-selection constraint does not directly apply to this group of workers. The reason is that since the self-selection problem will induce the national government to set a nonzero commodity tax rate,[17] the national government will use the labour income tax as an instrument to compensate the workers in sector *c* for this distortion.

3.3.4 Profit Taxation

Let us, briefly, consider the profit tax;

Proposition 5: *In the context of the decentralized federation, the profit tax implemented by the national government is implicitly determined by the following equation*

$$\frac{V_b^f}{\gamma} = 1 - t\frac{\partial x^f}{\partial b^f} - \sum_i \frac{\rho^i}{\gamma}\frac{\partial w^i}{\partial b^f} - \frac{\kappa}{\gamma}\frac{\partial \alpha}{\partial b^f} - \frac{\kappa^*}{\gamma}\frac{\partial \alpha^*}{\partial b^f} \tag{45}$$

Observe first that since the firm-owner in this model does not work, the profit tax does not distort any labour supply decision, which means that the profit tax, at a first glance, looks like a lump-sum tax on the firm-owner. If this would be the case, the marginal cost of public funds of such a tax would be equal to one. However, equation (45) shows that four factors will cause γ / V_b^f to deviate from one. The first is captured by the term $-t\partial x^f / \partial b^f$ and is a tax base effect which can be interpreted along the same lines as the corresponding terms in

[17] As long as consumption and leisure are not weakly separable.

equations (41) – (43). The remaining three terms in equation (45) are associated with the labour market distortions and the environmental targets and can be given interpretations similar to those in the analysis above.

4. Summary

This paper concerns optimal taxation and environmental policy in a decentralized federation where there are labour market distortions. The equilibrium features both environmental and wage bargaining externalities. The environmental damage is caused by the use of a dirty input (energy) in the production, whereas the wage bargaining externality arises as a consequence of (the possibility of) firm mobility. The decision making structure in the federation consists of one federal government and two national governments. The federal government determines environmental targets to be implemented by the national governments. At the national level, the governments face a mixed tax problem, where the set of tax instruments consists of a nonlinear income tax, a profit tax, and linear commodity and energy taxes. The assumption of a decentralized federation means that the national governments recognize, and take into account, that they are able to influence the decisions of the federal government. The labour market in each country is made up of two sectors; one which is unionized and one which functions competitively.

The idea is to characterize the incentives influencing the policies determined by a federal government and by national governments. The results in this paper suggest that a potentially important incentive influencing public policy may be the international wage bargaining externality. Since this externality is not internalized at the national level, its presence may instead affect the policies at the federal level. Within the framework of this paper, it will affect the size of the environmental target determined by the federal government. This has implications for the optimal tax structure at the national level. It is shown that the size of the environmental tax on the ‘dirty’ input that is chosen by the national government will be influenced by the presence of the international wage bargaining externality. However, the other taxes determined by the national government will not be influenced by it. In addition, it is shown that all domestic taxes, except the environmental tax, will be used by the national government as indirect instruments to influence the policy chosen by the federal government.

Clearly, there are several possible ways to extend the analysis. For example, it would be interesting to allow workers to migrate between countries and analyse whether this added interaction between countries may create other types of externalities that a federal government may want to internalize. I leave this and other extensions for future research.

Appendix

The Central Government

The first-order conditions corresponding to the central government's problem can be written as

$$\sum_n N^n V_G^n - p\gamma^F = 0 \tag{A.1}$$

$$\gamma^F \sum_i \frac{\Phi^{Fi}}{l^i}\frac{\partial L^i}{\partial \theta} + \gamma^F\left(\theta^F - \frac{\mu^F}{\gamma^F}\right)\frac{\partial E}{\partial \theta} - \sum_i \rho^{Fi}\frac{\partial w^i}{\partial \theta} = 0 \tag{A.2}$$

$$\gamma^F \sum_i \frac{\Phi^{Fi}}{l^i}\frac{\partial L^i}{\partial w^j} + \gamma^F\left(\theta^F - \frac{\mu^F}{\gamma^F}\right)\frac{\partial E}{\partial w^j} + \rho^{Fj} + \lambda^F\frac{\partial \phi}{\partial w^j} l^1 \hat{V}_z^2 - \sum_i \rho^{Fi*}\frac{\partial w^{i*}}{\partial \Pi}\frac{\partial \Pi}{\partial w^j} = 0 \tag{A.3}$$

$$\sum_n N^n V_D^n + \sum_n N^{n*} V_D^{n*} + \mu^F = 0 \tag{A.4}$$

Equations (24), (25) and (27) are readily obtained from (A.4), (A.2) and (A.3).

The National Government

The first-order conditions corresponding to the national government's problem can be written

$$N^1 V_b^1 - \lambda \hat{V}_b^2 + \gamma N^1\left(t\frac{\partial x^1}{\partial b^1} - 1\right) - \sum_i \rho^i \frac{\partial w^i}{\partial b^1} + \kappa\frac{\partial \alpha}{\partial b^1} + \kappa^*\frac{\partial \alpha^*}{\partial b^1} = 0 \tag{A.5}$$

$$-N^1 V_z^1 + \lambda\phi \hat{V}_z^2 + \gamma N^1\left(w^1 - t\frac{\partial x^1}{\partial z^1}\right) - \gamma\Phi^1\frac{N^1}{l^1} - \sum_i \rho^i \frac{\partial w^i}{\partial l^1} + \kappa\frac{\partial \alpha}{\partial l^1} + \kappa^*\frac{\partial \alpha^*}{\partial l^1} = 0 \tag{A.6}$$

$$\left(N^2 + \lambda\right)V_b^2 + \gamma N^2\left(t\frac{\partial x^2}{\partial b^2} - 1\right) - \sum_i \rho^i \frac{\partial w^i}{\partial b^2} + \kappa\frac{\partial \alpha}{\partial b^2} + \kappa^*\frac{\partial \alpha^*}{\partial b^2} = 0 \tag{A.7}$$

$$-\left(N^2 + \lambda\right)V_z^2 + \gamma N^2\left(w^2 - t\frac{\partial x^2}{\partial z^2}\right) - \gamma\Phi^2\frac{N^2}{l^2} - \sum_i \rho^i \frac{\partial w^i}{\partial l^2} + \kappa\frac{\partial \alpha}{\partial l^2} + \kappa^*\frac{\partial \alpha^*}{\partial l^2} = 0 \tag{A.8}$$

$$N^c V_b^c + \gamma N^c\left(t\frac{\partial x^c}{\partial b^c} - 1\right) - \sum_i \rho^i \frac{\partial w^i}{\partial b^c} + \kappa\frac{\partial \alpha}{\partial b^c} + \kappa^*\frac{\partial \alpha^*}{\partial b^c} = 0 \tag{A.9}$$

$$-N^c V_z^c + \gamma N^c \left(w^c - t\frac{\partial x^c}{\partial z^c} \right) - \gamma \Phi^c \frac{N^c}{l^c} - \sum_i \rho^i \frac{\partial w^i}{\partial l^c} + \kappa \frac{\partial \alpha}{\partial l^c} + \kappa^* \frac{\partial \alpha^*}{\partial l^c} = 0 \tag{A.10}$$

$$V_b^f + \gamma \left(t\frac{\partial x^f}{\partial b^f} - 1 \right) - \sum_i \rho^i \frac{\partial w^i}{\partial b^f} + \kappa \frac{\partial \alpha}{\partial b^f} + \kappa^* \frac{\partial \alpha^*}{\partial b^f} = 0 \tag{A.11}$$

$$\sum_n N^n V_G^n - p\gamma = 0 \tag{A.12}$$

$$\gamma \sum_i \frac{\Phi^i}{l^i} \frac{\partial L^i}{\partial \theta} + \gamma \left(\theta - \frac{\mu}{\gamma} \right) \frac{\partial E}{\partial \theta} - \sum_i \rho^i \frac{\partial w^i}{\partial \theta} = 0 \tag{A.13}$$

$$\begin{aligned} &-N^1 x^1 V_b^1 - \left(N^2 + \lambda \right) x^2 V_b^2 - N^c x^c V_b^c - x^f V_b^f + \lambda \hat{x}^2 \hat{V}_b^2 \\ &+ \gamma \sum_n N^n \left(x^n + t\frac{\partial x^n}{\partial q} \right) - \sum_i \rho^i \frac{\partial w^i}{\partial t} + \kappa \frac{\partial \alpha}{\partial t} + \kappa^* \frac{\partial \alpha^*}{\partial t} = 0 \end{aligned} \tag{A.14}$$

$$\gamma \sum_i \frac{\Phi^i}{l^i} \frac{\partial L^i}{\partial w^j} + \gamma \left(\theta - \frac{\mu}{\gamma} \right) \frac{\partial E}{\partial w^j} + \rho^j + \lambda \frac{\partial \phi}{\partial w^j} l^1 \hat{V}_z^2 = 0 \tag{A.15}$$

$$\sum_n N^n V_D^n + \lambda \left(V_D^2 - \hat{V}_D^2 \right) + \mu - \kappa = 0 \tag{A.16}$$

$$\sum_n N^n V_{D^*}^n - \kappa^* = 0 \tag{A.17}$$

To derive equation (31), first invert the conditional indirect utility functions to derive the following expenditure functions

$$b^k = b\left(q, z^k, G, D, D^*, U^k \right) \tag{A.18}$$

$$b^f = b\left(q, G, D, D^*, U^f \right) \tag{A.19}$$

as well as the following identities

$$V^k = v\left(q, b\left(q, z^k, G, D, D^*, U^k \right), z^k \right) + \Theta(G) + \varphi(D) + \Gamma\left(D^* \right) \equiv U^k \tag{A.20}$$

$$V^f = v\left(q, b\left(q, G, D, D^*, U^f \right) \right) + \Theta(G) + \varphi(D) + \Gamma\left(D^* \right) \equiv U^f \tag{A.21}$$

Note that this implies

$$\frac{\partial b^k}{\partial D} = -\frac{V_D^n}{V_b^n} = MWP_{Db}^n, \qquad \frac{\partial b^n}{\partial D} = -\frac{V_{D^*}^n}{V_b^n} = MWP_{D^*b}^n \tag{A.22}$$

Define also

$$c^k = c\left(b\left(q, z^k, G, D, D^*, U^k\right), q, z^k\right) = \tilde{c}\left(q, z^k, G, D, D^*, U^k\right) = \tilde{c}^k \tag{A.23}$$

$$c^f = c\left(b\left(q, G, D, D^*, U^f\right), q\right) = \tilde{c}\left(q, G, D, D^*, U^f\right) = \tilde{c}^f \tag{A.24}$$

$$x^k = c\left(b\left(q, z^k, G, D, D^*, U^k\right), q, z^k\right) = \tilde{x}\left(q, z^k, G, D, D^*, U^k\right) = \tilde{x}^k \tag{A.25}$$

$$x^f = c\left(b\left(q, G, D, D^*, U^f\right), q\right) = \tilde{x}\left(q, G, D, D^*, U^f\right) = \tilde{x}^f \tag{A.26}$$

Differentiate (A.23) – (A.26) w.r.t D and use (A.22) to obtain

$$\frac{\partial \tilde{c}^n}{\partial D} = MWP_{Db}^n \frac{\partial c^n}{\partial b^n}, \qquad \frac{\partial \tilde{x}^n}{\partial D} = MWP_{Db}^n \frac{\partial x^n}{\partial b^n} \tag{A.27}$$

Next, substitute $V_D^n = -V_b^n MWP_{Db}^n$ and $\hat{V}_D^2 = -\hat{V}_b^2 M\hat{W}P_{Db}^2$ into equation (A.16)

$$-\sum_n N^n V_b^n MWP_{Db}^n - \lambda\left(V_b^2 MWP_{Db}^2 - \hat{V}_b^2 M\hat{W}P_{Db}^2\right) + \mu - \kappa = 0 \tag{A.28}$$

Now, use the first order conditions for b^n to derive expressions for V_b^n to substitute into equation (A.28). Then, dividing by γ, using (A.27) and rearranging produces equation (31).

Equation (33) is obtained by rearranging equation (A.15).

Equation (34) is obtained by rearranging equation (A.13).

Equation (38) is obtained by combining equation (A.14) with equations (A.5), (A.7), (A.9) and (A.11), and solve for *t*.

The marginal income tax rates are obtained by combining the first-order conditions for b^k and l^k, for $k = 1, 2, c$, while equation (45) is readily obtained from equation (A.11).

References

Aronsson, T. and Sjögren, T. (2003), “Income Taxation, Commodity Taxation and Provision of Public Goods under Labor Market Distortions”, *FinanzArchiv* **59**, 347-370.

Aronsson, T. and Sjögren, T. (2004) , “Efficient Taxation, Wage Bargaining and Policy Coordination”, *Journal of Public Economics* **88**, 2711-2725.

Aronsson, T. and Sjögren, T. (2004), “Is the Optimal Labor Income Tax Progressive in a Unionized Economy?”, *Scandinavian Journal of Economics* **106 (4)**, 661-675.

Aronsson, T. (2005), “Environmental Policy, Efficient Taxation and Unemployment”, *International Tax and Public Finance* **12**, 131-144.

Aronsson, T., Jonsson, T. and Sjögren, T. (2006), “Environmental Policy and Optimal Taxation in a Decentralized Economic Federation”, *FinanzArchiv* **62**, 437-454.

Bovenberg, L. and Goulder, L. (1996), “Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analyses”, *Americanc Economic Review* **86**, 985-1000.

Bovenberg, L. and de Mooij R. (1994), “Environmental Levies and Distortionary, Taxation”, *Americanc Economic Review* **84**, 1085-1089.

Bovenberg, L. and van der Ploeg, F. (1996), “Optimal Taxation, Public Goods and Environmental Policy with Involuntary Unemployment“, *Journal of Public Economics* **62**, 69-83.

Bovenberg, L. and van der Ploeg, F. (1998), “Tax Reform, Structural Unemployment and the Environment“, *Scandinavian Journal of Economics* **100**, 593-610.

Caplan, A., Corner, R. and Silva, E. (2000), “Pure Public Goods and Income Redistribution in a Federation with Decentralized Leadership and Imperfect Labor Mobility”, *Journal of Public Economics* **77**, 265-284.

Caplan, A. and Silva, E. (1999), “Federal Acid Rain Games”, *Journal of Urban Economics* **46**, 25-52.

Cremer, H. and Gahvari, F. (2001), “Second-Best Taxation of Emission and Polluting Goods”, *Journal of Public Economics* **80**, 169-197.

Cremer, H., Gahvari, F. and Ladoux, N. (2001), “Second-Best Pollution Taxes and the Structure of Preferences”, *Southern Economic Journal* **68**, 258-280.

Fuest, C. and Huber, B. (1997), “Wage Bargaining, Labor-Tax Progression and Welfare”, *Journal of economics* **66 (2)**, 127-150.

Koskela, E., R., Schöb, R. And Sinn, H.-W. (2001),), “Green Tax Reform and Competitiveness“, *German Economic Review* **2**, 19-30.

Marceau, N. and Boadway, R. (1994), “Minimum Wage Legislation and Unemployment Insurance as Instruments for Redistribution”, *Scandinavian Journal of Economics* **96**, 67-81.

Parry, I., Williams, R. and Goulder, L. (1999), “When can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets“, *Journal of Environmental Economics and Management* **37**, 52-84.

Persson, L. (2008), “Environmental Policy, Commitment and Decentralized Leadership”, Mimeo Umeå University.

Pirttilä, J. and Tuomala, M. (1997), ”Income Tax, Commodity Tax and Environmental Policy”, *International Tax and Public Finance* **3**, 379-393.

Sandmo, A. (1975), “Optimal Taxation in the Presence of Externalities”, *Scandinavian Journal of Economics* **77**, 86-98.

Stern, N. H. (1982), “Optimum Taxation with Errors in Administration“, *Journal of Public Economics* **17**, 181-211.

Stiglitz, J. E. (1982), “Self-Selection and Pareto Efficient Taxation“,*Journal of Public Economics* **17**, 213-240.

Silva, E. and Caplan, A. (1997), “Transboundary Pollution Control in Federal Systems”, *Journal of Environmental Economics and Management* **34**, 173-186.