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Abstract

We develop a model of a small open economy, where pollution per unit of consumption between domestically produced and imported quantities of the same good differs. We show that the first-best policy combination calls for consumption taxes on all polluting goods, and Border Tax Adjustment (BTA) measures, i.e., tariffs or import subsidies. We identify conditions under which well known tariff-tax reform policies for developing economies, such as a *consumer-price-neutral* piecemeal reform of a trade and a consumption tax, and a *consumer-price-neutral* reform of all trade and consumption taxes improve welfare. We also evaluate whether a *consumer-price-neutral* reform of a tariff and a consumption tax is superior to a reform of a *tariff* alone.

JEL classification: F13, F18, H20, H21

Keywords: Consumption generated Pollution, Optimal Taxation, Border Tax Adjustments, Trade and Consumption Tax Reforms

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1 Introduction

Nowadays, consumption and residential activities are considered important sources of pollution emissions such as carbon dioxide, sulfur dioxide, and solid waste accumulation, e.g., Hu and McKitrick (2016).[1] In many cases, the same consumer needs are satisfied by different commodities produced in different countries using different materials and technologies. The consumption of such different varieties of the same product produced in one country or imported, satisfying the same consumer needs, may generate different rates of pollution per unit of consumption. For example, different brands of automobiles, air-conditioners and other electrical appliances, tires, etc., produced by different firms in different countries, have different energy requirements and thus they are attributed different energy classifications.[2]

To address this phenomenon, we construct a theoretical model of a competitive small open economy producing and consuming many traded goods. The consumption of goods generates pollution. The distinctive element in this modelling is that pollution per unit of imports consumption of a good differs from pollution per unit of consumption of the same commodity produced domestically. Within this framework we show that the first-best policy combination requires (i) consumption taxes on all polluting goods. While consumption taxes on imported and on domestically produced quantities of the same good are the same, they differ across commodities depending on their rates of pollution per unit of consumption; (ii) free-trade for all exportable goods, and (iii) a tariff (import subsidy) or free-trade on an importable if pollution per unit of imports consumption is higher (lower) or the same with pollution per unit of consumption of the domestically produced quantities of this good.

Studies which examine the optimal policies under consumption pollution externalities propose that for small open economies, the first-best policy combination requires an emission tax to control for the consumption pollution externality, and free trade, e.g., Krutilla (1991), Gulati and Roy (2008), Copeland (2011) and Chao *et al.* (2012).[3] However, more often than not, for political or political economy reasons emission taxes may be set at sub-optimal levels. For example, the implementation of Pigouvian emission taxes is infeasible in the presence of lobbying activities by large polluters, corruption, weak administrative capacity or technical and economic reasons, e.g., Eisenbarth (2017), McAusland (2008),

[1] In their study they note, "*....According to the US Environmental Protection Agency (EPA 2012), nearly one half of the emissions of smog-forming volatile organic compounds (VOCs), more than half of the nitrogen oxides (NOx) emissions, and about half of the toxic air pollutant emissions in US are generated from motor vehicles. .... For OECD countries, up to 90% of the total carbon monoxide (CO_2) is from the source "road" (OECD Statistics 2012).... The emissions related to consumption of energy in US are accountable for about 71% of US carbon dioxide emissions....*".

[2] Electrical devices are classified in 7 energy classes (from A to G), depending on the energy they consume towards the energy they attribute.

[3] In the context of large open economies, and the existence of terms of trade motives, the optimal trade policy is no longer free trade but a tariff, e.g., Syropoulos (2002).

Fullerton and West (2002). In these cases, governments can resort to other forms of taxation such as consumption and trade taxes.[4] In this paper we show that, in the absence of emission taxes and when the rates of pollution per unit of consumption between imported and domestically produced quantities of the same good differ, the first-best policy requires Border Tax Adjustment (BTA) measures, such as tariffs or import subsidies, in addition to consumption taxes on all polluting goods.[5] This first-best policy is equivalent to the first-best policy of emission taxes and zero trade taxes in terms of its effects on producer and consumer prices. The idea of BTA measures in the trade and environment literature is a topical issue, see Larch and Wanner (2017, pp.195-196). Recently, Fischer and Fox (2012), Jakob *et al.* (2013), Keen and Kotsogiannis (2014), and Böhringer *et al.* (2017) invoke the need for such measures in order to mitigate carbon leakage effects in the presence of production generated cross-border pollution.[6] Here the source of pollution is the consumption rather than the production activity, and the rates of pollution per unit of consumption between imported and domestically produced quantities of the same good differ.

Recently, the rapid and deepening globalization, and freer trade via reductions in trade taxes has been a consistent trend in the world economy. Since trade taxes, i.e., import tariffs and export taxes, constitute a major source of government revenue in many developing countries, their reduction has substantially lowered government revenues. To recoup these revenues losses a standard IMF and World Bank reform proposal, particularly to developing economies, is the pursuit of various types of coordinated tax reforms. Such is, reducing trade taxes and increasing domestic taxes, e.g., consumption or value-added (VAT) taxes, without, however, compromising governments' fiscal viability. These policy recommendations are addressed in a literature that examines the implications of different types of trade and domestic tax reforms on welfare, government tax revenues and market access, e.g., Michael *et al.* (1993), Hatzipanayotou *et al.* (1994), Abe (1995), Keen and Ligthart (2002), Emran and Stiglitz (2005), Kreickemeier and Raimondos-

[4]Real world evidence attests to the use of consumption taxes, e.g., taxes on energy consuming products, vehicles, mineral oils and on transport fuels, to encourage more environmetally resposible economic and recreational activites. For example, OECD (2014) pp. 135-160, reports: Per litre total taxation (VAT + excise) on premium unleaded gasoline: Australia 0.51, Canada 0.39, Germany 1.20, the U.K. 1.25, the U.S. 0.14. Per litre total taxation (VAT + excise) on light fuel oil for households: Austria 0.35, Germany 0.25, the Netherlands 0.81, the U.K. 0.37. Taxes on sales and registration of motor vehicles: Belgium VAT 21% + Entry into Service Tax (age, engine power, CO_2 emissions, type of fuel gas), Germany VAT 19%, Spain VAT 21% + Vehicle Registration Tax (CO_2 emissions), the US gas guzzler tax (fuel efficiency).

[5]Since 2007 China, invoking Article XX of the GATT allowing exemption from GATT rules for environmental objectives (WTO, 2013), has introduced export taxes and reduced export value-added tax (VAT) rebates on exports of pollution-, energy-, and resource-intensive products, in order to promote an environmentally friendlier trade structure, see Eisenbarth (2017).

[6]Fischer and Fox (2012) provide a comprehensive analysis, and review of studies examining the compatability of GATT/WTO rules with climate policy and alternative options of border tax adjutment measures. Nimubona and Rus (2015) examine the effectiveness of BTA measures to tackle cross-border pollution in the presence of environmental tied foreign aid.

Møller (2008), Keen (2008), Boadway and Sato (2009), Jones *et al.* (2011), Haibara (2012), Anderson and Neary (2016).

Within the present framework where pollution per unit of imports consumption of a good differs from pollution per unit of consumption of the same commodity produced domestically, we identify conditions under which the reforms proposed by the international institutions and examined in the relevant literature can improve welfare, raise government revenue, and possibly reduce pollution. That is, we aim at designing trade and consumption tax reform policies which can achieve a double, or even a triple dividend. To this end, we investigate two popular reform policies, first a *selective consumer-price-neutral* reform, i.e., a reduction of the trade tax and a change of the consumption tax so that the consumer price of the good carrying the highest, what we call, *welfare cost ratios* remains constant. Such a reform is welfare improving when it moves towards uniformity the *welfare cost ratios*. The latter measure is the per unit of price welfare cost of increasing production of a good by one unit, and reducing its imports by one unit, holding everything else constant. Second, we show that a policy of reducing only the tariff on a good is welfare superior to a *consumer-price-neutral* reduction in the tariff and increase in consumption tax rate on it, if this good, aside of being substitute to all other goods in consumption, (i) it carries the highest tariff rate, and (ii) its imported quantities generate the lowest rate of pollution per unit of consumption relative to all other imported and exported quantities. Finally, we show that a *consumer-price-neutral* adjustment in trade and consumption taxes according to what we call *welfare cost rule* is welfare improving.[7]

2 The Model

Consider a perfectly competitive small open economy with a representative agent, producing and consuming N internationally traded goods. Of these goods, the first K are the country's importables, and the remaining $N-K$ are its exportables. Consumption of all commodities generates pollution emissions. Under the assumption of a small open economy, the world prices of these internationally traded goods are fixed and set equal to 1. All goods are subject to specific trade taxes, i.e., import tariffs and export taxes, and to destination-based consumption taxes, i.e., taxes imposed in the country where goods are consumed. Let $t \equiv [t_1, t_2, ..., t_N]$ be the vector of trade taxes, where for $t_j > (<) 0$ indicates a tariff (import subsidy) or an export subsidy (tax),

[7] A more recent and growing trade and environment literature considers the welfare implications of various reform policies such as a piecemeal movement of trade and environmental taxes towards their optimal levels. In the presence of production generated pollution, see, e.g., Copeland, (1994), Neary (2006), and in the presence of consumption generated pollution see, e.g., Chao *et al.* (2012), Michael *et al.* (2015). Other studies examine the feasibility of welfare improving piecemeal multilateral policy reforms in the presence of transboundary pollution within multi-country/region models, see, e.g., Turunen-Red and Woodland (2004), Vlassis (2013), Tsakiris *et al.* (2014), Nimubona and Rus (2015).

and $\tau \equiv [\tau_1, \tau_2, ..., \tau_N]$ be the vector of consumption taxes. Government revenues from trade and consumption taxes are lump-sum distributed to the domestic agent. The vector of producer prices is $p \equiv (1+t) \equiv [1+t_1, 1+t_2, ..., 1+t_N]$ and of consumer prices is $q \equiv [1+t_1+\tau_1, .., 1+t_N+\tau_N]$. The country's budget constraint is given by the income-expenditure identity, equating the aggregate consumption expenditure to income from domestic production plus the lump-sum distributed government tax revenues (G), and is written as:

$$e(q,z,u) = r(p) + G, \tag{1}$$

where $e(q,z,u)$ denotes the representative agent's minimum expenditure on commodities needed to achieve a given level of welfare u at consumer prices q and consumption pollution z.[8] By the properties of the expenditure function, the partial derivative $e_{q_j} \equiv \frac{\partial e}{\partial q_j}$, $j = 1, ...N$, is the compensated demand function for the j^{th} commodity, and e_q is the vector of the country's compensated demand functions. The partial derivative $e_z \equiv \frac{\partial e}{\partial z}$, is the marginal willingness to pay for pollution reduction, and the partial derivative $e_u \equiv \frac{\partial e}{\partial u}$, denotes the reciprocal of the marginal utility of income. The $e(.)$ function is increasing in z and u, and non-decreasing and concave in q, i.e., e_{qq} is a $(N \times N)$ negative semi-definite matrix.[9] The country's Gross Domestic Product function (GDP) is given by $r(p)$ and denotes the maximum value of output at producers prices p, given the country's fixed factor supplies and production technologies.[10] Factor supplies are omitted from the GDP function since throughout the analysis are considered fixed. The partial derivative, $r_{p_j} \equiv \frac{\partial r}{\partial p_j}$, denotes the supply function of the j^{th} commodity, and r_p is the vector of the country's supply functions of the commodities. The $r(p)$ function is homogeneous of degree one and convex in p, i.e., r_{pp} is a positive semi-definite matrix.

Government revenues from trade and consumption taxes are given by:

$$G = t'M(.) + \tau' e_q(q,z,u), \tag{2}$$

where $M = e_q(q,z,u) - r_p(p)$ denotes the vector of compensated excess demand functions.

[8]The general specification of the minimum expenditure function in the presence of pollution can be written as $e(q,z,u) = \min_{x'} \{q'x : U(x,z) \geq u\}$ and, $U \equiv v(x) - h(z)$, x is the vector of consumptions, v is increasing and concave, and h is increasing and convex. The $e(.)$ function implies complete separability between consumption and pollution, i.e., $e_{q_j z} = 0$, $\forall\ j = 1, ...N$, ensuring that relative demands are independent of the environmental damage.

[9]The $e(.)$ function is increasing in z in the sense that when pollution increases the expenditures on goods must also increase in order to keep welfare constant. For details of the properties of the expenditure function in the presence of pollution see, e.g., Neary (2006), Copeland (2011), Tsakiris *et al.* (2017, 2018).

[10]We can write $r(p) = \max \left\{ \sum_{j=1}^{N} p_j x_j : F(X,\Phi) \leq 0 \right\}$, where $F(X,\Phi)$ is the aggregate production possibilities set, X is the vector of goods produced, and Φ is the vector of (fixed) factor supplies. For the properties of the GDP or *revenue* function, see e.g., Neary (2006), Nimubona and Rus (2015), Lapan and Sikdar (2017), Antoniou *et al.* (2017).

An element of this vector is positive (negative), i.e., $e_{q_j} - r_{p_j} > (<)0$, indicating imports (exports) of the j^{th} good.

The consumption of goods generates pollution. We assume that pollution per unit of consumption between the imported and the domestically produced quantities of the same good differ. For the j^{th} importable good, let a_j^* be the pollution per unit of consumption of imports, and a_j be the pollution per unit of consumption of its quantities domestically produced. For an exportable good, a_j denotes pollution per unit of its domestic consumption. Then, overall pollution (z) is defined as follows:

$$z = \left[\sum_{j=1}^{K} a_j r_{p_j} + \sum_{j=1}^{K} a_j^* (e_{q_j} - r_{p_j}) \right] + \left[\sum_{j=K+1}^{N} a_j e_{q_j} \right] \Longrightarrow$$

$$z = \sum_{j=1}^{K} a_j^* e_{q_j} + \sum_{j=K+1}^{N} a_j e_{q_j} + \sum_{j=1}^{K} (a_j - a_j^*) r_{p_j}. \tag{3}$$

The first bracketed right-hand-side term in the first line of equation (3) captures pollution from consumption of the domestically produced quantities of importable goods and pollution from consumption of imports. The second bracketed right-hand-side term captures pollution from domestic consumption of the exportable goods.[11] The equilibrium of this economy is described by equations (1), (2) and (3), which constitute a system of three equations with three endogenous variables, i.e., u, z, and G.

3 Optimal trade and consumption taxes

Equations (1), (2) and (3) determine the optimal trade and consumption taxes in our model. Totally differentiating equations (2) and (3) with respect to the trade and consumption tax on the i^{th} commodity, and noting that $dq_i = dt_i + d\tau_i$ and $dp_i = dt_i$, yields:

$$\begin{aligned} dG \;&=\; \left[(e_{q_i} - r_{p_i}) + \sum_{j=1}^{N} (t_j + \tau_j)\, e_{q_j q_i} - \sum_{j=1}^{N} t_j r_{p_j p_i} \right] dt_i + \left[e_{q_i} + \sum_{j=1}^{N} (t_j + \tau_j)\, e_{q_j q_i} \right] d\tau_i \\ &\quad + \sum_{j=1}^{N} (t_j + \tau_j)\, e_{q_j u} du, \quad \text{and} \end{aligned} \tag{4}$$

[11] For example, in the case of two commodities produced and consumed, good 1 being the exportable and good 2 being the importable, overall pollution in the country is $z = a_2^* e_{q_2} + a_1 e_{q_1} + (a_2 - a_2^*) r_{p_2}$.

$$dz = \left[\sum_{j=1}^{K} a_j^* e_{q_j q_i} + \sum_{j=K+1}^{N} a_j e_{q_j q_i} + \sum_{j=1}^{K} \left(a_j - a_j^* \right) r_{p_j p_i} \right] dt_i + \left(\sum_{j=1}^{K} a_j^* e_{q_j q_i} + \sum_{j=K+1}^{N} a_j e_{q_j q_i} \right) d\tau_i + \left(\sum_{j=1}^{K} a_j^* e_{q_j u} + \sum_{j=K+1}^{N} a_j e_{q_j u} \right) du. \quad (5)$$

Differentiating equation (1) and using equations (4) and (5) yields the welfare changes due to changes in t_i and τ_i as follows:

$$\Omega du = \left\{ \begin{array}{c} \sum_{j=1}^{N} \left(t_j + \tau_j \right) e_{q_j q_i} - \sum_{j=1}^{N} t_j r_{p_j p_i} \\ -e_z \left(\sum_{j=1}^{K} a_j^* e_{q_j q_i} + \sum_{j=K+1}^{N} a_j e_{q_j q_i} + \sum_{j=1}^{K} \left(a_j - a_j^* \right) r_{p_j p_i} \right) \end{array} \right\} dt_i + \left\{ \sum_{j=1}^{N} \left(t_j + \tau_j \right) e_{q_j q_i} - e_z \left(\sum_{j=1}^{K} a_j^* e_{q_j q_i} + \sum_{j=K+1}^{N} a_j e_{q_j q_i} \right) \right\} d\tau_i, \quad (6)$$

where $\Omega = e_u - \sum_{j=1}^{N} \left(t_j + \tau_j \right) e_{q_j u} + e_z \left(\sum_{j=1}^{K} a_j^* e_{q_j u} + \sum_{j=K+1}^{N} a_j e_{q_j u} \right)$ is positive. In the analysis to follow we assume that all goods are normal in consumption, i.e., $e_{q_j u} > 0, \ \forall \ j = 1, ...N$. The optimal choice of τ_i that maximizes welfare requires the following first-order-condition:

$$\Omega \frac{du}{d\tau_i} = 0 \Longrightarrow \sum_{j=1}^{N} \left(t_j + \tau_j \right) e_{q_j q_i} - e_z \left(\sum_{j=1}^{K} a_j^* e_{q_j q_i} + \sum_{j=K+1}^{N} a_j e_{q_j q_i} \right) = 0. \quad (7)$$

Substituting this result into the first-order-condition determining the optimal choice of t_i, i.e., $\Omega \frac{du}{dt_i} = 0$ we obtain:

$$\Omega \frac{du}{dt_i} = 0 \Longrightarrow \sum_{j=1}^{N} t_j r_{p_j p_i} = -e_z \sum_{j=1}^{K} \left(a_j - a_j^* \right) r_{p_j p_i}. \quad (8)$$

Repeating the analysis for all N commodities, we obtain a system of N equations in N unknowns. The solution of this simultaneous equations system yields the vector of optimal trade taxes $t^{opt} \equiv \left[t_1^{opt}, t_2^{opt}, ..., t_N^{opt} \right]$, where:

$$\begin{aligned} t_j^{opt} &= -e_z \left(a_j - a_j^* \right), \ \textit{if } j^{th} \textit{ good is an importable, and} \\ t_j^{opt} &= 0, \ \textit{if } j^{th} \textit{ good is an exportable.} \end{aligned} \quad (9)$$

Equations (9) indicate that, if the j^{th} commodity is an importable, then the optimal trade policy is a tariff (import subsidy) if the pollution per unit of imports consumption of this j^{th} commodity exceeds (is smaller than) the pollution per unit of consumption of its domestically produced quantities. For example, if $a_j < a_j^*$, then the optimal trade policy for this good is a tariff. The intuition is simple. Since the consumption of imports of this good create more pollution than the consumption of quantities domestically produced, it is optimum to reduce imports and increase domestic production by imposing a tariff. In the case where $a_j = a_j^*$, i.e., pollution per unit of consumption of imports and of domestically produced quantities of the j^{th} good are the same, then the optimal policy for the j^{th} importable good is free trade. If the j^{th} commodity is an exportable, then the optimal trade policy is free trade.

Substituting equations (9) into the first-order condition (7), we get

$$\sum_{j=1}^{N} (\tau_j - e_z a_j)\, e_{q_j q_i} = 0. \tag{10}$$

Repeating for all N commodities, we obtain a system of N equations in N unknowns, whose solution gives the vector of the optimal consumption taxes $\tau^{opt} \equiv \left[\tau_1^{opt}, \tau_2^{opt}, ..., \tau_N^{opt}\right]$, where:

$$\tau_j^{opt} = e_z a_j, \;\text{ for all } N \text{ goods.} \tag{11}$$

The following conclusions emerge from equations (9) and (11). First, tariffs (import subsidies) is the optimal trade policy for the importable goods, and zero export taxes (subsidies) is the optimal policy for the exportables. In this sense, it is the optimal trade policy that corrects for the difference in pollution per unit of consumption between the imported quantities and the quantities of the same goods that are domestically produced. Second, the optimum consumption tax on any j^{th} importable good is uniform on all quantities consumed, both domestically produced and imported, and it depends on the rate of pollution per unit of consumption of the domestically produced quantities.

Proposition 1 *Consider a small open economy where the consumption of goods generates pollution. The optimal trade and consumption tax policy combination is: (i) a uniform consumption tax on all quantities consumed of the same good, both domestically produced and imported, and (ii.a) free trade for the exportable goods, and (ii.b) a tariff, or import subsidy, or free trade, for an importable good if the pollution per unit of imports consumption, respectively, exceeds, or is smaller than, or equal to the corresponding pollution per unit of consumption of the quantities of the same good produced domestically.*

Thus, while free-trade is the optimal policy when pollution per unit of consumption of imports and of domestically produced quantities of importable goods are the same, this is not the case when these rates of consumption pollution differ. In our framework, import tariffs/subsidies entail the role of Border Tax Adjustment (BTA) measures which correct for this discrepancy in the rates of consumption pollution. As noted in the Introduction, BTA measures are proposed in the trade and environment literature in order to mitigate carbon leakage effects in the presence of production generated cross-border pollution, e.g., Fischer and Fox (2012), Jakob *et al.* (2013), Keen and Kotsogiannis (2014) and Böhringer *et al.* (2017). Here, we show that in the absence of emission taxes, BTA measures, e.g., import subsidies/tariffs, are required when pollution is consumption generated, and the rates of pollution per unit of consumption between imported and domestically produced quantities of the same good differ.

4 Piecemeal reforms under differentiated rates of consumption pollution

Having established the optimal trade and consumption tax structure we proceed to answer the following question: Given the existing trade and consumption tax structure, how should trade taxes change, in order to reach the optimum tax structure so that welfare and tax revenue do not decrease, and possibly pollution falls? That is, how to design a trade and consumption tax reform policies which can achieve a double, or even a triple dividend? To address this question we consider the following reform policies, widely examined in the literature and proposed by the IMF and the World Bank structural and adjustment programs. These are, (i) a *selective consumer-price-neutral* reform, and (ii) a *consumer-price-neutral* reform of all trade and consumption taxes, when the rates of pollution per unit of consumption between imported and domestically produced quantities of the same good differ.

4.1 Selective consumer-price-neutral reform

First, we examine the welfare, tax revenue and pollution implications of a marginal *consumer-price-neutral* tax piecemeal reform. This reform entails a marginal reduction of the trade tax and a change in the consumption tax on the n^{th} commodity, so that its consumer price remains constant i.e., $dq_n = dt_n + d\tau_n = 0$. By the properties of the GDP function, i.e., supply functions are homogeneous of degree zero in prices, i.e., $\sum_{j=1}^{N} p_j r_{p_j p_n} = 0$, we have $r_{p_n p_n} = -\sum_{j \neq n}^{N} \left(\frac{p_j}{p_n}\right) r_{p_j p_n}$, and by the reciprocity condition we also have $r_{p_j p_n} = r_{p_n p_j}$. Using the above properties in equation (6), the welfare effect of this reform is given as follows:

$$\Omega du = -\left[t_n + e_z\left(a_n - a_n^*\right)\right] r_{p_n p_n} dt_n - \sum_{j \neq n} \left[t_j + e_z\left(a_j - a_j^*\right)\right] r_{p_j p_n} dt_n \Rightarrow$$

$$\Omega \frac{du}{dt_n} = \sum_{j \neq n} \left(\gamma_n - \gamma_j\right) p_j r_{p_j p_n}, \qquad (12)$$

where $r_{p_j p_n} < (>) 0$ depending on whether the j^{th} and n^{th} commodities are substitutes (complements) in production, and $\gamma_i = \frac{t_i}{p_i} + e_z \mu_i$, for $i = j, n$, $\mu_i = \frac{\left(a_i - a_i^*\right)}{p_i}$, if the i^{th} good is an importable. $\frac{t_i}{p_i}$ is the effect of increasing the tariff rate on welfare due to the exacerbation of the production distortion. μ_i captures the induced pollution effect, as a fraction of producers' price, of consuming one unit of domestically produced output of the i^{th} good, instead of consuming one unit of imports of the same commodity. If either $a_i = a_i^*$ or the i^{th} good is an exportable, then $\mu_i = 0$. Thus, γ_i is the per unit of price welfare cost of increasing production of the i^{th} good by one unit, and reducing its imports by one unit, holding everything else constant. We call γ_i the *welfare cost ratio* of the i^{th} good.

In the context of a small open economy, it is well known that trade taxes entail a production and a consumption distrortions which affect welfare negatively. The proposed reform, leaves consumer prices unchanged, and it reduces the producers price of the n^{th} good, thus affecting the production of all goods. This change in production affects (i) the production distortions, and (ii) pollution when the rates of pollution per unit of consumption between imported and domestically produced quantities of the same good differ. The production distortions effect of the above reform policy is given by $\Omega\left(du/dt_n\right) = \sum_{j \neq n} \left(\frac{t_n}{pn} - \frac{t_j}{p_j}\right) p_j r_{p_j p_n}$ regardless of whether the n^{th} good is an exportable or an importable. This is the standard result of the literature in consumer-price-neutral piecemeal reforms of trade and consumption taxes, e.g., Keen and Ligthart (2002). This reform policy is welfare improving when it moves the trade tax ratios $\left(\frac{t_i}{pi}\right)$ towards uniformity. Sufficient, but not necessary, conditions for this result to hold are that the n^{th} commodity (i) is a substitute to all other goods in production, and (ii) it carries the highest trade tax per its price. Intuitively, when we reduce the tariff rate on the n^{th} good and increase the consumption tax so that its consumer price remains constant, then this policy reduces its production and increases the production of all other goods since they are substitutes in production. This reduces the production distortion created by the tariff on the n^{th} good, and increases the production distrotions created by the existence of trade taxes on all other goods. Since the tariff on the n^{th} good is the highest, the gain from the reduction in its production distortion outweighs the increase in production distortions on all other goods.

When the n^{th} good is an importable, in addition to the production distortions effect there is also a pollution effect, given by $e_z \sum_{j\neq n} (\mu_n - \mu_j) \, p_j r_{p_j p_n}$. If the n^{th} good carries the highest difference in the rates of pollution per unit of consumption between the domestically produced and imported quantities relative to all other goods, then the reduction in its production and increase in imports reduces overall pollution.

Here, as indicated by equation (12), and in contrast to the standard reform result, for the *consumer-price-neutral* piecemeal reform to be welfare improving, it is required that it moves towards uniformity the *welfare cost ratios*. That is, in the present framework, this reform policy to be welfare improving it is neither a necessary nor a sufficient condition to reduce the highest trade tax, but to reduce the trade tax on the commodity bearing the highest γ ratio. For example, a *consumer-price-neutral* reform of tariffs is welfare improving if in addition to the above standard conditions (i) and (ii), it is also required that (iii) the n^{th} importable commodity exhibits the highest positive difference in pollution per unit of consumption between domestically produced and imported quantities, relative to all other goods. In the unlikely case where the commodity bearing the highest *welfare cost ratio*, in absolute terms, is an exportable, then by reducing the export tax on it improves welfare, if this good is a substitute in production to all other goods.

The effect of the reform policy on the level of pollution, using equation (5), is given as follows:

$$\frac{dz}{dt_n} = (a^{*\prime} e_{qu} + a' e_{qu}) \frac{du}{dt_n} - \sum_{j\neq n} (\mu_n - \mu_j) \, p_j r_{p_j p_n}, \tag{13}$$

Recall from equation (12) that the sufficient conditions under which the particular *consumer-price-neutral* reform improves welfare, leads to an ambiguous effect on the overall level of consumption pollution. The intuition of the result is straightforward. On the one hand, the reform induced welfare improvement increases consumption and consumption generated pollution. On the other, the particular piecemeal reform by lowering domestic production of the n^{th} good and increasing production of all other goods, decreases overall consumption pollution since the difference in pollution per unit of consumption between the domestically produced and imported quantities of the n^{th} importable good is the highest relative to all other goods. Clearly, when $a_j = a_j^*$, $\forall j$, or if the n^{th} good is an exportable, then a welfare improving *consumer-price-neutral* reform of trade and consumption taxes is also pollution aggravating.

Using the properties of the revenue function, and equation (4) and (12), we can get the effect of this reform program on government revenue as follows:

$$\frac{dG}{dt_n} = -r_{p_n} + \sum_{j\neq n} \left(\frac{t_n}{p_n} - \frac{t_j}{p_j} \right) p_j r_{p_j p_n} + \sum_{j=1}^{N} (t_j + \tau_j) \, e_{q_j u} \frac{du}{dt_n} \tag{14}$$

It is clear from equation (14) that the reduction in the tariff rate on the n^{th} good increases government revenue if (i) the conditions that increase welfare as stated above are satisfied, and (ii) $(t_j + \tau_j)$ is non-negative for all goods. The above results are summarized in the following Proposition.

Proposition 2 *Consider a small open economy where the consumption of goods generates pollution. Reducing marginally the tariff rate on the n^{th} good while increasing its consumption tax so that its consumer price remains constant, increases welfare and may reduce pollution, if the n^{th} good (i) carries the highest tariff rate, (ii) exhibits the highest positive difference in pollution per unit of consumption between imported and domestically produced quantities of the same good per unit of price relative to all other goods and, (iii) is a substitute in production to all other goods. This policy is also revenue increasing if in addition to the above conditions, $(t_j + \tau_j) \geqslant 0, \forall j$ also holds.*

4.2 Only tariff vs. tariff and consumption tax reform

We now compare the welfare effects of a marginal *consumer-price-neutral* piecemeal reform of a tariff and consumption tax, to those of a *piecemeal tariff* reform only. For this comparison to be valid, we assume the same initial equilibrium conditions and zero initial consumption taxes, e.g., Kreickemeier and Raimondos-Møller 2008.

Using the properties of the expenditure function i.e., $\sum_{j=1}^{N} q_j e_{q_j q_n} = 0$, yields $e_{q_n q_n} = -\sum_{j \neq n}^{N} \left(\frac{q_j}{q_n}\right) e_{q_j q_n}$ and by the reciprocity we have $e_{q_j q_n} = e_{q_n q_j}$. Note that when $e_{q_j q_n} > 0 (< 0)$ the n^{th} importable good is a substitute (complement) to the j^{th} good in consumption. Using the above properties, in the case of the piecemeal *tariff* reform only, the effect on the levels of pollution and welfare are given by the following equations:

$$\begin{aligned} \frac{dz}{dt_n} &= \left(\sum_{j=1}^{K} a_j^* e_{qu} + \sum_{j=K+1}^{N} a_j e_{qu}\right) \frac{du}{dt_n} + \sum_{\substack{j \neq n \\ j=K+1}}^{N} \left(\frac{a_j}{q_j} - \frac{a_n^*}{q_n}\right) q_j e_{q_j q_n} + \\ & \sum_{\substack{j \neq n \\ j=1}}^{K} \left(\frac{a_j^*}{q_j} - \frac{a_n^*}{q_n}\right) q_j e_{q_j q_n} - \sum_{j \neq n} \left(\mu_n - \mu_j\right) p_j r_{p_j p_n}, \end{aligned} \tag{15}$$

$$\Omega \frac{du}{dt_n} = \sum_{\substack{j \neq n \\ j=K+1}}^{N} \left(\varepsilon_j - \delta_n\right) p_j e_{q_j q_n} + \sum_{\substack{j \neq n \\ j=1}}^{K} \left(\delta_j - \delta_n\right) p_j e_{q_j q_n} + \sum_{j \neq n} \left(\gamma_n - \gamma_j\right) p_j r_{p_j p_n}. \tag{16}$$

where $\delta_i = \frac{t_i - e_z a_i^*}{q_i}$, $i = j, n$, and $\varepsilon_j = \frac{t_j - e_z a_j}{q_j}$. Subtracting equation (5) from equation

(15), we obtain:

$$\frac{dz}{dt_n}\,|_{Tariff} - \frac{dz}{dt_n}\,|_{Tariff-Consumption\ Tax} = \sum_{\substack{j\neq n\\ j=K+1}}^{N} \left(\frac{a_j}{q_j} - \frac{a_n^*}{q_n}\right) q_j e_{q_j q_n} + \sum_{\substack{j\neq n\\ j=1}}^{K} \left(\frac{a_j^*}{q_j} - \frac{a_n^*}{q_n}\right) q_j e_{q_j q_n}. \tag{17}$$

Equation (17) indicates that, if the n^{th} importable commodity (i) is a substitute to all other goods in consumption, and (ii) its imported quantities exhibit the lowest pollution per unit of consumption as a fraction of its consumer price relative to all other imported and exported quantities, sufficient but not necessary conditions, then the right hand side of the equation is positive. This implies that reducing only the tariff rate is a superior piecemeal reform policy in terms of its effect on the level of pollution, than reducing the tariff rate and increasing its consumption tax so as to keep its consumer price constant.[12] Intuitively, since a tariff is a production subsidy and a consumption tax, the reduction in the tariff alone, reduces the consumption tax on this good, increases its consumption and reduces the consumption of all other goods. Since the n^{th} good causes the lowest pollution per unit of consumption relative to all other goods, the increase in pollution due to increase in its consumption is small relative to the decrease in pollution from the reduction in the consumption of all other goods. In the case where along with the decrease in the tariff we have also an increase in the consumption tax, the previous effect does not emerge since the consumer price do not change, therefore the consumption of goods and pollution do not change. Reversing condition (ii) above, however, i.e., letting the imported quantities of the n^{th} commodity exhibit the highest rate of pollution per unit of consumption as a fraction of its consumer price relative to all other imported and exported quantities, then the right hand side of equation (17) is negative. In this case, reducing only the tariff rate is an inferior piecemeal reform policy in terms of its effect on the level of pollution, than reducing the tariff rate and increasing its consumption tax so as to keep its consumer price constant.

To examine the welfare effects of the two piecemeal reform policies, we subtract equation (16) from (12), and noting that initially $\tau = 0$, to obtain:

$$\Omega\left(\frac{du}{dt_n}\,|_{Tariff} - \frac{du}{dt_n}\,|_{Tariff-Consumption\ Tax}\right) = \sum_{\substack{j\neq n\\ j=K+1}}^{N} (\varepsilon_j - \delta_n)\, q_j e_{q_j q_n} + \sum_{\substack{j\neq n\\ j=1}}^{K} (\delta_j - \delta_n)\, q_j e_{q_j q_n} =$$

[12]By this we mean that if the two reform policies reduce (increase) the level of pollution, this reduction (increase) is higher (lower) under the reduction of the tariff alone.

$$= \underbrace{\sum_{\substack{j\neq n\\ j=1}}^{N}\left(\frac{t_j}{q_j}-\frac{t_n}{q_n}\right)q_j e_{q_j q_n}}_{consumption\ distortion\ effect} + \underbrace{e_z\left[\sum_{\substack{j\neq n\\ j=1}}^{K}\left(\frac{a_n^*}{q_n}-\frac{a_j^*}{q_j}\right)q_j e_{q_j q_n} + \sum_{\substack{j\neq n\\ j=K+1}}^{N}\left(\frac{a_n^*}{q_n}-\frac{a_j}{q_j}\right)q_j e_{q_j q_n}\right]}_{pollution\ effect}. \tag{18}$$

The comparison of the welfare effects of the two tax reform programs rests on two effects. The first effect, we call it the *consumption distortion effect*, is the welfare comparison result in the relevant tax reform literature, e.g., Kreickemeier and Raimondos-Møller (2008). It captures the direct welfare change of reducing the tariff alone as opposed to a *consumer-price-neutral* reduction in the tariff and increase in the consumption tax. Specifically, in the context of a small open economy, the reduction of a tariff entails a double efficiency gain, i.e., a reduction in production and consumption distortions, while the *consumer-price-neutral* reform entails only the production efficiency gain, retaining the consumption distortion since consumer prices remain unchanged. The second effect, we call it the *pollution effect*, is the new effect brought forth by our analysis. It captures the effect of the change in pollution on welfare as a result of the two tax reform programs, when the rates of consumption pollution between imported and domestically produced quantities of a good differ.

Equation (18) shows that if the right hand side is negative (positive) then a marginal *consumer-price-neutral* reduction in the tariff rate and an increase in the consumption tax on the n^{th} good which leaves its consumer price constant, is a welfare inferior (superior) policy compared to a policy which only reduces the tariff rate on this commodity. Sufficient, but not necessary, conditions for the reduction in the tariff rate on n^{th} good to be a welfare superior reform relative to the other policy are that the n^{th} good (i) is a substitute to all other goods in consumption, (ii) carries the highest tariff per unit of price, and (iii) its imported quantities exhibit the lowest rate of pollution per unit of consumption as a fraction of its consumer price, relative to all other imported and exported quantities.[13] If, however, (i) its imported quantities exhibit the highest rate of pollution per unit of consumption as a fraction of its consumer price relative to all other imported and exported quantities, and (ii) this negative *pollution effect* outweighs the *consumption distortion effect*, then the *consumer-price-neutral* tax reform is a welfare superior policy than reducing the tariff rate alone. In the absence of consumption generated pollution, or when pollution per unit of consumption per price is the same for all quantities, imported and domestically produced, the second term in equation (18) is zero. In this case, if conditions (i) and (ii) hold, our analysis reproduces the standard result, i.e., that a marginal

[13] By this we mean that if the two policies increase (reduce) welfare, then this increase (reduction) is higher (lower) under the reduction of the tariff alone.

reduction of the tariff rate on the n^{th} good alone is a welfare superior policy compared to the case of a *consumer-price-neutral* tax reform.

Proposition 3 *Consider a small open economy where the consumption of goods generates pollution. Assume that the n^{th} importable commodity (i) is a substitute to all other goods in consumption and (ii) it carries the highest tariff rate per unit of price.*

- *If its imported quantities exhibit the lowest rate of pollution per unit of consumption as a fraction of its consumer price, relative to all other imported and exported quantities, then, reducing the tariff rate on this good alone is a superior policy in terms of increasing welfare and reducing pollution, relative to a consumer-price-neutral tariff reduction.*

- *If its imported quantities exhibit the highest rate of pollution per unit of consumption as a fraction of its consumer price, relative to all other imported and exported quantities, then, reducing the tariff rate on this good alone it is an inferior policy in terms of reducing pollution, thus it can be an inferior policy in terms of increasing welfare, relative to a consumer-price-neutral tariff reduction.*

5 Consumer-price-neutral reforms of all taxes

The standard trade and consumption tax reform literature has concluded that a proportional reduction in all trade taxes accompanied by an adjustment in consumption taxes, leaving all consumer prices unchanged is a welfare improving reform, e.g., Hatzipanayotou *et al.* (1994), Kreickemeier and Raimondos-Møller (2008). We revisit this result within the present framework, where the pollution per unit of consumption between the imported and domestically produced quantities of the importable goods are different. In this reform program we adjust trade and consumption taxes so that $dp = dt$ and $dq = dt + d\tau = 0$.

Considering the above reform program, we can write equations (4) and (6) in a vector format as follows:

$$dG = (t' + \tau')e_{qu}du - \left(t'r_{pp} + r'_p\right) dt, \text{ and} \quad (19)$$

$$\Omega du = -[t + e_z (a - a^*)]' r_{pp} dt. \quad (20)$$

Setting $dt = -\lambda t$, where λ is a small positive scalar, in equations (19) and (20), we can easily conclude that in the present framework of different pollution rates per unit of consumption of imports and of domestically produced quantities of the same good, the above *consumer-price-neutral* proportional reform of taxes has an ambiguous impact on the country's welfare and tax revenues. This reform policy is welfare improving once there is no difference in pollution per unit of consumption between imported and domestically produced quantities of the same good, i.e., $a - a^* = 0$. Furthermore, it is also revenue increasing if in addition to being welfare improving, $(t' + \tau')$ is non-negative.

Using equations (20), and setting $dt = -\lambda\xi$ it can be shown that this *consumer-price-neutral* reduction in trade taxes is welfare improving. That is:

$$\Omega du = \lambda \xi' r_{pp} \xi, \tag{21}$$

where ξ is a $(N \times 1)$ vector, whose j^{th} element is $\xi_j = t_j + e_z \left(a_j - a_j^*\right) = p_j \gamma_j$ when the j^{th} good is an importable, and it is $\xi_j = t_j$ when the j^{th} good is an exportable. Note that even for the importable goods ξ_j can be negative. Thus, if we adjust trade taxes according to the *rule* $dt = -\lambda \left[t + e_z \left(a - a^*\right)\right] = \lambda\xi$, then welfare improves. This is what we call *welfare cost rule* and it includes the direct cost due to production distortion, and the pollution effect. This rule dictates that even if all specific tariffs are the same, their reduction will not be the same. The most reduced tariff is the one on the importable good with the highest positive difference in pollution per unit of consumption between its domestically produced and imported quantities, relative to all other goods. That is, assuming that all tariffs are the same, the *welfare cost rule* calls for the highest reduction in t_j for the good with the highest positive difference $e_z \left(a_j - a_j^*\right)$. Thus, for the importable goods whose ξ_j is positive we reduce the tariff rate. For the importables for which ξ_j is negative, we increase the tariff rate. For the exportable goods we decrease the export tax. In this way, we adjust trade taxes in order to move the *welfare cost* on each good towards uniformity. Observing, however, equation (19) we conclude that even the above welfare improving *consumer-price-neutral* reform *rule* continues to deliver ambiguous tax revenue effects.

6 Concluding Remarks

The consumption of goods produced in different countries can generate different pollution per unit of consumption. Recognizing this real world phenomenon, the paper develops a small open economy model producing many traded goods, whose consumption generates pollution and where the pollution per unit of consumption between the imported and the domestically produced quantities of the same good is different. Within this framework we show that the first best policy combination calls for (i) consumption taxes on all polluting goods whose rates depends on their pollution per unit of consumption, (ii) free trade for all the exported goods and (iii) a tariff, or an import subsidy, or free trade on an imported good if the pollution per unit of its consumption of the imported quantities is, respectively, higher, or lower, or the same with that of the quantities of the same good that are domestically produced. Thus, this paper contributes to the literature on Border

Tax Adjustment (BTA) measures by showing that in the absence of emission taxes, the optimal policy is to introduce tariffs or import subsidies in addition to consumption taxes.

Our analysis identifies conditions under which a policy reform which reduces the tariff rate and increases the consumption tax on a good that keeps its consumer price constant increases welfare and tax revenue. This policy reform improves welfare when the *welfare cost ratio* of goods due to the tariffs, which in addition to the production distortion includes the pollution effect, move towards uniformity. We show that reducing only the tariff rate on a good is a welfare superior policy relative to a *consumer-price-neutral* reduction in the tariff and increase in the consumption tax, if it carries the highest tariff rate and in addition its imported quantities generate the lowest pollution per unit of consumption relative to all imported and exported quantities (a negative pollution effect). If, however, the pollution effect is positive, i.e., its imported quantities generate the highest pollution per unit of consumption relative to all imported and exported quantities, and is also sufficiently large, then we have a reversal of the well known result and in this case reducing only the tariff is a welfare inferior policy compare to the case where we reduce the tariff rate and increase its consumption tax as to keep its consumer price constant. Finally, we show that a *consumer-price neutral* adjustment in trade taxes which moves the *welfare cost* on all goods towards uniformity, is welfare improving.

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