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# The Effects of Environmental Taxes on Income Distribution

by

V. RAPANOS

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Vassilis Rapanos
Centre of Planning and Economic Research and
Department of Economics, University of Athens

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**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.

## 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 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.

At the theoretical level, the 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

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[1]. For a standard and comprehensive review of the literature see, for example, Baumol and Oates (1968).

[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).

following analysis.[1] The "polluter pays principle", which is 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. In other words, we shall deal with a tax that is used to reduce a producer-producer externality, in our case the externality being pollution. 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 taxes, or other measures of combatting pollution.[2]

In the second part of the paper, we set out the basic features of our model and derive the basic relationships of the model in terms of proportional changes. In the third part we examine the effects of a consumption tax on income distribution in the short-run. As short-run we consider the case where some factors of production are not shiftable from one sector to the other. In the fourth part, 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 being equivalent to that of a closed economy. Finally, we summarise the basic findings of our analysis, and make some comparisons with the results derived in the "traditional" approach of tax incidence.

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[1]. For a recent review of the literature on environment and taxation see Smith (1992). With regard to the incidence of a pollution tax see Rapanos (1992).

[2]. For an examination of the incidence of a pollution tax that is levied on a factor of production see Rapanos (1992). For a similar approach but within a different model, see Yohe (1979).

## 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, 1971), and extended by Herberg, Kemp and Tawada (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 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:

$$X_1 = F_1(K_1, L_1) \tag{1}$$

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.[1] 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:

$$X_2 = g(X_1)F_2(K_2, L_2) \tag{2}$$

where g is a continuous function, twice differentiable and describes the role of the externality. $F_2$ is a linearly homogeneous function in capital and labour, and has the usual properties.[2] 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 $L_2$.

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

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

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

$$L_1 + L_2 = L \tag{3}$$

$$K_1 = K_1 \tag{4}$$

$$K_2 = K_2 \tag{5}$$

$$w_i L_i + r_i K_i = p_i X_i \qquad (i = 1,2) \tag{6}$$

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, $r_1 = r_2$. Over the longer run, as we shall see later, $r_1 = r_2$ since capital will be also intersectorally mobile.

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:

$$s = (dg/dX_1)(X_1/g) \tag{8}$$

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 asumption 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 equations (1)-(7), and assuming cost minimization, we obtain:[1]

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

$$X_2^* = sX_1 + \Theta_{L2}L_2^* + \Theta_{K2}K_2^* \tag{10}$$

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

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

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

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

$$\Theta_{L2}w^* + \Theta_{K2}r_2^* = p_2^* + sX_1^* \tag{15}$$

where an asterisk (*) indicates proportional change i.e. $x^* = dx/x$, $\lambda_{ji}$ is the fraction of the jth factor employed in sector i, $\Theta_{ji}$ 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 ($\sigma_i$) can be defined as follows:

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

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 $\sigma_D$ 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 equations, (9)-(16), with nine unknowns, and we can, therefore, solve it.

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[1]. For more details see Appendix.

In the case of a large open economy, the situation is more complex since we have to take into account the demand conditions. Making use of (16) and (17), and after some substitutions into equations (9)-(15), we obtain:[1]

$$-(\Theta_{K1} + s\Theta_{L1}\sigma_1)(w^{\cdot}-r_1^{\cdot}) + \Theta_{K2}(w^{\cdot}-r_2^{\cdot})-(q_1^{\cdot}-q_2^{\cdot}) = -T^{\cdot} \tag{18}$$

$$-(1-s)\Theta_{L1}\sigma_1(w^{\cdot}-r_1^{\cdot}) + \Theta_{L2}\sigma_2(w^{\cdot}-r_2^{\cdot}) + \sigma_D(q_1^{\cdot}-q_2^{\cdot}) = 0 \tag{19}$$

$$\lambda_{L1}\sigma_1(w^{\cdot}-r_1^{\cdot}) + \lambda_{L2}\sigma_2(w^{\cdot}-r_2^{\cdot}) = 0 \tag{20}$$

We can now proceed to the examination of the consumption tax on the distribution of income between capital and labour.

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[1]. For further details see Appendix.

## 3. TAXATION AND THE DISTRIBUTION OF INCOME IN THE SHORT-RUN

### a. The Small Country Case

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

$$(\lambda_{L1}\sigma_1 + \lambda_{L2}\sigma_2)w^* - \lambda_{L1}\sigma_1 r_1^* - \lambda_{L2}\sigma_2 r_2^* = 0 \tag{21}$$

$$\Theta_{L1}w^* + \Theta_{K1}r_1^* = -T^* \tag{22}$$

$$(\Theta_{L2} + s\Theta_{L1}\sigma_1)w^* - s\Theta_{L1}\sigma_1 r_1^* + \Theta_{K2}r_2^* = 0 \tag{23}$$

Solving equations (21)-(23), we obtain:

$$w^* = -(\sigma_1/D')(\lambda_{L1}\Theta_{K2} + s\lambda_{L2}\Theta_{L1}\sigma_2)T^* \tag{24}$$

$$r_1^* = -(1/D')(\lambda_{L1}\Theta_{K2}\sigma_1 + \lambda_{L2}\sigma_2 + s\lambda_{L2}\Theta_{L1}\sigma_1\sigma_2)T^* \tag{25}$$

$$r_2^* = (\sigma_1/D')(\lambda_{L1}\Theta_{L2} - s\lambda_{L2}\Theta_{L1}\sigma_2)T^* \tag{26}$$

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 $\sigma_2$ is not very large. If however, the externality effect is very strong and $\sigma_2$ is also large, then the wage rate may even rise. From (24)-(26), 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 $\sigma_2$ is large, then the increase in the productivity of the second sector may be large enough to outweight the fall in the wage rate caused by the tax.

It is worth noting that because of the nature of the externality, it affects all factors of production equaproportionately (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.

### b. The Large Country Case

If the economy in consideration is a large open economy (or a closed one), then commodity-prices are determined endogenously. Solving simultaneously equations (18)-(20), we get:[1]

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

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

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

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 $D>0$.

We can see from equations (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 equations (27)-(29), 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

[1]. As it was pointed 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 $\sigma_D$ 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).

between the two commodities in consumption ($\sigma_D$) 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 $\sigma_D$ is different from one, the changes in the relative factor-prices are affected by the presence of pollution, positively or negatively according to whether $\sigma_D$ is greater or smaller than one.

From equation (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 equation (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 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:[1]

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

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

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

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

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

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 $\sigma_D$ 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 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:[1]

### a. The Small Open Economy

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

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

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

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

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

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

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

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 $\Delta' = \lambda(\Theta_{K2}\text{-}\Theta_{K1}) + s(\lambda_{K2}\delta_L + \lambda_{L2}\delta_K) > 0$, 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.

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[1]. For a detailed derivation see Appendix.

**b. The Large Open Economy**

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

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

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

$$X_1^{*}-X_2^{*}+\sigma_D(q_1^{*}-q_2^{*})=0 \tag{42}$$

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

$$w^{*}-r^{*}=(-1/\Delta)\lambda\sigma_D T^{*} \tag{43}$$

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

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 $\Delta$ is positive, so that the stability of the system is assured.

It is clear from equation (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 capital 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 $\Delta$ includes an externality factor, which is absent in that. A first observation is that if $\sigma_D$ 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.[1] If, however, $\sigma_D$ 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:

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

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

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

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

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 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:

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

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 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 (1979), 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 the externality 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 externality 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.

## APPENDIX

<u>The Model in the Short-Run</u>

Differentiating totally equation (2), yields:

$$dX_2 = (og/oX_1)dX_1\ F_2(.) + g(.)[(oF_2/oK_2)dK_2 + (oF_2/oL_2)dL_2]$$

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

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

$$L_2dw + wdL_2 + K_2dr_2 + r_2dK_2 = X_2dp_2\ + p_2dX_2$$

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 equation (10) into the above relationship, we can obtain equation (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 equation (16), we can rewrite equations (9) and (10) as follows:

$$X_1^{*} = -\Theta_{L1}\sigma_1(w^{*}-r_1^{*}) \tag{A1}$$

$$X_2^{*} = -\Theta_{L2}\sigma_2(w^{*}-r_2^{*})-s\Theta_{L1}\sigma_1(w^{*}-r_1^{*}) \tag{A2}$$

Substituting (A1) into (15) we obtain

$$(\Theta_{L2} + s\Theta_{L1}\sigma_1)w^{*} + \Theta_{K2}r_2^{*}-s\Theta_{L1}\sigma_1r_1^{*} = q_2^{*} \tag{A3}$$

Subtracting (A3) from (14) we obtain equation (18) of the text.

From equations (A1) and (A2) we get

$$X_1^{*}-X_2^{*} = [\Theta_{L2}\sigma_2 + (s-1)\Theta_{L1}\sigma_1]w^{*}-\Theta_{L2}\sigma_2r_2^{*} + (1-s)\Theta_{L1}\sigma_1r_1^{*} \tag{A4}$$

Equating (A4) and (17), we obtain equation (19) of the text.

Finally, making use of (11) and (16) and the fact that capital is specific to each sector, we can obtain equation (20). In the case of the small open economy, we have equation (21) which is a reproduction of (20), equation (23) which is (A3) with $q_2^{*}=0$, and equation (22) which is the same as (14) with $q_1^{*}=0$.

## The Model in the Longer-Run

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

$$\lambda_{K1}K_1^{*}+\lambda_{K2}K_2^{*}=K^{*}=0 \tag{A5}$$

Making use of the full employment conditions for labour and capital, (11) and (A5), and equation (16), we can solve for $L_1^{*}$, $K_1^{*}$, $L_2^{*}$, and $K_2^{*}$ in terms of $(w^{*}-r^{*})$, so that we have

$$L_1^{*}=-(\lambda_{L2}/\lambda_{L1})L_2^{*}=(\lambda_{L2}/\lambda)(\lambda_{K1}\sigma_1+\lambda_{K2}\sigma_2)(w^{*}-r^{*}) \tag{A6}$$

$$K_1^{*}=-(\lambda_{K2}/\lambda_{K1})K_2^{*}=(\lambda_{K2}/\lambda)(\lambda_{L2}\sigma_2+\lambda_{L1}\sigma_1)(w^{*}-r^{*}) \tag{A7}$$

Substituting (A6) and (A7) into equations (9) and (10), we obtain

$$L_1^{*}=X_1^{*}-\Theta_{K1}\sigma_1(w^{*}-r^{*}) \tag{A8}$$

$$L_2^{*}=X_2^{*}-\Theta_{K2}\sigma_2(w^{*}-r^{*})-sX_1^{*} \tag{A9}$$

$$K_1^{*}=X_1^{*}+\Theta_{L1}\sigma_1(w^{*}-r^{*}) \tag{A10}$$

$$K_2^{*}=X_2^{*}+\Theta_{L2}\sigma_2(w^{*}-r^{*})-sX_1^{*} \tag{A11}$$

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

$$X_1^{*}=(1/\lambda)(\lambda_{K2}\delta_L+\lambda_{L2}\delta_K)(w^{*}-r^{*}) \tag{A12}$$

$$X_2^{*}=-(1/\lambda)[(\lambda_{L1}-s\lambda_{L2})\delta_K+(\lambda_{K1}-s\lambda_{K2})\delta_L](w^{*}-r^{*}) \tag{A13}$$

For the small country case, substitute (A12) into (15) yields equation (37) of the text. Equation (36) is the same as (22).

With variable commodity-prices, subtract (A13) from (A12) to get equation (30) of the text. Also, substituting the value for $X_1^{\cdot}$ into equation (15), and in combination with (14) we obtain equation (31). Equation (42) is a reproduction of (17).

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