ELSEVIER

The effects of environmental taxes on income distribution

Vassilis T. Rapanos

Centre of Planning and Economic Research, and Department of Economics, University of Athens, 22, Hippokratous Street, Athens 106 80, Greece

Abstract

The 'polluter pays' principle has gained large popularity recently, as a means of controlling pollution. One set of instruments that is very often proposed for the reduction of pollution is taxes on polluters. This paper examines the effects of consumption taxes, that are imposed on polluting industries, on factor and commodity prices, and output. Our analysis shows that the standard neoclassical models of tax incidence may not be adequate in examining the above effects, and that explicit inclusion of the externality is required.

JEL classification: H23; Q28

Keywords: Pollution; Taxation; Income distribution

1. Introduction

The increasing concern for environmental problems has revived the interest of policy-makers and economists in the theory of externalities and the instruments by which they can be internalized. The efficiency arguments in favour of public intervention to mitigate pollution problems is well established in the theoretical literature. [1] The question that arises, however, is not so much whether there should

---

[1] For a standard and comprehensive review of the literature see, for example, Baumol and Oates (1988).

be government intervention or not, but rather which modes of intervention should the government focus on, so that a first or second best situation is achieved. [2]

The basic instruments that a government can employ to reduce the damages from pollution can be classified in three main categories: market based instruments (MBIs), command and control measures (CACM), and government production or expenditure.

In the past, the most widely used instruments could be considered as belonging to the second and third categories, while the market based incentives were used only to a limited extent. However, the recent more conservative trend in economic policy for less regulatory interventions, but also the interest for a cost effective set of policy instruments, has turned the attention of economists and policy-makers to the market based instruments. One basic advantage of the MBIs is that they work through the market, and are cheaper to manage than the CACM.

By now the economic literature is very rich on how MBIs (like taxes, subsidies, tradeable permits, etc.) can be used so that the inefficiencies caused by pollution, and external diseconomies in general, are minimized. Much less has been done, however, in the area of the distributional aspects of these policy measures, both at the theoretical and the empirical level. At the empirical level, these aspects have recently drawn the attention not only of economists but also of international organisations like the OECD (1994). At the theoretical level, the study of the distributional aspects of the various instruments, and in particular of taxes, has been rather limited. One reason may be that the theoretical literature on tax incidence is already very large, and therefore its results could be applied to the incidence of pollution taxes. [3] This is not so, however, as we shall attempt to show in the following analysis. [4] The 'polluter pays principle', which seems to be widely accepted by economists and politicians, has to be examined, therefore, from the point of view of its distributional effects.

The purpose of this paper is to examine the incidence effects of a tax which is imposed on the consumption of a commodity, with the aim of reducing the pollution generated by the production activity of that commodity, and which affects negatively the production of some other goods. Our analysis will be limited to the examination of a consumption tax, for example the value added tax or another excise tax, and will not deal with other taxes such as factor-income taxes. In a relatively recent paper, Rapanos (1992) has examined the incidence of the corporation income tax in the presence of externalities. The results of that paper,

---

[2] When there are few polluters and victims and when the number of beneficiaries from an agreement is given, the Coase (1960) proposition for no government intervention could be relevant. We assume, however, that this is not the case in our analysis.

[3] For a rather comprehensive review of the literature on tax incidence see Kotlikoff and Summers (1987).

[4] For a recent review of the literature on environment and taxation see Smith (1992). With regard to the incidence of pollution control measures, see Yohe (1979) and Rapanos (1992).

however, may be rather theoretical from a policy point of view, since the taxes that are usually proposed or exist for combatting pollution are mainly excises, for example taxes on plastic bags, fossil fuels, fertilizers, pesticides, mercury–cadmium batteries, etc. [5]

Moreover, pollution taxes is an issue that is hotly debated in parliaments and other fora mainly for their distributional aspects. Some analysts argue that the rather limited application of pollution taxes is due to the political resistance of industrialists, and even consumers since the imposition of taxes will affect both profits and commodity prices. A further political shortcoming of pollution taxes, particularly for environmentalists, is that they appear to give industry a 'licence to pollute'. This probably explains why the CAC measures or the marketable pollution permits are more popular among politicians, but also among many pressure groups or environmental lobbies. [6] The identification of gainers and losers is, therefore, a necessary step towards a positive investigation of environmental policies.

In Section 2 of the paper, we set out the main features of our model and derive some basic relationships in terms of proportional changes. In Section 3, we examine the effects of a consumption tax on income distribution in the short run. As a short run, we consider the case where some factors of production are not easily shiftable from one sector to the other. In Section 4, we consider the longer-run effects of this tax, where all factors of production are perfectly mobile between productive activities. In both cases, we shall consider the tax incidence in the framework of a small open economy, and a large open economy. The latter case will be approximated through the analysis of a closed economy. Finally, we summarise the basic findings of our analysis, and make some comparisons with the results derived in the 'standard' approach of tax incidence.

2. The basic structure of the model

The basic framework of our analysis is the general equilibrium, two-sector model, as developed by Jones (1965) and Jones (1971), and extended by Herberg et al. (1982).

We consider an economy which produces two final goods X_1 and X_2. Each commodity requires in its production process two factors of production: capital (K), which is specific to each activity, and labour (L), which is intersectorally mobile. In the longer run, however, capital will be also mobile between sectors. We further assume that the factors of production are inelastically supplied, and perfect competition prevails in all markets. It is also assumed that there are no

---

[5] For more details see OECD (1989).

[6] For further details see Dewees (1992).

other distortions in the economy, with the exception of pollution. The production function of the first commodity exhibits constant returns to scale, has the usual properties, and can be written as follows:

$$X_1 = F_1(K_1, L_1).$$ (1)

With regard to the second sector, we assume that the production process of the first commodity affects negatively the production of the second commodity. In other words, we assume that the production process of the first commodity generates an externality (pollution in our case) which enters into the production function of the second commodity. For the sake of simplicity, we assume that the pollution generated is directly related to the production of X_1, and the amount of X_1 produced can be considered as a proxy for the amount of pollution. The form of this externality is considered to be that of the public good nature. [7] As an example of this type of externality one could think of industrial activities which affect negatively tourism or agriculture. The production function of the second commodity can be, therefore, written as follows:

$$X_2 = g(X_1) F_2(K_2, L_2)$$ (2)

where g is a continuous function, twice differentiable which describes the role of the externality. F_2 is a linearly homogeneous function in capital and labour, and has the usual properties. [8] The pollution is, therefore, considered to be external to the firms of the second industry, but internal to that industry, and as a result all the output of that sector is distributed to K_2 and L_2.

The full employment and zero profit conditions in the short run are given by the following relationships:

$$L_1 + L_2 = \bar{L},$$ (3)

$$K_1 = \bar{K}_1,$$ (4)

$$K_2 = \bar{K}_2,$$ (5)

$$w_i L_i + r_i K_i = p_i X_i,$$ (6)

where w_i and r_i are the returns to labour and capital in the ith sector respectively, and p_i is the producer price of the ith commodity. Given the perfect intersectoral mobility of labour the wage rates should equalize across sectors, so that $w_1 = w_2 = w$, while the absence of capital mobility implies that, in general, r_1 is different from r_2. Over the longer run, as we shall see later, $r_1 = r_2$ since capital will be also intersectorally mobile.

---

[7] For the distinction between the different forms of externalities, see the classic article of Meade (1952).

[8] For more details on the shape and the properties of the production functions, see Herberg et al. (1982, pp. 67–70).

It is well-known that in the presence of pollution the competitive system does not yield an optimum outcome. The government, in order to correct the detrimental effects of pollution, levies a tax on the consumption of the commodity that generates the pollution. In the following analysis, we abstract from the normative aspects of taxation and do not examine whether this tax restores a first-best or a second-best optimum, but deal only with the incidence aspects of it. Suppose that the, ad valorem, tax rate is t, so that the consumer price of X_1 is

$$q_1 = p_1(1 + t) = p_1 T \tag{7}$$

where q_i is the consumer price of commodity X_i $(i = 1,2)$, and since the tax is imposed on the first commodity only, we have that the consumer and producer prices of X_2 coincide, i.e. $q_2 = p_2$.

Following Herberg et al. (1982), we define the degree of the negative effect of pollution on X_2 as follows:

$$s = (\mathrm{d}g/\mathrm{d}X_1)(X_1/g). \tag{8}$$

Since the effect of the production of X_1 on X_2 is detrimental, s is negative. If g is linear in X_1, a rather common assumption in the environmental economic literature, then $s = -1$. If we assume, however, that the negative effects on X_2 are not very strong so that an increase in X_1 by, say, 10% reduces X_2 by less than 10%, it seems plausible to assume that $0 < |s| < 1$.

Totally differentiating Eqs. (1)–(7), and assuming cost minimization, we obtain: [9]

$$X_1^* = \Theta_{L1} L_1^* + \Theta_{K1} K_1^*, \tag{9}$$

$$X_2^* = s X_1^* + \Theta_{L2} L_2^* + \Theta_{K2} K_2^*, \tag{10}$$

$$\lambda_{L1} L_1^* + \lambda_{L2} L_2^* = L^* = 0, \tag{11}$$

$$K_1^* = 0, \tag{12}$$

$$K_2^* = 0, \tag{13}$$

$$\Theta_{L1} w^* + \Theta_{K1} r_1^* = p_1^* = q_1^* - T^*, \tag{14}$$

$$\Theta_{L2} w^* + \Theta_{K2} r_2^* = p_2^* + s X_1^*, \tag{15}$$

where an asterisk $(*)$ indicates proportional change i.e. $x^* = \mathrm{d}x/x$, λ_{ji} is the fraction of the jth factor employed in sector i, Θ_{ji} is the distributive share of factor j in the output of sector i, $\lambda_{j1} + \lambda_{j2} = 1$, and $\Theta_{Li} + \Theta_{Ki} = 1$ $(i = 1,2; j = L,K)$.

The elasticity of substitution between factors of production (σ_i) can be defined as follows:

$$\sigma_i = (K_i^* - L_i^*)/(w^* - r_i^*). \tag{16}$$

---

[9] For more details see appendix.

On the demand side of the economy, we assume that consumers have identical and homothetic preferences, and that the tax proceeds are distributed to the consumers in a lump-sum manner, so that we have

$$X_1^* - X_2^* = -\sigma_D(q_1^* - q_2^*) \tag{17}$$

where σ_D is the elasticity of substitution between commodities in consumption. In the case of a small open economy, however, prices are exogenously determined, and demand conditions do not matter. With $q_1^* = q_2^* = 0$, we have a system of nine Eqs. (9)–(16), with nine unknowns. We can, therefore, proceed to the examination of the consumption tax on the distribution of income between capital and labour.

3. Taxation and the distribution of income in the short run

3.1. The small country case

By assuming that commodity prices are set exogenously, we can get from Eqs. (9)–(16), after substitution of (12), (13), and (16) into (9), (10), (11), and then (9) into (15), the following relationships:

$$(\lambda_{L1}\sigma_1 + \lambda_{L2}\sigma_2)w^* - \lambda_{L1}\sigma_1 r_1^* - \lambda_{L2}\sigma_2 r_2^* = 0, \tag{18}$$

$$\Theta_{L1}w^* + \Theta_{K1}r_1^* = -T^*, \tag{19}$$

$$(\Theta_{L2} + s\Theta_{L1}\sigma_1)w^* - s\Theta_{L1}\sigma_1 r_1^* + \Theta_{K2}r_2^* = 0. \tag{20}$$

Solving Eqs. (18)–(20), we obtain:

$$w^* = -(\sigma_1/D')(\lambda_{L1}\Theta_{K2} + s\lambda_{L2}\Theta_{L1}\sigma_2)T^*, \tag{21}$$

$$r_1^* = -(1/D')(\lambda_{L1}\Theta_{K2}\sigma_1 + \lambda_{L2}\sigma_2 + s\lambda_{L2}\Theta_{L1}\sigma_1\sigma_2)T^*, \tag{22}$$

$$r_2^* = (\sigma_1/D')(\lambda_{L1}\Theta_{L2} - s\lambda_{L2}\Theta_{L1}\sigma_2)T^*, \tag{23}$$

where $D' = \lambda_{L1}\Theta_{K2}\sigma_1 + \lambda_{L2}\Theta_{K1}\sigma_2 + s\lambda_{L2}\Theta_{L1}\sigma_1\sigma_2$. Following Panagariya (1986), we can show that stability requires that $D' > 0$.

With $D' > 0$, we observe that the imposition of the tax reduces the rental to capital in the taxed sector, and raises the return to capital in the other sector. With respect to the wage rate it will fall as long as the externality effect is not very strong and σ_2 is not very large. If however, the externality effect is very strong and σ_2 is also large, then the wage rate may even rise. From (21)–(23), it can be readily established that $w^* - r_1^* > 0$, and $w^* - r_2^* < 0$.

An intuitive explanation for these changes could be the following. The imposition of the consumption tax on the polluting industry reduces the producer price of the taxed commodity. As a result the returns to factors of production there fall, and since labour is mobile it will move to the untaxed sector where its return is higher.

This move however, reduces the marginal productivity of capital in the first sector and raises that of the second sector. Labour by being able to move avoids some of the tax and the wage rate changes by less than the change of the tax, while the return to capital in the polluting sector falls by more than the tax change. Similarly, r_2 rises by less than the change in the tax rate. If, however, the externality effect is very strong and σ_2 is large, then the increase in the productivity of the second sector may be large enough to outweigh the fall in the wage rate caused by the tax.

It is worth noting that because of its nature, the externality affects all factors of production equiproportionately (by the factor $s\lambda_{L2}\Theta_{L1}\sigma_1\sigma_2$). As a result the relative factor-price changes are not affected qualitatively by the presence of pollution, but only quantitatively.

3.2. The large country case

If the economy in consideration is a large open economy (or a closed one), then commodity-prices are determined endogenously, and we have, therefore, to take into account the demand conditions. [10]. Making use of (16) and (17), and after some substitutions into Eqs. (9)–(15), we obtain: [11]

$$-(\Theta_{K1} + s\Theta_{L1}\sigma_1)(w^* - r_1^*) + \Theta_{K2}(w^* - r_2^*) - (q_1^* - q_2^*) = -T^*,$$
(24)

$$-(1-s)\Theta_{L1}\sigma_1(w^* - r_1^*) + \Theta_{L2}\sigma_2(w^* - r_2^*) + \sigma_D(q_1^* - q_2^*) = 0,$$
(25)

$$\lambda_{L1}\sigma_1(w^* - r_1^*) + \lambda_{L2}\sigma_2(w^* - r_2^*) = 0.$$
(26)

Solving simultaneously Eqs. (24)–(26), we get:

$$w^* - r_1^* = (1/D)\lambda_{L2}\sigma_2\sigma_D T^*,$$
(27)

$$w^* - r_2^* = -(1/D)\lambda_{L1}\sigma_1\sigma_D T^*,$$
(28)

$$q_1^* - q_2^* = (1/D)\sigma_1\sigma_2[\lambda_{L2}\Theta_{L1}(1-s) + \lambda_{L1}\Theta_{L2}]T^*,$$
(29)

where $D = \sigma_D(\lambda_{L2}\Theta_{K1}\sigma_2 + \lambda_{L1}\Theta_{K2}\sigma_1) + \sigma_1\sigma_2(\lambda_{L2}\Theta_{L1} + \lambda_{L1}\Theta_{L2}) + s\sigma_1\sigma_2\lambda_{L2}\Theta_{L1}(\sigma_D - 1)$. Following Panagariya (1986) as before, it can be shown that stability requires that $D > 0$.

---

[10] As it was pointed out to me by one referee, the large open economy case is not identical to the closed economy case. The latter may be an approximation of the former. Nevertheless, the elasticity σ_D can stand as it is although it has a different interpretation, since it is not an elasticity of consumption but it depends, in a very complicated way, on domestic and foreign preferences, and on foreign technology and factor allocation. For a similar approach see Neary (1978).

[11] For further details see the appendix.

We can see from Eqs. (27)–(29), that the wage rate rises relative to the return of capital in the polluting industry, but falls relative to the return of capital in the non-polluting industry. Thus, most of the results derived for the small open economy still hold, at least qualitatively. With regard to the price of the taxed commodity, it will rise relative to the price of the untaxed commodity. The question that immediately arises is whether these results differ from those derived in the model without externalities (Bhatia, 1989). With regard to relative factor-price changes, we observe that the externality (pollution) effect (s) is not present in the numerator of Eqs. (27)–(28), but it is in the denominator D. Our results with regards to factor-prices are, therefore, qualitatively the same as those of the standard model, but differ quantitatively. It is also clear that if the elasticity of substitution between the two commodities in consumption (σ_D) is equal to one, then the denominator becomes $D'' = \sigma_D(\Theta_{K1}\lambda_{L2}\sigma_1 + \Theta_{K2}\lambda_{L1}\sigma_1) + \sigma_1\sigma_2(\Theta_{L1}\lambda_{L2} + \Theta_{L2}\lambda_{L1})$, as in the standard case. In other words, in such a case, the presence of pollution does not affect the distribution of income between labour and capital. If σ_D is different from one, the changes in the relative factor-prices are affected by the presence of pollution, positively or negatively according to whether σ_D is greater or smaller than one.

In order to see the importance played by the presence of the pollution and its interaction with the magnitude of σ_D, let us consider the following case. Suppose that $\sigma_D < 1$. This makes the last term in D, namely the term $s\sigma_1\sigma_2\lambda_{L2}\Theta_{L1}(\sigma_D - 1)$, positive, which implies that the value of (27) is less than in the case where pollution is absent. In other words, the pollution effect dampens the increase in the wage rate relative to the return to capital in the polluting sector. An intuitive explanation for this effect could be the following: The imposition of the tax reduces the output of the polluting sector, and therefore labour is shifted from that sector to the non-polluting sector. This raises the capital–labour ratio in the first sector, and the w/r_1 rises. The pollution, however, reduces this output effect for the following reason. The reduction of the detrimental effect of pollution raises the productivity of the non-polluting sector leading to a reduction of the unit costs, and the relative price of X_2. With $\sigma_D < 1$, the increase in demand for X_2 is less than the productivity gain, and therefore the increase in the demand for labour in the non-polluting sector is less than in the case with no pollution. As a result the w/r_1 rises by less than in the standard case without pollution. The opposite is true for $\sigma_D > 1$.

From Eq. (29) we have that the price of the taxed commodity will rise relative to the price of the untaxed good. Even if $\sigma_D = 1$ the presence of pollution makes this increase higher than in the standard case (without pollution). It can be also shown that the tax policy is effective in reducing pollution, since the latter is directly related to the production of commodity X_1. With the supply of capital been fixed we have, from the definition of the elasticity of substitution, that

$$L_1^* = -\sigma_1(w^* - r_1^*). \tag{30}$$

Making use of (27), (30), and (9), we get

$$X_1^* = -(1/D)(\sigma_1 \sigma_2 \sigma_D \lambda_{L2} \Theta_{L1})T^*. \tag{31}$$

As Eq. (31) reveals the production of X_1 will fall, and as a consequence the amount of pollution will also fall. Thus, the consumption tax is effective in reducing pollution.

In order to see more clearly the effects of pollution on factor rewards, we shall assume that all elasticities are equal to one, i.e $\sigma_D = \sigma_1 = \sigma_2 = 1$, and that X_2 is the numeraire so that $q_2^* = 0$. Under these assumptions, $D = 1$, and therefore: [12]

$$r_1^* = -(\lambda_{L1}\Theta_{K2} + \lambda_{L2} + s\lambda_{L2}\Theta_{L1})T^*, \tag{32}$$

$$r_2^* = (\lambda_{L1}\Theta_{L2} - s\lambda_{L2}\Theta_{L1})T^*, \tag{33}$$

$$w^* = -(\lambda_{L1}\Theta_{K2} + s\lambda_{L2}\Theta_{L1})T^*, \tag{34}$$

$$q_1^* = (\lambda_{L1}\Theta_{L2} + \lambda_{L2}\Theta_{L1} - s\lambda_{L2}\Theta_{L1})T^*. \tag{35}$$

It is clear that the damage caused by the pollution affects all factor rewards and the price of the polluting good positively, and by the same factor $(-s\lambda_{L2}\Theta_{L1})$. An intuitive explanation may be the following: In the absence of pollution the imposition of the tax would raise the return of capital in the untaxed sector, and would reduce the return to capital in the taxed sector and the wage rate. In the presence of pollution, however, things change since the reduction of the output of the taxed sector also reduces pollution and as a result the productivity of the untaxed sector is increased, leading to a reduction of the unit costs and the relative price of X_2 more and in above of the reduction in the standard case (without pollution). With $\sigma_D = 1$ a reduction of X_1 by one unit will be substituted by one unit of X_2. This will drive labour out of the first sector to the second one, but the quantity will be less than in the absence of pollution since the reduction of X_1 raises the productivity in the second sector. The outcome of this process is that the return to capital in the first sector will be reduced by less than otherwise, and the same holds for the capital in the second industry. With respect to labour, it is possible as we mentioned above to gain, by having the wage rate rising because of the strong externality effect. With σ_D different from one, the results will be quantitatively different but a similar interpretation can be provided.

The differential of returns to capital in the two sectors will be an incentive, over the longer run, for relocation of that factor until its returns are equalized across sectors. If all factors of production are perfectly mobile between sectors, then the

---

[12] With $q_2^* = 0$, we have the value of q_1^* from (29), and can calculate the value of $q_1^* - T^*$. Substitute this and (27) into (14), we can get the value of r_1^*. Similarly, we can obtain the value for r_2^*, and w^*.

above results will change, and it is this aspect that will be examined in the next section.

4. The model in the long run

When all factors of production are perfectly mobile intersectorally, their net returns will be equalized across sectors so that $w_1 = w_2 = w$ and $r_1 = r_2 = r$. With capital mobility, we also have that $K_1 + K_2 = K$, and after some substitutions and manipulations, we can obtain the basic relationships for the small country and the large country case respectively. [13]

4.1. The small open economy

With $q_1^* = q_2^* = 0$, we can get the following basic relationships:

$$\Theta_{L1}w^* + \Theta_{K1}r^* = -T^*, \tag{36}$$

$$\left[\lambda\Theta_{L2} - s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)\right]w^* + \left[\lambda\Theta_{K2} + s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)\right]r^* = 0, \tag{37}$$

where $\lambda = \lambda_{L1}\lambda_{K2} - \lambda_{K1}\lambda_{L2} = \lambda_{L1} - \lambda_{K1}$, $\Theta = \Theta_{L1}\Theta_{K2} - \Theta_{L2}\Theta_{K1} = \Theta_{L1} - \Theta_{L2}$, $\delta_L = \lambda_{L1}\Theta_{K1}\sigma_1 + \lambda_{L2}\Theta_{K2}\sigma_2$, and $\delta_K = \lambda_{K1}\Theta_{L1}\sigma_1 + \lambda_{K2}\Theta_{L2}\sigma_2$.

The solution of (36)–(37) is straightforward, and yields:

$$w^* = (-1/\Delta')\left[\lambda\Theta_{K2} + s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)\right]T^*, \tag{38}$$

$$r^* = (1/\Delta')\left[\lambda\Theta_{L2} - s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)\right]T^*, \tag{39}$$

where $\Delta' = \lambda\Theta + s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)$. Following Neary (1978), it can be easily shown that the stability of the system requires that $\Delta' > 0$.

It is obvious that the change in factor-prices depends on the relative factor intensities of the two sectors and the strength of the externality effect. The direction of change, however, depends solely on factor intensities. Suppose, for example, that the polluting industry is relatively labour intensive, i.e. $\lambda > 0$, and $\Theta > 0$. Since $\Delta' = \lambda(\Theta_{K2} - \Theta_{K1}) + s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K) > 0$, it implies that $\lambda\Theta_{K2} + s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K) > 0$, which means that the wage rate falls because of the tax, and the return to capital rises. If, on the other hand, the polluting industry is relatively capital intensive the above results will be reversed.

The question that now arises is what happens to the above results if we relax the assumption of the small open economy. This is examined in the following section.

---

[13] For a detailed derivation see the appendix.

4.2. The large open economy

With commodity prices determined endogenously, we can obtain after some manipulations the following relationships:

$$\lambda(X_1^* - X_2^*) - [\delta_L(1 - s\lambda_{K2}) + \delta_K(1 - s\lambda_{L2})](w^* - r^*) = 0, \qquad (40)$$

$$[\lambda\Theta + s(\lambda_{K2}\delta_L + \lambda_{K2}\delta_K)](w^* - r^*) - \lambda(q_1^* - q_2^*) = -\lambda T^*, \qquad (41)$$

$$X_1^* - X_2^* + \sigma_D(q_1^* - q_2^*) = 0. \qquad (42)$$

Solving simultaneously Eqs. (40)–(42) for relative factor and commodity price changes, $w^* - r^*$ and $q_1^* - q_2^*$, we obtain:

$$w^* - r^* = (-1/\Delta)\lambda\sigma_D T^*, \qquad (43)$$

$$q_1^* - q_2^* = (1/\Delta)[\delta_L + \delta_K - s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)]T^*, \qquad (44)$$

where $\Delta = \lambda\Theta\sigma_D + \delta_L + \delta_K + s(\sigma_D - 1)(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)$. Following Neary (1978), we can show that Δ is positive, so that the stability of the system is assured.

It is clear from Eq. (43) that the incidence of the consumption tax depends solely on relative factor intensities, as in the case of the Harberger (1962) model, with consumption taxes. If $\lambda > 0$, that is the polluting sector is relatively labour intensive, then labour bears the burden of the tax by more than its relative share in the income of that sector, and vice versa with $\lambda < 0$. There is a difference, however, with the results of Harberger's model, since the denominator Δ includes an externality factor, which is absent in that. A first observation is that if σ_D is equal to one, the externality factor vanishes, that is, the presence of pollution does not affect tax incidence, and the results of the Harberger (1962) model carry through. [14] If, however, σ_D is different from one then the change in the relative factor-price will be quantitatively different from Harberger's results. With respect to the relative commodity-price changes we observe that, even with $\sigma_D = 1$, the price of the taxed commodity will rise by more than in the case without pollution.

Expressing factor and commodity-price changes in terms of X_2, which is taken as the numeraire ($p_2^* = q_2^* = 0$) we obtain:

$$w^* = -(\sigma_D/\Delta)[\lambda\Theta_{K2} + s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)T^*, \qquad (45)$$

$$r^* = (\sigma_D/\Delta)[\lambda\Theta_{L2} - s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)T^*, \qquad (46)$$

$$q_1^* = (1/\Delta)[\delta_L + \delta_K - s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)T^*. \qquad (47)$$

As in the short run, we observe that the pollution affects all prices by the same factor $s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)$ and positively. In other words, the externality effect favours equally both labour and capital, and leads to an increase in the price of the

---

[14] For a similar result see Rapanos (1992).

taxed good by more than in the absence of the externality. An intuitive explanation for the above results could be similar as in the case of the short-run model.

With regard to the effect of the tax on the output of the polluting sector, we can get, after some manipulation, that

$$X_1^* = (-\sigma_D/\Delta)\left[\lambda_{L2}\Theta_{L1}(\lambda_{K1}\sigma_1 + \lambda_{K2}\sigma_2)\right.$$
$$\left. + \lambda_{K2}\Theta_{K1}(\lambda_{L1}\sigma_1 + \lambda_{L2}\sigma_2)\right]T^*. \tag{48}$$

It is clear, as in the short run, that the imposition of a consumption tax on the polluting sector leads to a reduction of its output, and therefore to the pollution generated by that sector.

5. Concluding remarks

In this paper we have attempted to examine the distributional effects of a consumption tax, that is imposed on a commodity that generates pollution in its production process. More specifically, we have assumed that the pollution takes the form of a producer–producer externality. Our basic findings show that the standard framework of analysis of tax incidence, as developed by Harberger (1962), and further extended by Mieszkowski (1967) and Bhatia (1989), is not adequate for the analysis of pollution taxes.

Our analysis has shown that the imposition of the tax leads to changes in relative factor and commodity-prices which may be qualitatively similar to those derived by Mieszkowski and Bhatia, but quantitatively they are quite different. The only case in which our results coincide with those of the above mentioned authors is when the elasticity of substitution between commodities in consumption is equal to one. With regard to the relative commodity-price changes, our analysis has revealed that the presence of pollution leads to an increase in the price of the taxed commodity that is higher than in the case without pollution, even when the elasticity of substitution between commodities in consumption is equal to one.

In addition to the change in relative factor and commodity prices, we have also examined their changes in terms of the numeraire. In all cases that we have studied, the presence of pollution affects factor and commodity-prices, and it may reverse some of the results derived by Mieszkowski and Bhatia. This depends on the strength of the pollution effect, the relative factor intensities and factor substitutability.

The preceding analysis has helped us to better understand the 'polluter pays principle', in the framework of a simple two-sector general equilibrium model. In order to see more clearly whether the taxes are paid by capitalists or workers, let us assume that capital is owned only by capitalists, and that they do not have incomes from labour. Similarly, suppose that the workers have no other income but their wages. In such a case, in the short run, the pollution tax will be born

mainly by the owners of capital of the polluting industry, and to a lesser extent by labour, but the capitalists of the non-polluting industries will benefit from this tax. In the longer run, however, the tax incidence depends on relative factor intensities. If the polluting industry is relatively capital intensive, then it is the capitalists who will bear the tax burden, while if that industry is relatively labour intensive the burden of the tax will be born by the workers. In reality, however, things are more complicated, since capitalists may also have income from labour and many workers have shares of capital in many industries. Despite these complications, our analysis could be considered as a useful step in better understanding the concept of the 'polluter pays' principle.

6. Acknowledgment

Appendix A

A.1. The model in the short run

Differentiating totally Eq. (2), yields

$$\mathrm{d}X_2 = (\partial g/\partial X_1)\mathrm{d}X_1.F_2(.) + g(.)\left[(\partial F_2/\partial K_2)\mathrm{d}K_2 + (\partial F_2/\partial L_2)\mathrm{d}L_2\right].$$

Dividing both sides by X_2, making use of (8), and the fact that F_2 is linearly homogeneous, we get Eq. (10) of the text. In the same way we can get Eq. (9)

Similarly, differentiate (6) to get for the second industry

$$L_2\mathrm{d}w + w\mathrm{d}L_2 + K_2\mathrm{d}r_2 + r_2\mathrm{d}K_2 = X_2\mathrm{d}p_2 + p_2\mathrm{d}X_2$$

and with some manipulations, we have that

$$\Theta_{L2}w^* + \Theta_{K2}r^* + \Theta_{L2}L_2^* + \Theta_{K2}K_2^* = p_2^* + X_2^*.$$

If we substitute Eq. (10) into the above relationship, we can obtain Eq. (15) of the text.

Making use of the assumption that the capital is specific in each sector, i.e. $K_1^* = K_2^* = 0$, and of Eq. (16), we can rewrite Eqs. (9) and (10) as follows:

$$X_1^* = -\Theta_{L1}\sigma_1(w^* - r_1^*), \tag{A.1}$$

$$X_2^* = -\Theta_{L2}\sigma_2(w^* - r_2^*) - s\Theta_{L1}\sigma_1(w^* - r_1^*). \tag{A.2}$$

Substituting (A.1) into (15) we obtain

$$(\Theta_{L2} + s\Theta_{L1}\sigma_1)w^* + \Theta_{K2}r_2^* - s\Theta_{L1}\sigma_1 r_1^* = q_2^*. \tag{A.3}$$

Subtracting (A.3) from (14) we obtain Eq. (24) of the text.

From Eqs. (A.1) and (A.2) we get

$$X_1^* - X_2^* = \left[\Theta_{L2}\sigma_2 + (s-1)\Theta_{L1}\sigma_1 \right] w^* - \Theta_{L2}\sigma_2 r_2^* + (1-s)\Theta_{L1}\sigma_1 r_1^*.$$

(A.4)

Equating (A.4) and (17), we obtain Eq. (25) of the text.

Finally, making use of (11) and (16) and the fact that capital is specific to each sector, we can obtain Eq. (26).

In the case of the small open economy, we have Eq. (18) which is the same as (26), Eq. (20) which is (A.3) with $q_2^* = 0$, and Eq. (19) which is the same as (14) with $q_1^* = 0$.

A.2. The model in the longer run

The full employment condition for capital, when it is intersectorally mobile implies

$$\lambda_{K1}K_1^* + \lambda_{K2}K_2^* = K^* = 0.$$

(A.5)

Making use of the full employment conditions for labour and capital, (11) and (A.5), and Eq. (16), we can solve for L_1^*, K_1^*, L_2^*, and K_2^* in terms of $(w^* - r^*)$, so that we have

$$L_1^* = -(\lambda_{L2}/\lambda_{L1})L_2^* = (\lambda_{L2}/\lambda)(\lambda_{K1}\sigma_1 + \lambda_{K2}\sigma_2)(w^* - r^*), \qquad \text{(A.6)}$$

$$K_1^* = -(\lambda_{K2}/\lambda_{K1})K_2^* = (\lambda_{K2}/\lambda)(\lambda_{L2}\sigma_2 + \lambda_{L1}\sigma_1)(w^* - r^*). \qquad \text{(A.7)}$$

Substituting (A.6) and (A.7) into Eqs. (9) and (10), we obtain:

$$L_1^* = X_1^* - \Theta_{K1}\sigma_1(w^* - r^*), \qquad \text{(A.8)}$$

$$L_2^* = X_2^* - \Theta_{K2}\sigma_2(w^* - r^*) - sX_1^*, \qquad \text{(A.9)}$$

$$K_1^* = X_1^* + \Theta_{L1}\sigma_1(w^* - r^*), \qquad \text{(A.10)}$$

$$K_2^* = X_2^* + \Theta_{L2}\sigma_2(w^* - r^*) - sX_1^*. \qquad \text{(A.11)}$$

Making use of the full employment conditions, we can solve for X_1^* and X_2^*, in order to get

$$X_1^* = (1/\lambda)(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K)(w^* - r^*), \qquad \text{(A.12)}$$

$$X_2^* = -(1/\lambda)\left[(\lambda_{L1} - s\lambda_{L2})\delta_K + (\lambda_{K1} - s\lambda_{K2})\delta_L \right](w^* - r^*). \qquad \text{(A.13)}$$

For the small country case, substituting (A.12) into (15) yields Eq. (37) of the text. Eq. (36) is the same as (19).

With variable commodity prices, subtract (A.13) from (A.12) to get Eq. (40) of the text. Also, substituting the value for X_1^* into Eq. (15), and in combination with (14) we obtain Eq. (41). Eq. (42) is a reproduction of (17).

References

Baumol, W.J. and W.F. Oates, 1988, The theory of environmental policy (Cambridge University Press, London).

Bhatia, K.B., 1989, Short run and long run in the theory of tax incidence, Public Finance/Finances Publiques 44, 343–360.

Coase, R.H., 1960, The problem of social cost, Journal of Law and Economics 3, 1–44.

Dewees, D.N., 1992, Taxation and the environment, in: R.M. Bird and J.M. Mintz, eds., Taxation to 2000 and beyond, Canadian Tax Papers No 93 (Canadian Tax Foundation).

Harberger, A.B., 1962, The incidence of the corporation income tax, Journal of Political Economy 70, 215–240.

Herberg, H., M., Kemp and M. Tawada, 1982, Further implications of variable returns to scale, Journal of International Economics 13, 65–84.

Jones, R.W., 1965, The structure of simple general equilibrium models, Journal of Political Economy 73, 557–572.

Jones, R.W., 1971, A three-factor model in theory, trade, and history, in: J.N. Bhagwati et al., eds., Trade, balance of payments, and growth: Papers in international economics in honour of C. P. Kindleberger (North-Holland, Amsterdam).

Kotlikoff, L. and L. Summers, 1987, Tax incidence, in: A. Auerbach and M. Feldstein, eds., Handbook of public economics (North-Holland, Amsterdam).

Meade, J.E., 1952, External economies and diseconomies in a competitive situation, Economic Journal 62, 54–67.

Mieszkowski, P.M., 1967, On the theory of tax incidence, Journal of Political Economy 75, 250–262.

Neary, J.P., 1978, Dynamic stability and the theory of factor-market distortions, American Economic Review 88, 671–682.

OECD, 1989, Economic instruments for environmental protection (OECD, Paris).

OECD, 1994, The distributive effects of economic instruments for environmental policy (OECD, Paris).

Panagariya, A., 1986, Increasing returns and the specific factor model, Southern Economic Journal 53, 1–17.

Rapanos, V.T., 1992, A note on externalities and taxation, Canadian Journal of Economics 25, 226–232.

Smith, S., 1992, Taxation and the environment: A survey, Fiscal Studies 13, 21–57.

Yohe, G.W., 1979, The backward incidence of pollution control: Some comparative statics in general equilibrium, Journal of Environmental Economics and Management 6, 187–198.