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Environmental Tax Reform in a Small Open Economy with Structural Unemployment[§]

by

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Abstract

The paper examines the effects of an environmental tax reform in a model of a small open economy with decentralised wage bargaining and monopolistically competitive firms. The economy includes a tradable sector as well as a non-tradable sector and features unemployment in general equilibrium. Firms in both sectors use labour and an imported polluting factor of production ("energy"). A tax on energy, recycled to reduce the payroll tax, will in general affect equilibrium unemployment in this economy. The effect works through a reallocation of employment from the tradable to the non-tradable sector. Total employment increases if workers in the tradable sector receive a wage premium relative to workers in the non-tradable sector. The sectoral relative wage is determined by the relative bargaining power of the unions and by parameters of preferences and technology. Parameterised versions of the model suggest that the tax reform has small effects on employment and that it typically reduces real *GDP*.

JEL-classification: H20, J51, J64, Q43.
Keywords: Environmental tax reform, wage bargaining, equilibrium unemployment.

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1. Introduction

Recent years have seen a rapid increase in studies of various aspects of environmental taxation. This research has primarily been theoretical, sometimes supplemented by numerical simulation models of the economy. One strand of the literature has been concerned with the so called double dividend issue. The basic question in this discussion is whether a switch from labour taxes to taxes on polluting goods or factors of production can achieve both an improvement of the environment and a reduction in distortions arising from labour taxation; see Goulder (1995) for a review of the main arguments.

The popular and political discussions on environmental taxation have increasingly been concerned with the possibility of reducing unemployment through lower labour taxes financed by higher taxes on the environment. The conceivable rise in employment from such a reform has been referred to as a "triple dividend". The idea here is that a reduction in taxes on labour, for example a cut in the payroll tax, would reduce labour costs and thereby increase employment. The shortfall in public revenues would be covered by higher "green taxes", and a cleaner environment would appear as an additional benefit.

Despite the interest that the employment issue has attracted in policy discussions, there has been rather little research on the implications for unemployment of an environmental tax reform. Most papers dealing with environmental taxation are based on models with market clearing wages, which obviously is an inadequate framework for analysing issues pertaining to unemployment. There are a few exceptions, however. Bovenberg and van der Ploeg (1996) examine the impact of environmental taxation in an economy with an exogenously fixed real consumer wage. In this set-up, an environmental tax reform involving a switch from labour taxes to green taxes may boost employment under certain conditions.

The assumption of a rigid consumer wage is not very appealing, however. It is at variance with a large number of empirical studies showing that real wages are responsive to changes in labour taxes. It is preferable to specify a model where real wage resistance (or its absence) is derived from more primitive assumptions about preferences, technology and wage setting mechanisms. Models of wage bargaining are the natural candidates here, but they have only very recently been invoked in investigations of environmental taxation. The contributions include Bovenberg and van der Ploeg (1995), Brunello (1996), Carraro et al (1996), Nielsen et al (1995), Koskela and Schöb (1996), and Strand (1996). The paper by Bovenberg and van der Ploeg uses a matching model of the type presented in Pissarides (1990), augmented to account for a polluting factor of production. Brunello, Carraro et al and Koskela and Schöb consider models with union-firm bargaining over wages, whereas Nielsen et al and Strand make use of a monopoly union model.

Although the claim that a cut in labour taxes is good for employment seems intuitively plausible, it is *not* a necessary implication from models of equilibrium unemployment. A typical feature of models of wage bargaining is that equilibrium real wage resistance is crucially dependent on the "benefit regime", i.e., the characteristics of workers' unemployment compensation. This is true for models with unions, as in Johnson and Layard (1986) or Layard et al (1991), or in matching models with individual worker-firm bargaining, as in Pissarides (1990). It holds also for various efficiency wage models. There is in general complete real wage flexibility with respect to changes in labour taxes if real unemployment compensation is indexed to the real consumption wage through a fixed replacement ratio. Labour taxes are in this case completely borne by labour, and there is no effect on employment in equilibrium. The equilibrium can graphically be described in the real wage and employment space as an intersection between a downward sloping labour demand (or price setting) schedule and a *vertical* (long run) wage setting schedule.

If however unemployment compensation is fixed in real terms, i.e., the nominal benefits are linked to the price level rather than to the wage level, real wage resistance is the typical outcome in models of wage bargaining as well as in efficiency wage models. The wage setting schedule is positively sloped in the real wage and employment space, so shifts of labour demand will in general affect employment. The reason that indexation to wages gives more wage flexibility than indexation to prices is that the former rule causes benefit levels to adjust downward when real wages fall as a response to a labour demand shift, thus producing an additional incentive for wage moderation.[1] With price indexation of benefits there is a potential employment dividend to be reaped from a cut in labour taxes. Whether it actually can be

[1] Pissarides (1996) presents a number of simulation exercises which highlight the importance of the benefit regime in models of equilibrium unemployment.

reaped depends, *inter alia*, on how easy it is to cover the shortfall in government revenues by higher taxes on the environment, and on how environmental taxes affect labour demand. Although wage indexation of benefits is common in many countries, this does not necessarily imply complete real wage flexibility. A crucial issue is the extent to which the unemployed have access to other sources of income than regular unemployment benefits, for example income from capital or the underground economy, services derived from household production, and perhaps some utility from leisure. These sources of unemployment income are untaxed (and possibly untaxable), and their presence implies that wage indexation of regular benefits will not translate into complete indexation of total unemployment income to changes in real wages. This is arguably a realistic case to consider, and it is discussed at some length in Bovenberg and van der Ploeg (1995), although there is very little hard evidence on the magnitudes involved.

There is a large empirical literature on the incidence of income and payroll taxes. This literature typically focuses on how real labour costs respond to taxes, and there are also a few attempts to directly estimate how taxes affect equilibrium unemployment. The results are not conclusive; several studies suggest that labour costs are indeed pushed up by higher labour taxes, whereas other studies find no effects.[2] Tyrväinen (1995) and Jackman et al (1996) are two recent papers that report conflicting results.

The potential for employment gains from lower labour taxes that appears in the model of Bovenberg and van der Ploeg (1995) derives from the impact of the tax reform on the effective replacement ratio. The rise in employment that is caused by a cut in labour taxes hinges on the presence of fixed elements in unemployment income that makes the effective replacement ratio imperfectly indexed to the general wage level. Our investigation is concerned with the question of whether a reform that involves higher taxes on an imported polluting factor of production

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[2] An implicit assumption in much of the empirical literature is that the absence of an effect of taxes on labour costs implies that there is no effect on unemployment either. This implication does not follow, however, if the price-setting schedule is horizontal, in which case real producer wages would be fixed by firms' price setting behaviour. Labour taxes would increase unemployment in such an economy to the extent that there is some fixed element in total unemployment compensation, resulting in a positively sloped wage setting schedule.

can boost employment even when the replacement ratio is not affected. The answer to the question is a qualified yes.

The model, developed in section 2 of the paper, features a small open economy with decentralised wage bargaining, monopolistically competitive firms and equilibrium unemployment. There is a tradable sector and a non-tradable (sheltered) sector. All firms use labour and an imported factor of production. We think of the imported input as a polluting factor (such as oil) and will refer to it as energy. The polluting feature of this imported factor is of no relevance in the positive analysis. It will have implications for the normative analysis, however, as total energy consumption in the economy affects household utility negatively. The analysis is concerned with long-run equilibrium with balanced trade and endogenously determined relative prices and relative wages.[3]

We examine the effects of taxes on labour and energy, including a reform where revenues from the energy tax are recycled to allow for a cut in the payroll tax. It turns out that labour taxes have no effect on unemployment, which is a standard result in models of equilibrium unemployment with fixed replacement ratios. Energy taxes are not neutral with respect to unemployment, however. A rise in the energy tax will in general affect unemployment, and the direction of the effect depends on the sectoral relative wage, i.e., the ratio between the equilibrium wage in the non-tradable and the tradable sector. A tax increase induces a reallocation of employment from the tradable to the non-tradable sector, which in turn increases total employment if wages are lower in the non-tradable sector. Consequently, if there is a tradable sector wage premium, a rise in the energy tax boosts employment, whereas employment falls if wages are higher in the sheltered sector. The sectoral wage differential is determined by parameters of preferences and technology as well as the relative bargaining power of the unions.

Section 3 of the paper contains a brief discussion of the welfare implications of energy taxes. Even if energy taxes may boost employment, it does not necessarily follow that they are welfare-improving. Consumers care about environmental quality in addition to the consumption of traded and non-traded goods. Energy taxes will affect the quantities of the two types of goods as well as the amount of pollution. Numerical simulations of the model suggest that energy taxes in general will provide an environmental dividend but also reduce real *GDP*.

2. The Model

2.1 The Consumers

The economy consists of a fixed number of identical consumers. The size of the population is normalised to unity. The individuals consume two types of goods. The first type consists of goods that are traded on the world market while the second type consists of goods that are produced and consumed domestically. The utility function characterising consumer preferences for the two types of goods is given by

(1) $$U_i = \left(\frac{D_{ci}}{\alpha}\right)^{\alpha}\left(\frac{D_{si}}{1-\alpha}\right)^{1-\alpha} - v(e), \qquad 0<\alpha<1.$$

D_{ci} is individual i's consumption of the tradable goods and D_{si} is the consumption of goods produced in the sheltered sector. The term $v(e)$ captures the disutility from the aggregate use of energy, e, in production; we assume $v'(e) > 0$. The individuals supply one unit of labour inelastically without loss of utility. The sub-utility for the different varieties of the traded and the non-traded goods are captured by

(2) $$D_{ci} = k_c^{\frac{1}{1-\mu}}\left(\sum_{g=1}^{k_c} D_{ci}^{g\,\frac{\mu-1}{\mu}}\right)^{\frac{\mu}{\mu-1}},$$
$$D_{si} = k_s^{\frac{1}{1-\sigma}}\left(\sum_{j=1}^{k_s} D_{si}^{j\,\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}},$$

where k_c and k_s are the number of varieties available of the two types. The parameters μ and σ are the elasticities of substitution in consumption between any two traded and non-traded

[3] The model has some similarities with the so called Scandinavian model of inflation; see for example Edgren et al (1973) and the exposition in Lindbeck (1979). In fact, some relationships that were

goods. These elasticities are restricted to be greater than unity to guarantee the existence of an equilibrium.

An individual is either unemployed or employed in one of the two sectors. The individual consequently receives unemployment benefits, B, or labour income, w_i. In addition, non-labour income in terms of a share of profits, π, adds to the individual income. Profits are assumed to be equally distributed across individuals. The budget constraint then takes the form

(3) $$I_i = \sum_{g=1}^{k_c} P_g D_{ci}^g + \sum_{j=1}^{k_s} P_j D_{si}^j ,$$

where $I_i = w_i + \pi$ if employed and $I_i = B + \pi$ if unemployed. The price levels for the two types of goods are calculated as cost-of-living indexes based on the sub-utility functions in (2):

(4) $$P_c = \left(\frac{1}{k_c} \sum_{g=1}^{k_c} P_g^{1-\mu} \right)^{\frac{1}{1-\mu}} ,$$
$$P_s = \left(\frac{1}{k_s} \sum_{j=1}^{k_s} P_j^{1-\sigma} \right)^{\frac{1}{1-\sigma}} .$$

The general price level in the economy is calculated as a cost-of-living index based on the utility for the two types of goods in (1) and takes the form:

(5) $$P = P_c^{\alpha} P_s^{1-\alpha} .$$

Consumers choose an optimal bundle of commodities given their budget constraints. The externality affecting consumers' utility is taken as given since the consumers can not influence the use of energy in production. The parameters α and 1-α are the fixed fractions of income that the consumer allocates to consumption of the traded and the non-traded goods. From the

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postulated in that model (e.g. fixed relative wages) are *derived* in our analysis.

solution of the consumer's maximisation problem, we can derive the demand function facing a specific firm in the sheltered sector as

(6) $$D_s^j = \frac{(1-\alpha)}{k_s}\left(\frac{P_j}{P_s}\right)^{-\sigma}\frac{\bar{I}}{P_s}, \qquad j=1,\ldots,k_s ,$$

where $\bar{I}$ is the aggregate income in the economy. The market demand for good depends on the firm's price relative to the general price level in the sheltered sector. The closer substitutes the goods are, i.e. the higher is σ, the more costly it is in terms of reduced demand to increase the price above the general sector price. The elasticity of substitution,σ, is thus the demand elasticity facing firms as well. The total income is deflated by the general sector price. There will hence be no cross price effects between the two sectors. This follows from the fact that individuals assign a fixed share, 1α, of their income to consumption of non-tradable goods.

Let $k_c^{\bar{h}}$ be the fixed number of varieties of the tradable good that is produced domestically. The demand function facing an arbitrary firm producing a variety that is consumed domestically as well as abroad is given by

(7) $$D_c^h = \frac{\alpha}{k_c}\left(\frac{P_h}{P_c}\right)^{-\mu}\frac{I^0}{P_c}, \qquad h = 1,\ldots,k_c^{\bar{h}} .$$

I^0 is the world aggregate income, i.e. $I^0 = \bar{I} + \bar{\bar{I}}$, where $\bar{\bar{I}}$ is the aggregate income in the rest of the world. We will take the rest-of-the-world real income,$\bar{\bar{I}} / P_c$, as exogenous throughout the analysis.[4] The properties of the demand function facing firms in the tradable sector is analogous to the one for firms in the sheltered sector. The demand elasticity is given by μ .

2.2 The Firms

[4] To arrive at these particular demand functions we have assumed that consumers have identical preferences across countries. Less restrictive assumptions can be made without altering the results.

There are a fixed number of firms operating in each sector. Firms in the *dbs* choose labour and energy so as to maximise profits given the technology, producer wage and demand they face. Labour is immobile between countries whereas energy is mobile and imported at a fixed (foreign currency) price from abroad. Let the technology be represented by a production function with constant returns to scale given by

(8) $$y_s = n_s^{\delta} e_s^{1-\delta}, \qquad 0<\delta<1,$$

where n and e_s are the amount of labour and energy used in production in a representative firm. The profit-maximising price for a particular firm is given as:

(9) $$P_{sj} = c_1 \left[w_s (1+t_n) \right]^{\delta} \left[q(1+t_e) \right]^{1-\delta}, \qquad 1,\ldots, \quad _s \ .$$

c_1 is a constant that depends on δ and σ.[5] t_n and t_e are the tax rates on labour and energy and q is the domestic pre-tax price of energy. Cost minimisation implies $n_s / e_s = const\left(q\left(1+t_e\right)\right) / \left(w_s\left(1+t_n\right)\right)$, which together with (6), (8) and (9) yield the wage elasticity of labour demand at the firm level: $-\partial \ln n_s / \partial \ln w_s = \delta(\sigma - 1) + 1$.

Since all firms in the sheltered sector face the same problem, all prices will be set equal in the sector in a symmetric equilibrium. The general price of non-tradables is thus given by eq. (9). By using the relations derived from firms' optimisation and imposing equilibrium in the product market, we can derive the equilibrium demand for labour and energy at the firm level as

(10) $$n_s = c_2 \frac{\bar{I}}{w_s\left(1+t_n\right)},$$

(11) $$e_s = c_3 \frac{\bar{I}}{q\left(1+t_e\right)}.$$

c_2 and c_3 are constants including technology and preference parameters as well as the number of varieties available of the non-traded goods. We notice that there will be no cross price

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[5] All constants are defined as positive and shown in an appendix.

effects between the demand for the two factors in equilibrium. When the price of energy increases, the demand for energy, as well as the demand for labour, falls for a given general sector price. This follows from the fact that the factors are gross complements in demand. In equilibrium, however, the general sector price increases since it is a weighted average of the energy price and the producer wage. This has a twofold effect on each firm’s demand for labour. A higher sector price reduces the firm’s relative price, which increases the demand for the firm’s product and thereby the firm’s demand for labour. There will, however, also be a negative effect due to the decline in aggregate real demand for non-tradables; this reduces the demand for the firm’s product and thereby also its demand for labour. The positive effect on the demand for labour dominates, however. This positive effect completely outweighs the direct negative cross price effect. In equilibrium there will thus be no effects from changes in the price of energy on the demand for labour. Analogous properties hold for the firm’s equilibrium demand for energy in the sheltered sector.

In the *tct* , the production technology is represented by a constant returns to scale Cobb-Douglas function given by

(12) $$y_c = n_c^{\gamma} e_c^{1-\gamma}, \qquad 0<\gamma<1,$$

where n_c and $_c$ are the amount of labour and energy used in a representative firm. The firm’s profit-maximising price, and the demand for labour and energy, are obtained as:

$$P_{ch} = c_4\left[w_c\left(1+t_n\right)\right]^{\gamma}\left[q\left(1+t_e\right)\right]^{1-\gamma}, \qquad h=1,\ldots,k_c^{\bar{h}},$$

(13) $$n_c = c_5\left[w_c\left(1+t_n\right)\right]^{-\gamma(\mu-1)-1}\left[q\left(1+t_e\right)\right]^{-(1-\gamma)(\mu-1)} P_c^{\mu}\left(I^0 / P_c\right),$$

$$e_c = c_6\left[w_c\left(1+t_n\right)\right]^{-\gamma(\mu-1)}\left[q\left(1+t_e\right)\right]^{-(1-\gamma)(\mu-1)-1} P_c^{\mu}\left(I^0 / P_c\right).$$

c_5 and c_6 are constants that depend on the parameters of preferences and technology. The wage elasticity of labour demand is thus given as $-\partial \ln n_c / \partial \ln w_c = \gamma\left(\mu-1\right)+1$.

The two factors of production are gross complements in demand; an increase in the unit cost of one factor reduces the use of both factors. In general equilibrium, domestic firms producing tradables will set the same prices since they face the same conditions. We will, however, not impose symmetric world equilibrium in the sense that the prices will be set equal across firms in different countries. This implies that the general price of tradables in general will differ from the price of domestically produced tradables, i.e. $P_{ch} \neq P_c$. Furthermore, with the volume of domestically produced goods traded on the world market being small relative to the world trade, there will be a negligible impact on the general price of tradables from changes in the price of the domestically produced goods.

2.3 The Unions[6]

There is one union in each firm and each union cares about the utility of its members. The indirect utility function for the individual is given as

(14) $$V_i^* = \frac{I_i}{P} - v(e),$$

where I_i is the state-dependent income. Workers are concerned with their expected lifetime utility, and consider the possibility of transitions across sectors and labour force states. Define V_c^h, V_c as the expected lifetime utility of a worker employed in a particular firm *h*, and an arbitrary firm, in the tradable sector; V_s^j, V_s as the expected lifetime utility of a worker employed in a particular firm *j*, and an arbitrary firm, in the sheltered sector; and V_u as the expected lifetime utility of an unemployed individual. Assuming an infinite time horizon we can write the value functions as:[7]

[6] The model of unions and wage bargaining draws heavily on Holmlund (1996) and Kolm (1996).

[7] The probability that an unemployed worker will get an offer from both sectors at the same time is assumed to be negligible.

(15)
$$rV_c^h = \frac{w_c^h + \pi}{P} - v(e) + x_c\left(V_u - V_c^h\right),$$
$$rV_s^j = \frac{w_s^j + \pi}{P} - v(e) + x_s\left(V_u - V_s^j\right),$$
$$rV_u = \frac{B + \pi}{P} - v(e) + a_c\left(V_c - V_u\right) + a_s\left(V_s - V_u\right).$$

B is nominal unemployment benefits, r is the discount rate and x_i is the exogenous probability that a worker is separated from his job in sector i. The probability of leaving unemployment for employment in sector i is denoted a_i. The workers possess no sector-specific skills and move between firms through a spell of unemployment. On-the-job search and job-to-job mobility are ruled out by assumption.

From (15) we can derive expressions for the utility differences between employment and unemployment of the form:

(16)
$$V_c^h - V_u = \frac{1}{x_c + r}\left\{\frac{w_c^h}{P} - \overline{V}\right\},$$
$$V_s^j - V_u = \frac{1}{x_s + r}\left\{\frac{w_s^j}{P} - \overline{V}\right\}.$$

$\overline{V}$ is the utility value of outside opportunities net of the share of profits and the disutility of pollution, i.e., $\overline{V} \equiv V_u - (1/r)\left(\pi / P + v(e)\right)$. Non-labour income and the disutility of pollution do not affect the utility differences between employment and unemployment since they are state-independent. $\overline{V}$ is common for all workers since their former labour market histories are irrelevant for the job-finding probabilities.

2.4 Wage Bargaining

The nominal wage is set in decentralised union-firm bargains, while the firms determine employment. The general price level is taken as given in these negotiations. Wages are chosen according to Nash bargains of the form:

$$\Omega_c^h = \left[n_c^h \left(V_c^h \left(w_c^h \right) - V_u \right) \right]^{\lambda_c} \left[R_h(.) - w_c^h (1 + t_n) n_c^h - q(1 + t_e) e_c^h \right]^{1-\lambda_c},$$

(17)

$$\Omega_s^j = \left[n_s^j \left(V_s^j \left(w_s^j \right) - V_u \right) \right]^{\lambda_s} \left[R_j(.) - w_s^j (1 + t_n) n_s^j - q(1 + t_e) e_s^j \right]^{1-\lambda_s}.$$

The union's contribution to theNash bargain is given by its "rent", i.e.,$n_c^h \left(V_c^h \left(w_c^h \right) - V_u \right)$for the tradable sector and $n_s^j \left(V_s^j \left(w_s^j \right) - V_u \right)$ for the sheltered sector. $R_h(.)$ and $R_j(.)$ are the firms' revenues. The parameters λ_c and λ_s measure the relative bargaining power of the unions relative to the firms, with $0<\lambda_i<1$, for $=c, s$. The wage bargains recognise that the firms will unilaterally determine employment and energy consumption, i.e.,$n_c^h = n_c\left(w_c^h\right)$, $e_c^h = e_c\left(w_c^h\right)$, $_s^j = {}_s\left(w_s^j\right)$ and $e_s^j = e_s\left(w_s^j\right)$. By solving for the real wages implied by the negotiations we get:

(18) $$\frac{w_c^h}{P} = \left(\frac{\lambda_c + \gamma(\mu - 1)}{\gamma(\mu - 1)} \right) \overline{V}, \qquad =1,\ldots, k_c^{\bar{h}},$$

(19) $$\frac{w_s^j}{P} = \left(\frac{\lambda_s + \delta(\sigma - 1)}{\delta(\sigma - 1)} \right) \overline{V}, \qquad = 1,\ldots,k_s.$$

Each wage is then given as a constant mark-up on the measure of outside opportunities. Differences in mark-ups between the two sectors depend onsectoral differences in bargaining power (λ_c vs. λ_s) as well as parameters of preferences and technology. The larger is σ or δ, the larger is the wage elasticity of labour demand and the lower is the mark-up in the sheltered sector. Analogously, the larger is γ or μ, the lower is the mark-up in the tradable sector. Wages are in equilibrium set equal across the bargaining units within each sector, an implication of the fact that all union-firm pairs within a sector have identical technologies and face the same maximisation problem.

From equations (18) and (19) we obtain the relative wage: $z \equiv w_s / w_c$. Since all workers face the same outside opportunities the relative wage takes the form:

(20) $$z = \frac{\gamma(\mu-1)\big(\lambda_s + \delta(\sigma-1)\big)}{\delta(\sigma-1)\big(\lambda_c + \gamma(\mu-1)\big)}.$$

The relative wage is thus fixed by preference and technology parameters as well as by the measure of union bargaining power. The relative wage obviously increases in the bargaining power of the unions in the sheltered sector, λ_s, while it falls in the unions' relative bargaining power in the tradable sector, λ_c. It will also increase in γ and μ while it falls in δ and σ. The lower the wage elasticity of labour demand in the sheltered sector relative to the labour demand elasticity in the tradable sector, the higher is the relative wage in the sheltered sector.

Flow equilibrium requires equality between the inflow of workers to a sector (hirings) and the outflow from it (separations). This implies:

(21) $$\begin{aligned} x_c n_c &= a_c u, \\ x_s n_s &= a_s u. \end{aligned}$$

With the labour force normalised to unity we have n_c, n_s and u in levels as well as in rates, and the labour force identity given by $1 = n_c + n_s + u$.

In a symmetric equilibrium, outside opportunities are given by a probability-weighted average of the utilities in the different states. The probabilities are the expected fractions of time spent in the different states. For simplicity, we focus on the case when the discount rate approaches zero.[8] Using (21) as well as the labour force identity we can write the outside opportunities, net of the disutility from pollution and the non-labour income, as follows:

(22) $$\overline{V} = u\frac{B}{P} + n_c\frac{w_c}{P} + n_s\frac{w_s}{P}.$$

[8] The value functions are not defined when the discount rate is strictly zero. The analysis is valid as an approximation when the discount rate is arbitrarily close to zero. We assume that the parameters are such that all job offers are accepted.

The wage equations in (18) and (19) can be expressed as an equilibrium relationship between employment in the two sectors, n_c and n_s, by eliminating $\overline{V}$ by means of eq. (22) and by using the labour force identity. The resulting employment relationship takes the form

(23) $$n_c = c_7 - \frac{(z-b)}{(1-b)} n_s,$$

where c_7 is a constant, and c_7 1. The parameter b is the constant replacement ratio with the unemployment benefits indexed to the average wage in the tradable sector, i.e., $B = bw_c$; the results of the paper do not hinge on which of the sector's wages benefits are indexed to. The wage from working must be higher than the benefit level, i.e. bz and b 1, to ensure the existence of the two sectors. The magnitude of the relative wage, z, plays a crucial role in determining the trade-off between employment in the two sectors. If wages are equal in the sectors, i.e. z 1, an increase in employment in the sheltered sector will be exactly offset by a decrease in employment in the tradable sector. On the other hand, if the wage in the sheltered sector is lower than the wage in the tradable sector, i.e. z 1, an expansion of sheltered employment will not be completely offset by a fall in employment in the tradable sector.[9]

Consider an exogenous increase in the demand for labour in the sheltered sector and suppose that z<1 holds. This increases the value attached to unemployment, which induces higher wage demands. Lower employment in the tradable sector follows as a consequence. The expansion of employment in the sheltered sector thus crowds out employment in the tradable sector. A wage premium for workers in the tradable sector will restrain the wage push since the relative probability for an unemployed worker of getting a job in the higher paying sector has decreased. The fall in employment in the tradable sector will therefore not completely offset the increase in employment in the sheltered sector.

2.5 The Trade Balance

The trade balance is defined as the difference between the value of exports and the value of imports:

[9] If the labour market were competitive we would have c_7=z=1 and (23) would simply state that total employment is equal to the labour force, i.e., n_c+n_s=1.

(24) $$TB = \sum_{h=1}^{k_c^{\bar{h}}} P_{ch} y_h - \sum_{g=1}^{k_c} P_{cg} D_c^g - q\left(e_c + e_s\right).$$

The value of exports is given by the value of what is not consumed domestically of the $k_c^{\bar{h}}$ goods, i.e. $\sum_{h=1}^{k_c^{\bar{h}}} P_{ch}\left(y_h - D_c^h\right)$. The value of imports is given by the value of the $k_c - k_c^{\bar{h}}$ goods that are imported, i.e. $\sum_{g=k_c^{\bar{h}}}^{k_c} P_{cg} D_c^g$, as well as the value of the imported energy, i.e. $q\left(e_c + e_s\right)$. Balanced trade requires that there must be positive net exports of the domestically produced traded goods to cover imports of energy as well as imports of the traded goods produced abroad.

By substituting each sector's demand for labour and energy into (24) and imposing TB=0 ("external balance") we can derive a relationship between real income, measured in units of the tradable goods, and the real producer wage in the tradable sector. This trade balance condition takes the form

(25) $$\bar{I} / P_c = \left(I^0 / P_c\right)\left(\frac{w_c\left(1+t_n\right)}{P_c}\right)^{-\gamma(\mu-1)}\left(\frac{q\left(1+t_e\right)}{P_c}\right)^{-(1-\gamma)(\mu-1)} \frac{1}{T\left(t_e\right)},$$

where $T(t_e)$ is given by

(26) $$T\left(t_e\right) = \frac{\alpha\left(1+t_e\right)+c_8}{c_9\left(1+t_e\right)-c_{10}} > 0 .$$

$c_8 - c_{10}$ are constants and $c_9 > c_{10}$. $T\left(t_e\right)$ is decreasing in the energy tax rate, i.e., $T'\left(t_e\right) < 0$. Recall that $I^0 / P_c = (\bar{I} + \bar{\bar{I}}) / P_c$, where foreign real income, $\bar{\bar{I}} / P_c$, is exogenous. The trade balance condition in eq. (25) can accordingly be viewed as a relationship between two endogenous variables, namely domestic real income (in terms of tradeables) and the real producer wage in the tradeable sector. The real energy price is exogenous by virtue of the assumption of a small open economy, where domestic influences on the general price in the tradeable sector are negligible.

It is clear from eq. (25) that a rise in the real pre-tax energy price $\left(q / P_c\right)$ is *not* equivalent to an increase in the energy tax. A rise in the real pre-tax energy price worsens the trade balance, which has to be offset by increased exports and/or reduced imports. This is accomplished through a lower real producer wage in the tradable sector and a lower real income. A rise in the energy tax has similar but not identical effects. The reason is that the value of imports is determined by the *pre-tax* energy price (q), whereas the firm's demand for inputs are determined by the *s* energy price $\left(q\left(1+t_e\right)\right)$. The effects of an energy tax on the trade balance work only through the real factor prices, while a higher energy price in addition has a "direct" negative impact on the trade balance by making imports more expensive. The fact that a higher energy tax does not have this direct negative effect on the trade balance appears as a positive effect in eq. (25) and is captured by the function $T\left(t_e\right)$.

2.6 General Equilibrium

The general equilibrium of the economy can be given a simple representation by means of four equations. We combine the aggregate labour demand relationship for the tradable sector, obtained from eq. (13) after multiplication with the number of firms, with the trade balance equation (25); this makes it possible to obtain a relationship, given by eq. (27) below, between tradable sector employment and real income, the latter measured in wage units of the tradable sector. The remaining equations have already been derived and are repeated for convenience. Eq (28) is the aggregate labour demand relationship for the sheltered sector, eq. (29) the relative wage, and eq. (30) the trade-off between sectoral employment levels that is implied by the wage-setting relationships. The model is thus given by the following equations:

(27) $$n_c = \frac{c_{11}\bar{I} \cdot T\left(t_e\right)}{w_c\left(1+t_n\right)},$$

(28) $$n_s = \frac{c_{12}\bar{I}}{w_s\left(1+t_n\right)},$$

(29) $$z = \frac{w_s}{w_c},$$

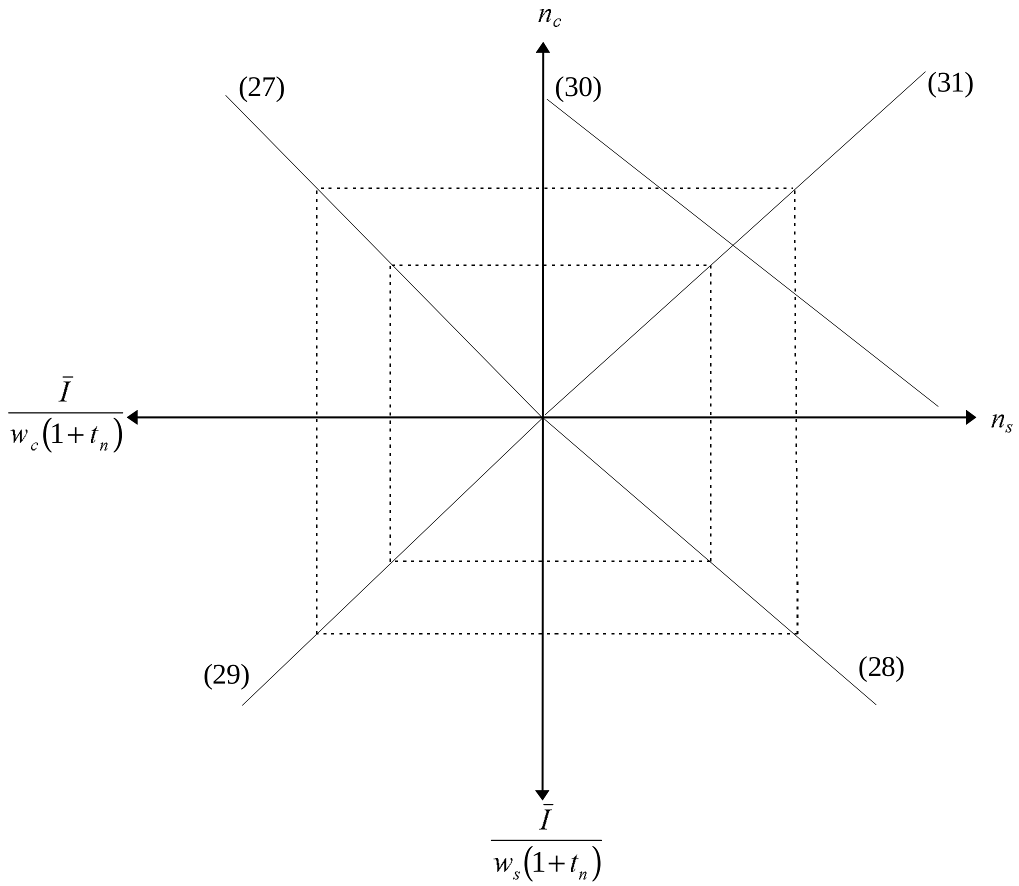
(30) $$n_c = c_7 - \frac{(z-b)}{(1-b)} n_s.$$

These equations determine employment in the two sectors as well as real income in wage cost units. A graphical representation is given in *Figu* 1. Eqs. (27) and (28), the two aggregate labour demand schedules, are illustrated in the second and fourth quadrants in the figure. Quadrant 3 displays the relative wage line given by (29). The trade-off between employment in the two sectors given by (30) is illustrated by the negatively sloped line in the first quadrant. The labour demand relationships and the relative wage line can be combined to trace out the positively sloped locus in the first quadrant. The equation of this locus is obtained from eqs. (27)-(30) and given as

(31) $$\frac{n_c}{n_s} = c_{13} z \cdot T\left(t_e\right).$$

Since the relative wage is fixed by eq. (20), the relative equilibrium employment is determined by the relative sector demand for labour. The government can determine the relative sector employment in the economy through its choice of energy tax. By using (30) together with (31) we can solve for the equilbrium levels of employment in the two sectors. The solution of the system is illustrated in the first quadrant of Figure 1. Note that the labour tax does affect

Figure 1. Employment and producer wages in general equilibrium.



this solution, whereas the energy tax rate does. The tax rate on labour has thus no effect on relative or total employment.[10]

We also note that real energy prices are absent from eqs. (27)-(30), implying that higher energy prices, like labour taxes, have no effect on sectoral or total employment. Recall that a higher price of energy reduces the demand for labour in the tradable sector in *ill* equilibrium, due to the negative cross price effect; cf. eq. (13). This negative effect is completely offset in *gl* equilibrium by the induced trade balance adjustments.

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[10] If the payroll tax rate is increased, the immediate effect would be a drop in each sector's labour demand. The threat of increased unemployment would induce wage moderation, which in turn leads to a downward adjustment of real unemployment benefits through the fixed replacement ratio. This process continues until real producer wages have returned to their initial values. If however the payroll tax increases were *differentiated* between the two sectors, relative demand and thereby possibly total employment could be affected; see Kolm (1996).

The tax revenues are used to finance unemployment benefits. The tax on energy is adjusted so as to keep the government's budget balanced. The government's budget restriction is given as

(32) $$t_n\left(w_c n_c + w_s n_s\right) + t_e\left(qe_c + qe_s\right) = (1 - n_c - n_s)bw_c\,,$$

which can be rewritten as

(32') $$t_n\left(n_c + zn_s\right) + t_e\left(\frac{q}{P_c}\frac{P_c}{w_c^*}\right)\left(e_c + e_s\right)(1 + t_n) = (1 - n_c - n_s)b\,,$$

where $w_c^* \equiv w_c(1 + t_n)$ is the nominal wage cost in the tradable sector. The labour tax rate can be computed residually from (32') once the energy tax rate and the endogenous variables of the model are determined. By using eqs. (27)-(30) together with the trade balance condition in eq. (25) we can determine the real after-tax producer wage, i.e., w_c^* / P_c. Total energy consumption is obtained by invoking eqs. (11) and (13) and can be written as:

(33) $$e \equiv e_c + e_s = \left(c_{10}T(.) + c_8\right)\left(\frac{q\left(1 + t_e\right)}{P_c}\right)^{-1}\left(\bar{I} / P_c\right).$$

The labour tax rate is thus determined from (32') as a function of the exogenous real energy price, the replacement ratio, the energy tax rate and the endogenously determined real variables.

2.7 Employment Effects of an Energy Tax

The solution of the system obtained from eqs. (30) and (31) takes the form

(34)
$$n_s = \frac{c_7(1-b)}{c_{13}T(.)z(1-b)+z-b},$$
$$n_c = \frac{c_{14}(1-b)zT(.)}{c_{13}T(.)z(1-b)+z-b},$$

where $c_{14} = c_7 c_{13}$ and $\partial n_s / \partial t_e > 0$, $\partial n_c / \partial t_e < 0$. The tax rate on energy will thus always influence the sectoral allocation of employment. A higher energy tax reduces employment in the tradable sector while employment in the sheltered sector increases. The immediate effect is that the demand for employment in the tradable sector drops for given pre-tax wages. This reduces the value of outside opportunities, which induces wage moderation in both sectors. This wage moderation dampens the decline in demand for labour in the tradable sector while the demand for labour in the sheltered sector increases.

The unemployment rate can be derived from (34) together with the labour force identity,i.e, $u = 1 - n_c - n_s$. We obtain:

(35)
$$u = 1 - \frac{(1-b)\left(c_7 + c_{14}zT(.)\right)}{c_{13}T(.)z(1-b)+z-b}.$$

The effect on unemployment of an increase in the energy tax is given as:

(35)
$$\frac{du}{dt_e} = \frac{c_{14}(1-b)z(1-z)}{\left(c_{13}z(1-b)\cdot T(.)+z-b\right)^2} T'\left(t_e\right),$$
$$\begin{aligned} &< 0 \; if \;\; z < 1, \\ &> 0 \; if \;\; z > 1, \\ &= 0 \; if \;\; z = 1. \end{aligned}$$

If wages are equal in the sectors, i.e. z=1, the increased employment in the sheltered sector exactly offsets the fall in employment in the tradable sector. There is thus no effect on the unemployment rate in this case. If, on the other hand, there is a wage premium in the tradable sector, i.e. z<1, there is a possibility of reducing unemployment by increasing the tax on energy. A higher energy tax induces a reallocation of employment from the tradable to the sheltered sector and this have effects on total employment to the extent that the unions' bargaining power in the labour market, or firms' monopoly power in the product market, differ across the two sectors. A reallocation of employment towards the sector where the unions and/or the firms have less market power would thus increase total employment.

3. Welfare Analysis

We will now briefly consider the normative issues. To that end we make use of a utilitarian social welfare function given as the sum of the individual indirect utility functions:

(36) $$SW = n_c \frac{w_c}{P} + n_s \frac{w_s}{P} + u\frac{B}{P} + \frac{\Pi_c}{P} + \frac{\Pi_s}{P} - v(e_c + e_s).$$

n_c and n_s are the number of individuals employed in the tradable and sheltered sectors and u is the number of unemployed. Π_c / P and $\Pi \ / P$ are total real profits in the two sectors and $v(e_c + e_s)$ captures the disutility from the aggregate use of energy.

Substituting the expressions for profits, $\Pi_c = \sum_{h=1}^{k_c^{\bar{h}}} P_{ch} y_{ch} - w_c(1+t_n)n_c - q(1+t_e)e_c$ and $\Pi_s = \sum_{j=1}^{k_s} P_{sj} y_{sj} - w_s(1+t_n)n_s - q(1+t_e)e_s$, into (36) and making use of the government budget restriction in (32) as well as the condition for balanced trade, TB=0, we can rewrite the welfare function as:

(37) $$SW = (1/P)(P_c D_c + P_s D_s) - v(e_c + e_s).$$

The first component is real GDP and the second captures the disutility from the aggregate use of the polluting factor of production. By invoking the expression for the aggregate price level given by (5) and the consumers' demand equations we can write real GDP as:

(38) $$GDP = \left(\frac{\bar{I}}{P_c}\right)\left(\frac{P_s}{P_c}\right)^{\alpha-1}.$$

In order to determine the effect of an energy tax on *GDP* we thus need to determine the effects on the real income in terms of tradeables as well as the relative price of non-tradables. There are a number of effects involved, which are briefly discussed in an appendix. The impact on *GDP* is in general ambiguous.

The equilibrium relationship between total energy consumption and the energy tax, conditional on real income in units of tradables is given by eq. (33). Total energy consumption is reduced by higher energy taxes through the "*T*-effect" as well as by the rise in the real unit cost of energy. There will however also be an impact on real income, which can not be signed in general. Somewhat surprisingly, the general equlibrium effect on energy consumption of a rise in the energy tax is ambiguous.[11]

We have undertaken some numerical simulation experiments to explore the consequences of a tax reform that involves introduction of an energy tax and a concomitant adjustment of the payroll tax so as to keep the government's budget balanced. *Table* 1 presents the results for three different parameter configurations corresponding to three different relative wages. We make no attempt to measure the impact on social welfare since this would require explicit assumptions regarding the valuation of environmental benefits.[12] We focus on the impact on energy consumption (pollution), *GDP* and unemployment.

Total energy consumption is substantially reduced in all experiments that we have performed. It is striking how small the effects on *GDP* and unemployment appear to be for modest energy tax rates, irrespective of the parameter configurations. *GDP* is always reduced when wages are equal across sectors as well as when there is a wage premium in the sheltered sector; the decline amounts to approximately 2 percent when the energy tax rate is increased from zero to 100 percent, allowing a cut in the payroll tax rate of roughly 5 percentage points.

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[11] A similar ambiguity is present in other models as well. Carraro et al (1996) report simulations of energy taxation to control carbon emission using a large general equilibrium model. They find find that there is typically no long run effect on emissions and in some cases the tax reform produces *higher* emission levels.

[12] For particular functional forms of $v(e)$, such as $v(e) = \theta e^{\rho}$, with $\theta > 0$ and $\rho \geq 1$, there exists an *optimal* tax rate on energy in this model.

Table 1. Environmental tax reform with fixed replacement ratios.

z	t_e %	t_n %	n_c/n_s	e	GDP	u %	Double dividend
1	0	5.88	1.174	100.0	100.0	10.53	-
1	25	3.58	1.137	78.72	99.72	10.53	No
1	50	2.10	1.113	64.70	99.19	10.53	No
1	100	0.31	1.083	47.44	97.92	10.53	No
1.25	0	5.67	4.057	100.0	100.0	10.65	-
1.25	25	3.46	3.957	78.30	99.64	10.81	No
1.25	50	2.05	3.892	64.11	99.04	10.92	No
1.25	100	0.33	3.814	46.75	97.66	11.06	No
0.75	0	8.55	0.129	100.0	100.0	11.82	-
0.75	25	5.05	0.114	70.95	100.2	10.91	Yes
0.75	50	3.03	0.105	53.86	99.77	10.36	No
0.75	100	0.81	0.096	35.07	98.28	9.73	No

Notes: The parameters for all cases are as follows: $q/P_c = \bar{\bar{I}} / P_c = k_c = k_s = 1$, $k_c^{\bar{h}} = 0.05$, $b=0.5$. To generate different wages across sectors, the parameters of technology, δ, γ, union bargaining power, λ_c, λ_s, and demand elasticities, σ, μ, are varied. α is used to calibrate an unemployment rate when $z \neq 1$. When $z=1$ the parameters are: $\delta = \gamma = 0.9$, $\lambda_c = \lambda_s = 0.2$, $\sigma = \mu = 5$ and $\alpha = 0.5$. When =1.25 the parameters are: $\delta = \gamma = 0.9$, $\lambda_c = 0.05$, $\lambda_s = 0.6$, $\sigma = 3.5$, $\mu = 8$ and $\alpha = 0.7$. When =0.75 the parameters are: $\delta = 0.95$, $\gamma = 0.6$, $\lambda_c = 0.6$, $\lambda_s = 0.05$, $\sigma = 8$, $\mu = 4$ and $\alpha = 0.15$.

Table 2. Environmental tax reform with fixed real unemployment benefits.

z	t_e	t_n	n_c/n_s	e	GDP	u	Double dividend
1	0	5.89	1.174	100.0	100.0	10.53	-
1	25	3.56	1.137	78.74	99.75	10.51	No
1	50	2.11	1.113	64.70	99.18	10.53	No
1	100	0.44	1.083	47.38	97.80	10.64	No
1.25	0	5.67	4.057	100.0	100.0	10.65	-
1.25	25	3.48	3.957	78.30	99.63	10.82	No
1.25	50	2.11	3.892	64.07	98.98	10.98	No
1.25	100	0.55	3.814	46.66	97.47	11.25	No
0.75	0	8.56	0.129	100.0	100.0	11.82	-
0.75	25	4.73	0.114	71.09	100.5	10.64	Yes
0.75	50	2.72	0.105	53.97	100.1	10.09	No
0.75	100	0.79	0.096	35.09	98.36	9.66	No

: The same parameters as in table 1 are valid for the three different relative wages. The replacement ratio, $B\, w_c$, is used to calibrate the same initial level of unemployment and is hence set to 0.5 initially.

We know from the theory that there will be an employment dividend when there is a wage premium for workers in the tradable sector and the simulations confirm this. In one case, with a modest energy tax rate, there is also a double dividend in the form of a tiny increase in *GDP*. Notice, however, that an increase in the energy tax rate from zero to 100 percent produces a reduction in *GDP* of almost 2 percent despite the decline in unemployment of 2 percentage points.

To what extent are these results sensitive to the benefit regime? We have also considered the case with fixed real unemployment benefits, as opposed to constant replacement ratios; the results are reported in *Table* 2. The results are remarkably similar to those shown in Table 1. There is virtually no effect on unemployment when sectoral wages are equal. We suspect that our specification of labour and energy as cooperant factors is crucial for this result. A reduction in energy usage will reduce the marginal productivity of labour and hence the demand for labour. It is conceivable that a richer production structure (including additional factors of production) may lead to other results.

4. Concluding Remarks

We have examined the impact of an environmental tax reform in an imperfectly competitive small open economy with unemployment in general equilibrium. The reform involves a tax levied on the use of imported energy, where the revenues are recycled to achieve a payroll tax cut. We have focused on the case where real unemployment compensation is indexed to the real consumption wage through a fixed replacement ratio. A key finding is that an environmental tax reform will reduce equilibrium unemployment provided that unions in the tradable sector have a stronger bargaining position than unions in the sheltered sector, resulting in a tradable sector wage premium. If there is a sheltered sector wage premium, the reform will actually increase unemployment.

Although employment gains are theoretically possible, our simulation experiments suggest that they are quantitatively small. Moreover, they do not come without cost, as real *GDP* typically falls when the energy tax is increased. This is also the typical outcome when we consider a benefit regime with fixed real unemployment benefits, as opposed to constant replacement ratios.

How plausible is an outcome where a tradable sector wage premium emerges in equilibrium? It could be argued that firms in the tradable sector in general are unable to exercise much market power; indeed, a popular model of a small open economy features price-taking firms in the tradable sector. Absence of significant product market rents would imply negligible rents in the wage bargains, so a tradable sector wage premium would appear as an unlikely outcome. On the other hand, there are sheltered (service) sectors which produce goods that are close substitutes to goods produced within the households, making the price elasticity of demand quite high. The presence of quasi-fixed capital could also be a source of rents in the wage bargains, presumably in general favouring workers in the tradable sector (as the share of capital is higher there). On balance, however, we do not find substantial tradable sector wage premiums plausible as a long run outcome in a small open economy with international capital mobility. The case for an environmental tax reform as a means to reduce unemployment would therefore seem rather weak. This conclusion is broadly in agreement with recent results reported by Brunello (1996) and Carraro et al (1996) using large-scale econometric general equilibrium models augmented with non-competitive wage setting mechanisms.

References

Bovenberg L and F van der Ploeg (1996), Optimal Taxation, Public Goods and Environmental Policy with Involuntary Unemployment, *Journal of Public Economics* 62, 59-83.

Bovenberg L and F van der Ploeg (1995), Tax Reform, Structural Unemployment and the Environment, Fondazione Eni Enrico Mattei Discussion Paper 6/95.

Brunello G (1996), Labour Market Institutions and the Double Dividend Hypothesis, in C Carraro and D Siniscalco (ed), *Environmental Fiscal Reform and Unemployment*, Kluwer Academic Publishers.

Carraro C, M Galeotti and M Gallo (1996), Environmental Taxation and Unemployment: Some Evidence on the 'Double Dividend Hypothesis' in Europe, *Journal of Public Economics* 62, 141-181.

Edgren G, K-O Faxén and C-E Odhner (1973), *Wage Formation and the Economy*, George Allen & Unwin.

Goulder L (1995), Environmental Taxation and the Double Dividend: A Reader's Guide, *International Tax and Public Finance* 2, 157-183.

Holmlund B (1996), Macroeconomic Implications of Cash Limits in the Public Sector, *Economica* (forthcoming).

Jackman R, R Layard and S Nickell (1996), Combatting Unemployment: Is Flexibility Enough? Discussion Paper No 293, Centre for Economic Performance, London School of Economics.

Johnson G and R Layard (1986), The Natural Rate of Unemployment: Explanation and Policy, in O Ashenfelter and R Layard (eds), *Handbook of Labor Economics*, vol 2, North-Holland.

Kolm A-S (1996), Differentiated Payroll Taxes, Unemployment and Welfare, Working Paper 1996:10, Department of Economics, Uppsala University.

Koskela E and R Schöb (1996), Alleviating Unemployment: The Case for Green Tax Reforms, CES Working Paper No 106, University of Munich.

Layard R, S Nickell and R Jackman (1991), *Unemployment: Macroeconomic Performance and the Labour Market*, Oxford University Press.

Lindbeck A (1979), Imported and Structural Inflation and Aggregate Demand: The Scandinavian Model Reconstructed, in A Lindbeck (ed), *Inflation and Employment in Open Economies*, North-Holland.

Nielsen S B, L H Pedersen and P B Sorensen (1995), Environmental Policy, Pollution, Unemployment and Endogenous Growth, *International Tax and Public Finance* 2, 185-205.

Pissarides C (1990), *Equilibrium Unemployment Theory*, Basil Blackwell.

Pissarides C (1996), Are Employment Tax Cuts the Answer to Europe’s Unemployment Problem, manuscript, Centre for Economic Performance, London School of Economics.

Strand J (1996), Pollution Taxation and Revenue Recycling under Monopoly Unions, Memorandum from Department of Economics, University of Oslo.

Tyrväinen T (1995), Real Wage Resistance and Unemployment, The OECD Jobs Study, Working Paper Series No 10, OECD.

Appendix A

Constants in the Main Text

$$c_1 = \delta^{-\delta}(1-\delta)^{-(1-\delta)}\frac{\sigma}{\sigma-1}$$

$$c_2 = \frac{\sigma-1}{\sigma}\frac{\delta(1-\alpha)}{k_s}$$

$$c_3 = \frac{\sigma-1}{\sigma}\frac{(1-\delta)(1-\alpha)}{k_s}$$

$$c_4 = \frac{\mu}{\mu-1}\gamma^{-\gamma}(1-\gamma)^{-(1-\gamma)}$$

$$c_5 = \left(\frac{\mu}{\mu-1}\right)^{-\mu}\gamma^{\gamma(\mu-1)+1}(1-\gamma)^{(1-\gamma)(\mu-1)}\frac{\alpha}{k_c}$$

$$c_6 = \left(\frac{\mu}{\mu-1}\right)^{-\mu}\gamma^{\gamma(\mu-1)}(1-\gamma)^{(1-\gamma)(\mu-1)+1}\frac{\alpha}{k_c}$$

$$c_7 = 1-\frac{\lambda_c}{(\gamma(\mu-1)+\lambda_c)(1-b)}$$

$$c_8 = \frac{\sigma-1}{\sigma}(1-\delta)(1-\alpha)$$

$$c_9 = \left(\frac{\mu}{\mu-1}\right)^{1-\mu}\gamma^{\gamma(\mu-1)}(1-\gamma)^{(1-\gamma)(\mu-1)}\frac{\alpha}{k_c}k_c^{\bar{h}}$$

$$c_{10} = \left(\frac{\mu}{\mu-1}\right)^{-\mu}\gamma^{\gamma(\mu-1)}(1-\gamma)^{(1-\gamma)(\mu-1)+1}\frac{\alpha}{k_c}k_c^{\bar{h}}$$

$$c_{11} = \left(\frac{\mu}{\mu-1}\right)^{-\mu}\gamma^{\gamma(\mu-1)+1}(1-\gamma)^{(1-\gamma)(\mu-1)}\frac{\alpha}{k_c}k_c^{\bar{h}}$$

$$c_{12} = \frac{\sigma-1}{\sigma}\delta(1-\alpha)$$

$$c_{13} = c_{11}/c_{12}$$

$$c_{14} = c_7 c_{13}$$

Appendix B

The Energy Tax and *GDP*

To determine the effect of an environmental tax reform on real *GDP* we need to consider the effects on real income and the relative price of non-tradables; cf. eq. (38) in the main text. This appendix provides a brief heuristic discussion of some mechanisms involved.

The level of real income is determined by the trade balance condition in (25) for a given level of the real producer wage in the tradable sector. From eqs. (27)-(30) we can derive a relationship between the real producer wage, real income and the energy tax of the form

(B1) $$\frac{w_c\left(1+t_n\right)}{P_c}=\frac{\bar{I}}{P_c}\frac{c_{11}T(.)}{n_c}=\frac{\bar{I}}{P_c}J\left(t_e\right),$$

where $J\left(t_e\right)$ is given by

(B2) $$J\left(t_e\right)=\frac{w_c\left(1+t_n\right)}{\bar{I}}=\frac{c_{11}T(.)+\left(c_{12}/z\right)\left(\frac{z-b}{1-b}\right)}{c_7},$$

and $J'(.)<0$. A rise in the energy tax reduces the demand for labour in the tradable sector, which causes the wage demands in income units to fall. The "*J*-effect" thus reduces the producer wage measured in tradable goods.

By substituting the expression for the tradeble sector's real producer wage (B1) into the trade balance condition (25) we obtain the level of real income in equilibrium as:

(B3) $$\frac{\bar{I}}{P_c}=\left(\frac{I^0}{P_c}\right)^{\frac{1}{1+\gamma(\mu-1)}}T^{\frac{-1}{1+\gamma(\mu-1)}}J^{\frac{-\gamma(\mu-1)}{1+\gamma(\mu-1)}}\left(\frac{q\left(1+t_e\right)}{P_c}\right)^{\frac{-(1-\gamma)(\mu-1)}{1+\gamma(\mu-1)}}.$$

The impact of the energy tax on the trade balance and consequently the real income can be seen as involving effects via the real energy price, the producer wage measured in income units, and *T*. A higher unit cost of energy worsens the trade balance and reduces real income.

However, a higher energy tax reduces the wage demands which will improve the trade balance and consequently increase the real income (the "J-effect"). Recall that there will also be a positive effect on the level of real income due to the direct impact of the "T-effect" on the trade balance; this is due to the fact that the energy tax is separable from real energy prices in the trade balance equation. It turns out to be difficult to draw unambiguous conclusions regarding the effects of the energy tax on the trade balance and consequently on the level of real income.

The relative price of non-tradables is determined in eq. (9). Rewritten as a function of the real producer wage in the tradable sector and the real producer price of energy the relative price is given by

(B4)
$$\frac{P_s}{P_c} = c_1 z^{\delta} \left(\frac{w_c(1+t_n)}{P_c} \right)^{\delta} \left(\frac{q(1+t_e)}{P_c} \right)^{1-\delta},$$

where we have made use of the equilibrium relative wage, i.e., $z \equiv w_s / w_c$. Recall that the real producer wage is determined by (B1) which gives the relative price of non-tradables in equilibrium as

(B5)
$$\frac{P_s}{P_c} = c_1 z^{\delta} J^{\delta} \left(\frac{\bar{I}}{P_c} \right)^{\delta} \left(\frac{q(1+t_e)}{P_c} \right)^{1-\delta},$$

where $\bar{I} / P_c$ is determined in (B3). A higher tax on energy increases the real unit costs of energy which increases the relative price on non-tradables. As a counteracting effect, a higher energy tax reduces the wage demands which cause the real producer wage and hence the relative price on non-tradables to fall. These counteracting effects seem intuitive since the prices of non-tradables are set as a mark-up on marginal costs. In addition, as we previously concluded, the impact on the real income of the energy tax is inconclusive. This leaves the impact of the energy tax on the relative price on non-tradables ambiguous.

In conclusion, then, we have that the effect of the energy tax on the real income is ambiguous due to (i) the positive impact on the trade balance caused by reduced wage demands and the "T-effect", and (ii) the negative impact on the trade balance caused by a higher real producer price on energy. The effect of the energy tax on the relative price is ambiguous as well. This is due to (i) the positive impact caused by reduced wage demands, (ii) the negative impact caused by a higher real producer price on energy, and (iii) the ambiguous impact on the real income.