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POLLUTION AND REFORMS OF DOMESTIC AND TRADE TAXES TOWARDS UNIFORMITY

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Pollution and Reforms of Domestic and Trade Taxes towards Uniformity

Michael S. Michael[♣] and Panos Hatzipanayotou[♠]

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Abstract

This paper builds a small open economy trade model where there is pollution from the production and consumption of goods. In the presence of production and consumption pollution, we examine a piecemeal *consumer-price-neutral* reform of the tariff and consumption tax and a piecemeal producer-*price-neutral* reform of the export and production taxes on a specific good. The paper identifies sufficient conditions under which the above tax reforms improve welfare and increase government tax revenues.

Keywords: Domestic and trade tax reforms, Production and consumption generated pollution, Government tax revenues, Welfare.

J.E.L Classification: **F13, H20**

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1. Introduction

During the past couple of decades, there is a general consensus regarding the reform of national tax systems. International institutions such as the GATT/WTO, the IMF and the World Bank have been encouraging governments to reform their indirect tax structures requiring the reliance for raising public sector revenues primarily on taxes such as income taxes, consumption taxes, and VATs, rather than on trade taxes. Such tax reforms, however, are likely to reduce government revenues for many LDCs which historically have relied on trade taxes for their tax revenues. In light of such undesirable revenue implications of the proposed indirect tax reforms, designing tax reform strategies which improve welfare without, however, eroding government tax revenues has been an important issue both in theoretical research and in policy agendas.

Motivated by such considerations, a theoretical literature identifies sufficient conditions under which reducing trade taxes and increasing domestic taxes, improves welfare and either retains constant or increases government tax revenues, e.g., see, Michael et al. (1993), Hatzipanayotou et al. (1994), Keen and Lighthart (2002), Emran (2005), Naito (2006), and Naito and Abe (2008). [1]

Many production and consumption activities entail the emission of environmentally harmful pollutants which affect negatively households' welfare. Tax policies affect the aggregate levels of pollution due to their effects on economic activity, and thus, tax reform policies traditionally viewed as welfare improving and revenue increasing may not be able to achieve these objectives due to the presence of pollution. A strand of literature has extensively examined the relationship among expanding economic activity, growing volumes of international trade and environmental quality. Yet, only a few studies address the welfare implications of tax

[1] Kreickemeier and Raimondos-Møller (2008) examine whether a consumer-price-neutral uniform reduction in tariffs and increase in consumption taxes improves the market access of a small open economy. Moreover, they note that such a reform scheme is less efficient; both in terms of welfare and market access considerations, compared to a reform of only tariffs (e.g., see Ju and Krishna, 2000). For the welfare and market access implications of tariff reforms, see, among others, Anderson and Neary (2007).

reforms in the presence of pollution generated from production or consumption activities. Most of the studies, in doing so, abstract from government revenue considerations, e.g., Copeland (1994), Beghin et al. (1997), Turunen-Red and Woodland (2004). Notable exceptions, within a static general equilibrium framework, are Beghin and Dessus (1999), and Naito (2005) in a dynamic framework of an open economy.

The strand of the literature that examines the welfare implications of tax reforms in the presence of production or consumption generated pollution, has not considered at all either *consumer-price-neutral* or *producer-price-neutral* indirect tax reforms of the type considered by, among others, Keen and Lighthart (2002), Emran (2005). These type of reforms in domestic and trade taxes are viewed as a very practical tax reform strategies which yield, in the absence of pollution, as clear-cut and unambiguously beneficial welfare and tax revenue results, as one can hope for, e.g., see Keen and Lighthart (2002)).[2] With these results at hand, one may ponder whether such clear cut conclusions continue to hold in the presence of production and consumption pollution.

To address this issue, we construct a general equilibrium model of a small open economy producing many traded goods, whose production and consumption generates pollution that adversely affect households' utility. The country's structure of indirect taxes consists of trade, production and consumption taxes. We consider two types of indirect tax reforms. A *consumer-price-neutral* reform whereby we reduce the tariff rate on a given good and equally increase its consumption tax, leaving its consumer price unchanged. A *producer-price-neutral* reform whereby we reduce the export tax on a given good and equally increase its production tax, leaving its producer price unchanged. For better analytical interpretation of the results, our analysis unfolds as follows. We first consider the existence of only production pollution and we examine the welfare and tax revenue implications of the piecemeal *consumer-price-neutral* and *producer-price-neutral* reforms in domestic and trade taxes. Next, we allow only for consumption pollution, and we perform similar analysis of the indirect tax reforms as in the case of only production pollution.

[2] Keen and Lighthart (2002), among others, examine the welfare and tax revenue implications of the aforementioned tax reforms in the context of perfectly competitive models. There is, however, a literature concluding that under imperfect competition there are cases whereby unambiguously welfare improving reform programs under perfect competition can become welfare worsening, e.g., Davies and Paz (2010).

2. The Model

Consider a small open, perfectly competitive economy, which produces and consumes K internationally traded goods, $j = 1, 2, ...K$. There are pollution emissions associated with the production and consumption of all goods.

The supply of factors of production is fixed. The country is a price taker in world commodity markets.[3] Thus, the international prices of all goods are fixed and are denoted by the price vector $p^* \equiv (p_1^*, ..., p_K^*)$, a $(1 \times K)$ vector. Various restrictions exist on all goods in the form of specific domestic taxes, i.e., production and consumption taxes, and of specific trade taxes, i.e., export taxes and import tariffs.[4] Thus, for the j^{th} commodity, the domestic prices for consumers (q_j) and producers (p_j) are respectively given by $q_j = p_j^* + \tau_j + t_j$ and $p_j = p_j^* + \tau_j - s_j$, where $\tau_j > 0 (< 0)$ denotes a specific import tariff (export tax), t_j and s_j respectively denote a consumption and production tax on the same good.

The economy's production side is represented by the revenue function $R(p)$, which captures the economy's maximum revenue from production of the traded goods, with producers' price vector p.[5] The $R(p)$ function is convex and homogeneous of degree one in producer prices, and by the envelope theorem $R_{p_j} (= \partial R / \partial p_j)$ is the supply function of the j^{th} good.

The economy has a number of identical households which consume the K commodities, whose utility is adversely affected by production and consumption pollution. A representative household's preferences are captured by the expenditure function $E(q, z, r, u)$ denoting the minimum expenditure on goods achieving a level of utility (u), at consumer price vector $q \equiv (q_1, ..., q_K)$, and the levels of production and consumption pollutants z and r, respectively. The $E(q, z, r, u)$ function is increasing in z, r, and u, non-decreasing and concave in q, i.e., E_{qq} is a $(K \times K)$ negative semi-definite matrix. The derivative $E_{q_j} (= \partial E / \partial q_j)$ is the compensated demand for the j^{th} good, and the derivatives E_z and E_r, respectively, denote the household's marginal

[3] We follow a standard practice of the literature of indirect tax reforms, which, for analytical convenience confines the analysis of such tax reforms in the context of small open economies.
[4] Using ad-valorem taxes produces qualitatively similar results to the ones we derive here.
[5] Often, the $R(p)$ function is referred to as GNP or GDP function, capturing an economy's maximum revenues from the production of private goods given its (fixed) stock of factor endowments.

damage caused by the pollutants z and r, thus capturing the household's *marginal willingness to pay* for reducing the production or consumption pollutant by one unit (e.g., see Copeland, 1994).[6]

We assume that production of any good entails the creation of the same type of pollutant, but at different units per unit of output produced. Thus, we define $z = \sum_{j=1}^{K} \alpha_j R_{p_j}(p) = \alpha' R_p(p)$ to be the aggregate level of production pollution, where $\alpha_j \geq 0$ denotes the units of pollution per unit of output of the j^{th} good, and $\alpha' = [\alpha_1, \alpha_2, ..., \alpha_K]$. Similarly, consumption of any good entails the creation of the same type of pollutant, but at different units of pollution per unit of output consumed. We define $r = \sum_{j=1}^{K} \beta_j E_{q_j}(q, r, z, u) = \beta' E_q(q, r, z, u)$ to be the aggregate level of consumption pollution, where $\beta_j \geq 0$ denotes the units of pollution per unit of consumption of the j^{th} good, and $\beta' = [\beta_1, \beta_2, ..., \beta_K]$.[7]

Government tax revenue (T) is lump-sum distributed to domestic households, and it equals the sum of production, consumption and trade tax revenues. That is,

$$T = s' R_p(p) + t' E_q(q, z, r, u) + \tau' \left[E_q(q, z, r, u) - R_p(p) \right], \tag{1}$$

where E_q and R_p, respectively, are the vectors of compensated demand and supply of goods, τ, s and t are the vectors of trade, production and consumption taxes.[8] A

[6] The $E(.)$ function is increasing in z and r since an increase in any type of pollutant is assumed to harm the households' utility. Therefore, to attain a given level of utility, u, private spending on consumption must rise. Moreover, $E_u (= \partial E / \partial u)$ denotes the reciprocal of the marginal utility of income.

[7] Beghin *et al.* (1997) assume that production and consumption activities generate a single type of pollutant, in which case aggregate pollution in the economy is defined as the sum $T = \alpha' R_p(p) + \beta' E_q(q, p, T, u)$. A more general specification would allow for different types of pollutants, at different rates, for every unit of the j^{th} output produced and consumed. In this case, z, r respectively are vectors of production and consumption pollutants with elements $z_j = \alpha_j R_{p_j}(p)$ and $r_j = \beta_j E_{q_j}(q, r, z, u)$ for every j^{th} commodity. This latter specification results to quite cumbersome algebraic calculations without adding substantively to the generality of the results.

[8] When pollution is generated from production, our vector of production taxes (s) is equivalent to the vector of pollution taxes (s) in Copeland (1994). When pollution is generated from consumption, consumption taxes (t) are equivalent to pollution taxes.

prime ($'$) denotes a transposed vector or matrix.The country's income-expenditure identity requires that private spending on goods must equal income from production plus income from tax revenue. That is,

$$E(q,z,r,u) = R(p) + T\,. \tag{2}$$

Equations (1) and (2) are the main equations of the model, used to examine the effects of indirect tax reform. In the analysis to follow, two reform programs are considered. First, we examine a piecemeal tax reform entailing a simultaneous small increase in the consumption tax and a decrease in the import tariff on a specific commodity, so that its consumer price is held constant. This we call a "*consumer-price-neutral*" indirect tax reform. Second, we examine a piecemeal tax reform entailing a simultaneous small increase in the production tax and a decrease in the export tax on a specific commodity, so that its producer price is held constant. This we call a "*producer-price-neutral*" indirect tax reform. We consider these reforms in the case where only production pollution exists, and when we have only consumption pollution.

3. Piecemeal reform of trade and domestic taxes under production pollution

We consider the case where consumption is "clean", i.e., $\beta_j = 0 \forall j \in K$, and only production generates pollution. The aggregate level of pollution in the economy is $z = \sum_{j=1}^{K} \alpha_j R_{p_j}(p)$.

3.1 Consumer-price-neutral reforms of tariffs and consumption taxes

The government pursues a *consumer-price-neutral* reform policy by simultaneously reducing tariffs and increasing consumption taxes by the same amount, i.e., $dt + d\tau = 0$, so that consumer prices remain constant, i.e., $dq = 0$. Export and production taxes are held constant. Equations (1) and (2) yield the following changes in tax revenue and welfare:

$$dT = \theta' E_{qu} du - \left[R_p{}' - \left(\varphi' + \theta' E_{qz} \alpha' \right) R_{pp} \right] d\tau \text{, and} \tag{3}$$

$$\Lambda du = (\varphi' + \theta' E_{qz} \alpha' - \alpha' E_z) R_{pp} d\tau\,, \tag{4}$$

where E_{qu} is a vector whose all elements are positive, assuming that all goods are normal in consumption and $\Lambda = E_u - \theta' E_{qu}$, and is assumed positive,[9] $\theta = \tau + t$ is the vector of net consumption taxes and $\varphi = s - \tau$ is the vector of net production taxes.[10] For the imported goods the corresponding elements of vector θ are positive and those of φ are negative, i.e., net production subsidies, if $\tau_i > s_i$. For the exported goods the corresponding elements of vector φ are positive and those of the vector θ are negative, i.e., net consumption subsidies, if $-\tau_i > t_i$. The vectors E_{qz} and E_{qr}, respectively, capture the response of compensated demands for goods to changes in the levels of production and consumption pollution.

We first examine the welfare and tax revenue implications of what we call the *consumer-price-neutral* piecemeal reform of a tariff and a consumption tax. That is, the tax reform program which calls for simultaneously reducing the tariff and increasing the consumption tax on the k^{th} imported good so that its consumer price remains constant, i.e., $d\tau_k < 0$ and $dt_k > 0$, so that $dq_k = dt_k + d\tau_k = 0$. Using equation (4) and the above conditions, the welfare effect of the *consumer-price-neutral* tax reform is given as follows:

$$\Lambda \frac{du}{d\tau_k} = \left(\varphi' + \theta' E_{qz}\alpha' - \alpha' E_z\right) R_{pp_k} = \left(\varphi_k + \alpha_k \theta' E_{qz} - \alpha_k E_z\right) R_{p_k p_k} + \sum_{j \neq k} \left(\varphi_j + \alpha_j \theta' E_{qz} - \alpha_j E_z\right) R_{p_k p_j} . \quad (5)$$

Equation (5) can be further elaborated on by using the properties of the revenue function, i.e., output supply functions are homogeneous of degree zero in prices.

[9] The positive sign of Λ is justified in various ways. Here Λ^{-1} is the tax multiplier, equivalent to the so-called tariff multiplier, for example in Copeland (1994), Neary and Ruane (1988). A negative multiplier would imply that an increase in lump-sum taxes on consumers would raise utility. Alternatively, by the homogeneity of degree one of the expenditure function in consumer prices, $q' E_{qu} = E_u$. Then, $\Lambda = p^{*\prime} E_{qu}$, and is positive since all goods are assumed normal in consumption, e.g., see Emran 2005.

[10] Subscripts on the functions, i.e., $E_{qp}, E_{qz}, E_{qr}, E_{qu}$ and R_{pp} denote partial derivatives. For example, $E_{qq} = \partial E_q / \partial q$, $R_{pp} = \partial R_p / \partial p$.

Specifically, $\sum_{K} p_j R_{p_j p_k} = 0$ yields $R_{p_k p_k} = -\sum_{j \neq k}^{K} \left(p_j / p_k \right) R_{p_j p_k}$, and by the reciprocity conditions we have $R_{p_j p_k} = R_{p_k p_j}$. Using the above properties in equation (5), the welfare effect of the proposed *consumer-price-neutral* tax reform, is given as follows:

$$\Lambda \frac{du}{d\tau_k} = \sum_{j \neq k} (\gamma_j - \gamma_k) p_j R_{p_j p_k}, \tag{6}$$

where $\gamma_i = \frac{\varphi_i + \alpha_i \theta' E_{qz} - \alpha_i E_z}{p_i}, i = j,k$. We call γ_i the *rate of excess taxation of production pollution* of the i^{th} good, which can be positive or negative. It is worth elaborating a little more on the meaning of this rate of excess taxation γ_i . The term $\varphi_i (= s_i - \tau_i)$ is positive, i.e., a production tax, if the i^{th} good is an exported, and it is negative, i.e., a net production subsidy, if the i^{th} commodity is an imported one and $-\tau_i > s_i$. This term captures the direct effect on tax revenue due to a unit change in the production of the i^{th} commodity. Changing, however, production of the i^{th} commodity entails changes in production generated pollution z , which in turn affects the consumption of all goods, and thus, consumption tax revenues are affected. The aforementioned consumption tax revenue effect is captured by the term $\alpha_i \theta' E_{qz}$ in the numerator of γ_i . We call the term $\left(\varphi_i + \alpha_i \theta' E_{qz} \right)$, the *total tax revenue effect*, direct and indirect, due to a unit change in the production of the i^{th} commodity as a result of the *consumer-price-neutral* tax reform.[11] Finally, the term $\alpha_i E_z$, is the marginal welfare damage of pollution created by the production of one unit of the i^{th} good or is the marginal willingness to pay for reducing the pollution generated from the production of one unit of the i^{th} good. Thus, the *rate of excess taxation of production pollution* $\left(\gamma_i \right)$ is positive if the tax revenue effect of a unit change in production of the

[11] For example, let the k^{th} good be an imported commodity, and $d\tau_k < 0$ and $dt_k > 0$, so that $dq_k = dt_k + d\tau_k = 0$. This reform implies an increase (decrease) in the net production tax (subsidy) on the k^{th} good. Production of this commodity falls, and so does production generated pollution. Given that θ_k is positive, and assuming that clean environment is substitute to all goods in consumption, i.e., all elements of the E_{qz} vector are positive, then consumption of all commodities rises and tax revenues increase by $\alpha_t \theta' E_{q_k z}$, leading to an overall positive tax revenue effect.

i^{th} good, due to the *consumer-price-neutral* reform, is positive and it exceeds the marginal welfare damage to consumers from the pollution generated from the production of one unit of the i^{th} good. On the other hand, γ_i is negative if the tax revenue effect of the unit change in production of the i^{th} good is smaller than the induced marginal welfare damage to consumers.

Equation (6) indicates that the proposed *consumer-price-neutral* reduction in the tariff rate on the k^{th} good increases social welfare if, first, the k^{th} good is a substitute in production with all other goods. Second, the *rate of excess taxation of production pollution* of the k^{th} good is the lowest, either positive or negative rate. Intuitively, since a tariff is a production subsidy and a consumption tax, then reducing the tariff rate on the k^{th} good and equally increasing its consumption tax, leaves its consumer price unchanged, reduces the production subsidy and thus the producer's price of this good decreases. Production of the k^{th} good falls and that of all other goods increases since we assume that goods are substitutes in production. Since the k^{th} good whose production decreases has the lowest *rate of excess taxation of production pollution* (γ_k), the proposed reform raises its *rate of excess taxation of production pollution*, and increases social welfare. Thus, the proposed reform causes welfare to increase if it brings towards uniformity the *rates of excess taxation of production pollution*.

The effect of the *consumer-price-neutral* reform on the level of production pollution is as follows:[12]

$$\frac{dz}{d\tau_k} = \sum_{j \neq k} \left(\frac{\alpha_j}{p_j} - \frac{\alpha_k}{p_k} \right) p_j R_{p_j p_k} \,. \tag{7}$$

Equation (7) indicates that the sufficient conditions for the consumer-price-neutral reduction in the tariff rate on the kth good to reduce the level of production pollution, i.e., $dz / d\tau_k > 0$, are that the k^{th} imported good (i) is a substitute to all other goods in production, and (ii) it carries the highest rate of pollution per unit of output as a

[12] Writing overall pollution as $z = \alpha_k R_{p_k}(p) + \sum_{j \neq k} \alpha_j R_{p_j}(p)$, differentiating with respect to τ_k, and using the homogeneity properties of the output supply functions, we obtain equation (7).

fraction of its producer price, i.e., $(\alpha_k / p_k) > (\alpha_j / p_j) \forall j \neq k$. The intuition of this result is rather straightforward.

Using equation (3) and the homogeneity properties of the revenue function, changes in the level of government revenue, due to the proposed tax reform program, are given as follows:

$$\frac{dT}{d\tau_k} = \theta' E_{qu} \frac{du}{d\tau_k} - \left(R_{p_k} - (\varphi' + \theta' E_{qz} \alpha') R_{pp_k} \right) = \theta' E_{qu} \frac{du}{d\tau_k} - R_{p_k} + \sum_{j \neq k} \left(\mu_j - \mu_k \right) p_j R_{p_j p_k} \text{ , (8)}$$

where $\mu_i = \frac{\varphi_i + \alpha_i \theta' E_{qz}}{p_i}, i = j,k$ and captures the impact on total tax revenue of raising production of the i^{th} good by one unit (see footnote 11). We call μ_i the *tax impact factor* of the i^{th} good. It shows the effect of a unit increase in the production of the i^{th} good on total tax revenue, directly though the change in net production taxes and indirectly through the change in pollution, consumption of all goods and thus the changes in consumption tax revenue. From the above expression it is clear that sufficient, but not necessary, conditions for the *consumer-price-neutral* decrease in the tariff rate on the k^{th} good to increase the government tax revenue are that (i) the reform is welfare improving, (ii) the k^{th} good is a substitute in production with all other goods, and (iii) the *tax impact factor* of the k^{th} imported good is the lowest.

The results of equations (6)-(8) are summarized in the following proposition:

Proposition 1: *Consider a small open economy where there exists only production pollution, and whose structure of indirect taxes consists of trade, production and consumption taxes. Let also the k^{th} imported good be a substitute in production to all other goods. Then, a tax reform entailing a simultaneous small decrease of the tariff rate of the k^{th} good and a small increase in its consumption tax, leaving its consumer price unchanged,*

- *increases social welfare if the k^{th} good has the lowest rate of excess taxation of production pollution,*
- *increases total tax revenue if the reform is welfare increasing and the k^{th} good carries the lowest tax impact factor.*

Given that $\gamma_i = \dfrac{\varphi_i + \alpha_i \theta' E_{qz} - \alpha_i E_z}{p_i}$ and $\mu_i = \dfrac{\varphi_i + \alpha_i \theta' E_{qz}}{p_i}$, then $\gamma_i = \mu_i - E_z\left(\alpha_i / p_i\right)$. Thus, if the k^{th} imported good has the lowest tax impact factor and the highest rate of pollution per unit of output as a fraction of its producer price, then it also carries the lowest rate of excess taxation of production pollution. But, when a good carries the lowest rate of excess taxation of production pollution, it does not necessarily mean that it also has the lowest tax impact factor and the highest pollution per unit of output as a fraction of its producer price. Therefore, given the substitutability assumption, the conditions that the k^{th} imported good has the lowest tax impact factor and the highest rate of pollution per unit of output as a fraction of its producer price, are sufficient but not necessary for the *consumer-price-neutral* decrease in the tariff rate on the k^{th} good to increase the government tax revenue and welfare. Consider for example the special case where production taxes are zero and goods and pollution are independent in consumption. In this case, given the substitutability assumption, by decreasing the tariff rate on the good with the highest tariff rate (i.e., highest production subsidy) and the highest pollution per unit of output as a fraction of its producer price, increases welfare and revenue.

Corollary 1: The tax reform suggested in Proposition 1 increases both social welfare and total tax revenue if the k^{th} good carries the lowest tax impact factor and the highest pollution per unit of output as a fraction of its producer price.

The above results can be compared to related results of the tax reform literature in the absence of pollution. For example, assuming substitutability of goods in production, Keen and Ligthart (2002), Corollary 1.c, demonstrate that reducing the highest tariff rate and increasing the consumption tax on the same good so that its consumer price remains constant, improves welfare and raises government revenues. This reform entails an increase in the lowest net production tax and brings towards uniformity the net production taxes. In our analysis, again under the assumption of substitutability of goods in production, the proposed welfare improving, revenue increasing *consumer-price-neutral* reform of tariffs and consumption taxes requires lowering the tariff rate and equally increasing the consumption tax on the good exhibiting the lowest *rate of excess taxation of production pollution* and the lowest *tax impact factor* and bring these rates towards uniformity. This rates account not only

for the net production taxes, but also for the change in consumption tax revenue due to changes in pollution and consumption of goods, for the pollution generated per unit of output and for the households' marginal willingness to pay for reducing the pollution generated from its production.

3.2 Producer-price neutral reforms of production and export taxes

Now, continuing to assume the existence of only production pollution, we examine the welfare and tax revenue implications of a *producer-price-neutral* reform by simultaneously reducing export taxes and increasing production taxes by the same amount, i.e., $d\tau - ds = 0$, so that producer prices are held constant, i.e., $dp = 0$. Since producer prices remain constant, the level of production pollution does not change. Tariffs and consumption taxes remain unchanged. Using equations (1) and (2), we get

$$dT = \theta' E_{qu} du + (\theta' E_{qq} + E_q')d\tau \text{, and} \tag{9}$$

$$\Lambda du = \theta' E_{qq} d\tau . \tag{10}$$

A piecemeal *producer-price-neutral* reform of production and export taxes entails the increase in the production tax on a certain exported commodity, e.g., $ds_k > 0$, and of simultaneously reducing its export tax, i.e., $d\tau_k > 0$, so that its producer price is held constant, i.e., $dp_k = d\tau_k - ds_k = 0$.[13] Using equations (9) and (10) and the zero homogeneity properties of the compensated demand functions in prices, i.e., $\sum_K q_j E_{q_j q_k} = 0$ yields $E_{q_k q_k} = -\sum_{j \neq k} \left(q_j / q_k \right) E_{q_j q_k}$, after some manipulations, the welfare and tax revenue effects of this reform are given as follows:

$$\Lambda \frac{du}{d\tau_k} = \sum_{j \neq k} (\sigma_j - \sigma_k) q_j E_{q_j q_k} , \tag{11}$$

$$\frac{dT}{d\tau_k} = \theta' E_{qu} \frac{du}{d\tau_k} + \left(E_{q_k} + \theta' E_{qq_k} \right) = E_{q_k} + \Lambda^{-1} E_u \sum_{j \neq k} (\sigma_j - \sigma_k) q_j E_{q_j q_k} , \tag{12}$$

where $\sigma_i = \frac{\theta_i}{q_i}, i = j,k$ is the net consumption tax of the i^{th} exported good as a fraction of its consumer price. In this case, the piecemeal *producer-price-neutral* reduction in the export tax and increase in the production tax of the k^{th} good improves

[13] Since we denote an export tax by $\tau_i < 0$, a reduction of its size implies that, algebraically, τ_i rises.

welfare and raises government tax revenues, i.e., $du/d\tau_k > 0$ and $dT/d\tau_k > 0$, if the k^{th} good is a substitute in consumption to all other goods and it carries the lowest net consumption tax as a fraction of its consumer price.

Since, due to the *producer-price-neutral reform*, production of goods and thus production generated pollution remain unchanged, the conditions for welfare improvement and revenue increase described above are the same as the ones we get in the absence of any pollution. Specifically, in a model without pollution, Keen and Ligthart (2002), consider the *producer-price-neutral* reform in export and production taxes and note that such a reform increases welfare and public revenue if the increased consumer prices reduce the value of compensated demand at world prices, and all goods are Hicksian substitutes.[14]

The following proposition summarizes the findings of this section:

Proposition 2: *Consider a small open economy where there exists only production pollution, and whose structure of indirect taxes consists of trade, consumption and production taxes. Let also the k^{th} exported good be a substitute to all other goods in consumption. Then a piecemeal producer-price-neutral reform entailing a small decrease of the export tax on the k^{th} good and a small increase in its production tax, leaving its producer price unchanged, improves social welfare and increases tax revenues if it carries the lowest net consumption tax as a fraction of its consumer price.*

In closing the analysis of this section, it is worth noting two interesting findings in the present context with production pollution. First, from proposition 1, the welfare increase is a necessary condition for a *consumer-price-neutral* piecemeal reform of a tariff and a consumption tax to increase tax revenues. This condition is not needed for a *producer-price-neutral* piecemeal reform in an export and production taxes to raise tax revenues (proposition 2). Second, in the absence of consumption pollution, whether or not production is "clean" activity bears no impact, relative to the standard results of the literature without pollution, on the welfare and tax revenue implications of a piecemeal reform in export and production taxes.

[14] Emran (2005) examines the effects of the same reform on welfare and revenue in an economy where the administration of taxes is costly but there is no pollution.

4. Piecemeal reforms of trade and domestic taxes under consumption pollution

We consider the case where production is "clean", i.e., $\alpha_j = 0 \forall j \in K$, and only consumption generates pollution. The aggregate level of pollution in the economy is $r = \sum_{j=1}^{K} \beta_j E_{q_j}(q, r, u)$.

4.1 Consumer-price-neutral reforms of tariffs and consumption taxes

The government pursues a *consumer-price-neutral* reform policy by simultaneously reducing tariffs and increasing consumption taxes by the same amount so that consumer prices remain constant. Export and production taxes remain unchanged. Equations (1) and (2), yield the following changes in tax revenue and welfare.[15]

$$dT = \left(\theta' E_{qu} + \delta^{-1}\theta' E_{qr}\beta' E_{qu}\right)du + \left(\varphi' R_{pp} - R_p'\right)d\tau, \tag{13}$$

$$\Delta du = \varphi' R_{pp} d\tau, \tag{14}$$

where, $\delta = \left(1 - \beta' E_{qr}\right) > 0$;[16] and $\Delta = \left[E_u - \theta' E_{qu} + \delta^{-1}\left(E_r - \theta' E_{qr}\right)\beta' E_{qu}\right]$ are assume to be positive scalars. Thus Δ^{-1} is an "augmented" tax multiplier adjusted for the presence of consumption pollution and of domestic and trade taxes (see footnote 9).[17]

We first examine the welfare and tax revenue implications of a *consumer-price-neutral* piecemeal reform of a tariff and a consumption tax. It entails the simultaneous reduction of the tariff rate and the equal increase of the consumption tax on the k^{th} imported good so that its consumer price remains constant, i.e., $d\tau_k < 0$ and $dt_k > 0$, so that $dq_k = dt_k + d\tau_k = 0$. Using equations (13)-(14) and the above assumptions, the welfare and tax revenue effects of the *consumer-price-neutral* tax reform, after some algebraic manipulations, are given as follows:

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[15] In this case, $dE_q = E_{qr}dr + E_{qu}du$, and $dR_p = R_{pp}d\tau$. Using these expressions in equations (1) and (2) we obtain equations (13) and (14). Moreover, if goods and clean environment are independent in consumption, i.e., $E_{qr} = 0$, then $dr = \beta' E_{qu}du$ and $dE_q = E_{qu}du$.

[16] With only consumption pollution, the *consumer-price-neutral* reform in tariffs and consumption taxes leads to $dr = \delta^{-1}\beta' E_{qu}du$. Then, had δ being negative, an increase in income and consumption would result to a lower level of consumption generated pollution.

[17] In this case**,** for given taxes, producer and consumer prices, using equation (1) and (2), we get that $(E_u - \theta' E_{qu})du = -(E_r - \theta' E_{qr})dr$. Thus, the term $(E_r - \theta' E_{qr})$ must be positive for an increase in pollution to reduce welfare. Thus the assumptions that goods i) are normal in consumption, ii) an increase in consumption of goods increases pollution and iii) the increase in pollution reduces welfare (given everything else) are sufficient conditions for Δ to be positive.

$$\Delta\frac{du}{d\tau_k}=\left(\varphi_k R_{p_k p_k}+\sum_{j\neq k}\varphi_j R_{p_j p_k}\right)=\sum_{j\neq k}\left(\xi_j-\xi_k\right)p_j R_{p_j p_k}\,, \tag{15}$$

$$\frac{dT}{d\tau_k}=-R_{p_k}+\Omega\sum_{j\neq k}\left(\xi_j-\xi_k\right)p_j R_{p_j p_k}\,, \tag{16}$$

where, $\Omega=\left(\delta\Delta\right)^{-1}\left(\delta E_u+E_r\beta' E_{qu}\right)$ is a positive scalar, and $\xi_i=\frac{\varphi_i}{p_i}, i=j,k$ is the net production tax on the i^{th} good as a fraction of its producer price.[18] Since $dr=\delta^{-1}\beta' E_{qu}du$ then a *consumer-price-neutral* piecemeal reform which improves welfare it exacerbates the level of consumption pollution.

From equations (15) and (16) we get the following proposition.

Proposition 3: *Consider a small open economy where there is only consumption pollution, and whose structure of indirect taxes consists of trade, consumption and production taxes. Let also the k^{th} imported good be a substitute to all other goods in production. Then, a piecemeal consumer-price-neutral reform entailing a small decrease of the tariff on the k^{th} good and a small increase in its consumption tax, leaving its consumer price unchanged, improves social welfare and increases tax revenues if it carries the lowest net production tax as a fraction of its producer price.*

Proposition 3 implies that the existence of consumption pollution alone does not affect the sufficient conditions of the standard literature without pollution, for a piecemeal *consumer-price-reform* of tariffs and consumption taxes to be welfare-improving and tax revenue-enhancing. The reasoning for this result is the following. The consumer-price neutral reduction in the tariff rate on the k^{th} good does not change the consumer prices and thus the consumption of goods and pollution is not directly affected. The increase in welfare, however, caused by this reform, increases consumption of goods which indirectly increases pollution. In terms of equations (15) and (16), this indirect effect is imbedded in the expressions for Ω, Δ and δ. Thus, while the sufficient conditions for welfare and revenue increase are not affected by the presence of pollution, the magnitude of these reforms on welfare and tax revenue is different in the two cases since the presence of pollution affects the size of Ω, Δ and δ. Note that under our assumptions and assuming that everything else is the same, we have that $\Delta>\Lambda$. Thus, the augmented, due to pollution, tax multiplier Δ^{-1} is smaller compared to the tax multiplier Λ^{-1} for the non-pollution case. Therefore, in the

[18] Equation (16) emerges after using equation (15) into (13), and applying the principle of the proposed *consumer-price-neutral* piecemeal reform.

presence of pollution and assuming that everything else is the same, the impact of the tax reform policy on welfare is of a smaller magnitude compared to the impact of the same size reform in the non-pollution case.

4.2 Producer-price-neutral reforms of export and production taxes

Now we examine the welfare and tax revenue implications of a *producer-price-neutral* reform by simultaneously reducing export taxes and increasing production taxes by the same amount, i.e., $d\tau - ds = 0$, so that producer prices are held constant, i.e., $dp = 0$. Equations (1) and (2) now give:[19]

$$dT = \left[E'_q + \theta' E_{qq} + \delta^{-1}\theta' E_{qr}\beta' E_{qq} \right] d\tau + [\theta' E_{qu} + \delta^{-1}\theta' E_{qr}\beta' E_{qu}]du\,, \tag{17}$$

$$\Delta du = [\left(\theta - \delta^{-1}\beta E_r\right)' + \delta^{-1}\theta' E_{qr}\beta']E_{qq}d\tau. \tag{18}$$

The algebra of equations (17) and (18) is extremely cumbersome and the emerging results far from intuitively revealing of the impact of this reform policy on the country's welfare and tax revenues. To facilitate the analysis we assume that goods and clean environment are independent in consumption.[20] Then, equations (17) and (18) reduce to:

$$dT = \left(E'_q + \theta' E_{qq}\right) d\tau + \theta' E_{qu} du\,, \tag{19}$$

$$\Delta_1 du = \left(\theta - \beta E_r\right)' E_{qq} d\tau\ , \tag{20}$$

where $\Delta_1 = E_u + \left(\beta E_r - \theta\right)' E_{qu}$ is assumed positive.

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[19] In this case, $dE_q = E_{qq}d\tau + E_{qr}dr + E_{qu}du$, $dr = \delta^{-1}\beta'(E_{qq}d\tau + E_{qu}du)$, $dR_p = d\varphi = [0]$. Substituting these expressions into equations (1) and (2), after some algebra we obtain equations (17) and (18).

[20] The assumption that the demand for goods is independent of the environmental quality is often made in the literature (i.e., Bovenberg 1999, Beghin and Dessus 1999). In the analysis to follow we assume $E_{qr} = E_{qz} = 0$ while $E_{qu} > 0$. This result emerges if the expenditure function has the following form $E(q,u,z,r) = g(q)\bar{u} + z + r$. Among others, Wilson (1991) considers an example of a direct utility function and Copeland and Taylor (2004) an example of an indirect utility function by which ordinary, not compensated, demand functions for goods are independent of public good and pollution, respectively. Lahiri and Raimondos-Møller (1998) discuss the implications of zero income effects on the *non-numeraire* commodity and of the separability between private and public goods in consumption. Hatzipanayotou *et al.* (2008) also discuss the (non-) separability between private goods and clean environment in consumption.

Using equations (19)-(20) and the homogeneity properties of the expenditure function, the welfare implication of a *producer-price-neutral* piecemeal reform in the export and production taxes on the k^{th} good, i.e., $ds_k > 0$ and $d\tau_k > 0$ so that $dp_k = d\tau_k - ds_k = 0$, is given as follows:

$$\Delta_1 \frac{du}{d\tau_k} = \left(\theta - \beta E_r\right)' E_{qq_k} = (\theta_k - \beta_k E_{r_k}) E_{q_k q_k} + \sum_{j \neq k} (\theta_j - \beta_j E_{r_j}) E_{q_k qj} = \sum_{j \neq k} (\eta_j - \eta_k) q_j E_{q_j q_k} \quad ,(21)$$

where $\eta_i = \dfrac{(\theta_i - \beta_i E_r)}{q_i}$, $i = j,k$. The θ_i is positive (i.e., net consumption tax) if the i^{th} good is an imported good and it is negative (i.e., net consumption subsidy) if it is an exported one and $-\tau_i > t_i$. The term $\beta_i E_r$ is the marginal willingness to pay for reducing the pollution generated from the consumption of one unit of the i^{th} good. Thus, the term η_i, which we called *the rate of excess taxation of consumption pollution* of the i^{th} good, can be positive or negative depending on whether the net consumption tax on the i^{th} good is greater or smaller than the marginal willingness to pay for the pollution generated from the consumption of one unit of this good

Equation (21) shows that the proposed *producer-price-neutral* decrease in the export tax on the k^{th} good increases social welfare (i.e., $\left(du / d\tau_k\right) > 0$), if (i) it is a substitute in consumption to all other goods, and (ii) the *rate of excess taxation of consumption pollution* is the lowest, either positive or negative. This proposed reform results in increasing the lowest rate of *excess taxation of consumption pollution* and thus it brings the rates of excess taxation of consumption pollution towards uniformity.

Intuitively, since the export tax is a production tax and consumption subsidy, then by reducing the export tax on the k^{th} good and equally increasing its production tax, leaves its producer price constant, reduces the consumption subsidy, increases its consumer price and reduces its consumption. Production of all goods remains unchanged, while the higher consumer price of the k^{th} exported good causes the consumption of all other goods to increase since are assumed substitutes in consumption. The k^{th} exported good has the lowest rate of *excess taxation of*

consumption pollution and the above changes causes this rate to increase, resulting in total welfare increase.

Using equations (19)-(20), and the homogeneity properties of the expenditure function, changes in the level of government revenue, due to the proposed tax reform program, are given as follows:

$$\frac{dT}{d\tau_k} = \theta' E_{qu} \frac{du}{d\tau_k} + E_{q_k} + \sum_{j \neq k} (-\sigma_k + \sigma_j) q_j E_{q_j q_k} , \qquad (22)$$

From the above expression it is clear that sufficient, but not necessary, conditions for the *producer-price-neutral* decrease in the export tax on the k^{th} good to increase the total government tax revenue, i.e., $dT / d\tau_k > 0$, are that (i) the k^{th} good is a substitute in consumption to all other goods, (ii) its net consumption tax as a fraction of its consumer price is the lowest and (iii) this reform increases welfare. Intuitively, assuming that the k^{th} exported good carries the lowest net consumption tax ratio relative to all other goods (or the highest net consumption subsidy), this reform decreases the cost of the subsidy and increases total tax revenues.

Proposition 4: *Consider a small open economy where there is only consumption pollution, goods and clean environment are independent in consumption, and whose structure of indirect taxes consists of trade, consumption and production taxes. Let also the k^{th} exported good be a substitute in consumption to all other goods. Then, a tax reform entailing a small decrease of the export tax of the k^{th} good and a small increase in its production tax, leaving its producer price unchanged,*

- *improves social welfare if the k^{th} good has the lowest rate of excess taxation of consumption pollution,*
- *increases government tax revenue if the reform is welfare increasing and the k^{th} good carries the lowest net consumption tax (sufficient but not necessary).*

Since $\eta_i = \frac{(\theta_i - \beta_i E_r)}{q_i}$ and $\sigma_i = \frac{\theta_i}{q_i}$, then $\eta_i = \sigma_i - E_r \frac{\beta_i}{q_i}$. Thus, if a good has the lowest net consumption tax and the highest pollution per unit of consumption as a fraction of its consumer price, then it also has the lowest rate of excess taxation of consumption pollution. Note that the reverse is not necessarily true. Therefore, besides the substitutability conditions, sufficient but not necessary conditions for the *producer-price-neutral* decrease in the export tax on the k^{th} good to increase the tax

revenue and welfare are that the k^{th} good has the lowest net consumption tax and the highest pollution per unit of output as a fraction of its consumer price.[21] Consider, for example, the special case where consumption taxes are zero. In this case, given the substitutability assumption, the *producer-price-neutral* decrease in the export tax on the good with the highest export tax (i.e., highest consumption subsidy and thus lowest net consumption tax) and the highest pollution per unit of consumption as a fraction of its consumer price, increases welfare and revenue.

Corollary 2: The tax reform suggested in Proposition 4 increases both social welfare and total tax revenue if the k^{th} good carries the lowest net consumption tax and the highest pollution per unit of consumption as a fraction of its consumer price.

5. Concluding Remarks

This paper derives sufficient conditions under which piecemeal reforms in trade and domestic taxes improve welfare and increase government tax revenues in the presence of pollution. In the presence of production or consumption pollution, the piecemeal reforms we consider here are (i) a *consumer-price-neutral* reform of reducing tariffs and increasing consumption taxes, and (ii) a *producer-price-neutral* reform of reducing export taxes and increasing production taxes. The propositions of the paper summarize the conditions that are needed for the above reforms to increase welfare and government revenues. These conditions, on the one hand, contain certain relationships, as the standard tax reform literature, e.g., substitutability in production or consumption between the imported or exported good whose taxes are reformed, to all other goods. On the other hand, they contain conditions resulting from the presence of production and or consumption generated pollution, e.g., the rates of excess taxation of production or consumption pollution and the tax impact factor of a good. These rates of excess taxation and the tax impact factors, in addition to the indirect tax structure consisting of both trade and domestic taxes, depend also on the

[21] It can be easily shown that in the presence of only consumption pollution, the effect of the producer-price-neutral reduction in export taxes on the level of pollution is give by $\delta(dr/\tau_k) = \beta' E_{qu}(du/d\tau_k) + \sum_{j\neq k}[(\beta_j/q_j) - (\beta_k/q_k)]q_j E_{q_j q_k}$. Thus, the reform that increases welfare may also increase pollution. Therefore, the conditions that the k^{th} good (i) is a substitute to all other goods in consumption and (ii) it carries the highest rate of pollution per unit of consumption as a fraction of its consumer price, is necessary but not sufficient for the welfare improving reform to reduce pollution.

relationship between goods and clean environment in consumption, on the pollution per unit of output produced or consumed and the marginal welfare damage caused by the pollution created from the consumption or production of the good whose taxes are reformed.

While in some cases the presence of pollution does affect the welfare improving and revenue increasing sufficient conditions of a proposed piecemeal tax reform, in some other cases it does not. For example, the presence of production pollution affects the sufficient conditions for a welfare improving and revenue enhancing *consumer-price-neutral* reform. It does not affect, however, the corresponding sufficient conditions of a *producer-price-neutral* reform of export and production taxes. Similarly, the presence of consumption pollution does not affect the sufficient conditions for a *consumer-price-neutral* piecemeal reform of a tariff and a consumption tax to be welfare improving and revenue enhancing, even though the magnitude of the impact of these reforms on welfare and revenue is affected. The presence of consumption pollution, however, affects the conditions needed for a producer-price-neutral reform to increase welfare and revenue.

Finally, from a policy view point, we may argue that, in the presence of production or consumption pollution, our analysis identifies sufficient conditions in selecting the commodities for which taxes should be adjusted in the pursuit of welfare and tax revenue increasing reforms. For example, in the presence of consumption pollution, implementing a producer-price-neutral tax reforms one should aim at reducing the export tax on the good with the lowest net consumption tax (i.e., highest export tax when consumption taxes are zero) and the highest pollution per unit of consumption as a fraction of its consumer price. In the presence of production pollution, when implementing a consumer price neutral reform, one should aim at reducing the tariff rate on the good with the lowest tax impact factor (i.e., highest tariff rate when consumption taxes are zero and goods and pollution are independent in consumption) and the highest pollution per unit of output as a fraction of its producer price.

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