On the Structure of Indirect Taxes when Consumption Pollution of Domestic and Foreign Goods Differs

Nikos Tsakiris,[*] Panos Hatzipanayotou,[†] Michael S. Michael[‡]

March 2, 2018

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 differ. We show that the first-best policy combination calls for consumption taxes on all polluting goods, zero export taxes and import tariffs or subsidies. We identify conditions under which 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 improves 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

Keywords: Trade and Consumption Tax Reforms, Consumption generated Pollution

[*]Department of Economics, University of Ioannina, P.O. Box 1186, 45110 Ioannina, Greece. E-mail: ntsak@cc.uoi.gr

[†]**Corresponding Author:** Department of International and European Economic Studies, Athens University of Economics and Business; 76, Patission str., Athens 104 34, Greece, and CESifo (Center for Economic Studies and the Ifo Institute of Economic Research). E-mail: hatzip@aueb.gr

[‡]Department of Economics, University of Cyprus; P.O. Box 20537 Nicosia, CY 1678, Cyprus, and CESifo. E-mail: m.s.michael@ucy.ac.cy

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] The US Environmental protection Agency (EPA) reports that in 2014, about 40 percent of greenhouse gases are attributed to residential activity.[2] The "*Oslo Declaration on Sustainable Consumption*" (2005) calls for an intensification of efforts by researchers and policy-makers to implement more sustainable modes of consumption. The Declaration proposes the launching of a comprehensive effort on increasing the "understanding of the consumption-environment connection", including "the environmental impacts of consumption in developed countries upon trading with developing nations". More often than not, the same consumer needs are satisfied by different commodities produced by different firms in different countries using different materials and technologies. As a result the consumption of different varieties of the same product produced in one country or imported, and satisfying the same consumer needs, generates different rates of pollution per unit of consumption. For example, different brands of 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.[3]

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 imports and on consumed quantities of the same good produced domestically 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) an import tariff, subsidy or free-trade on an importable if pollution per unit of imports

[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] Residential activity is largerly held accontable for CO_2 emissions attributed to fossil fuels burned for heat, electricity, the use of products containing greenhouse gases, the handling of waste, and to recreational transportation such as use of passenger cars, sport utility vehicles, pickup trucks, and minivans.

[3] Electrical devices are classified in 7 energy classes (from A to G), depending on the energy they consume towards the energy they attribute. In particular, air conditioning units are rated on the basis of their Energy Efficiency Rate (EER) for summer and of Coefficient of Performance (COP) for winter. The higher these factors are the better energy classifications and the more economical operation the units have . For example, Class A devices have an EER rate of 3.2 and a COP rate of 3.6, while for Class B devices the respective rates are 3.0 and 3.4, etc.

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 international trade-cum-environment linkage 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), Beghin et al. (1997), McAusland (2008), Gulati (2008), Copeland (2011) and Chao et al. (2012).[4] However, while emission taxes is a commonly used instrument when pollution is a by-product of production, rarely are implemented when pollution emanates from consumption activities.[5] We show that a combination of consumption taxes and import tariffs or subsidies lead to the first-best policy choice. This first-best policy is equivalent to the first-best policy recommendation proposed in the relevant literature in terms of its effects on producer and consumer prices, e.g., Copeland (2011). Yet, it is more appealing and practical from an implementation point of view.

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, various types of coordinated tax reforms have been proposed such as replacing trade taxes with consumption taxes. Reducing trade taxes and increasing domestic taxes, e.g., consumption or value-added (VAT) taxes, without, however, compromizing governments' fiscal viability is a standard IMF reform proposal. A sizable literature has addressed the impications of different types of *trade-cum-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), Emran (2005), Kreickemeier and Raimondos-Møller (2008), Boadway and Sato (2009), Jones *et al.* (2011), and Haibara (2012).

[4] 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), Costinot *et al.* (2015).

[5] 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, Austria 0.95, Canada 0.39, Germany 1.20, Greece 1.29, Japan 0.65, Norway 1.47, Sweden 1.26, Switzerland 0.93, 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, Denmark 0.95, Germany 0.25, Hungary 0.88, Israel 1.1, Korea 0.21, the Netherlands 0.81, Norway 0.63, Sweden 1.01, the U.K. 0.37. Taxes on sales and registration of motor vehicles: Austria VAT 20% + New Registration Tax (fuel efficiency, CO_2 emissions, polluting emissions), Belgium VAT 21% + Entry into Service Tax (age, engine power, CO_2 emissions, type of fuel gas), Germany VAT 19%, Iceland VAT 25.5% + Vehicle registration Fee (CO_2 emissions, electric propulsion), the Netherlands VAT 21% + Registration Tax (CO_2 emissions, motor fuel, value, electric propulsion), Norway VAT 25% + Registration Tax (engine performance, CO_2 emissions, NOx emissions, type of fuel, electric propulsion), Spain VAT 21% + Vehicle Registration Tax (CO_2 emissions), the US gas guzzler tax (fuel efficiency). See also Fullerton and West (2002).

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 above literature can improve welfare and raise government revenue. These reforms are, first, a *selective consumer-price-neutral reform* i.e., a reduction of the highest trade tax and a change of the consumption tax so that the consumer price of the good carrying the highest trade tax remains constant. Such a reform is welfare and tax revenue increasing when it moves towards uniformity the *total welfare burden* on goods due to the trade taxes. The latter measure is the sum of the trade tax and pollution burdens induced by the trade taxes. 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 (i) 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 taxes according to the *total welfare burden* rule is welfare improving.[6]

2 The Model

Consider a perfectly competitive small open economy 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. Let $t \equiv [t_1, t_2, ..., t_N]$ be the vector of trade taxes, where for $t_j > (<) 0$ indicates an import tariff (subsidy) or an export subsidy (tax), 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 domestic households. 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, and

[6] A newer and growing trade-cum-environment literature considers the welfare implications of various reform policies such as a radial reduction in trade taxes towards their optimal levels. In the presence of production generated pollution, see, e.g.,Copeland, (1994), Neary (2006), Michael *et al.* (2013), Yanase (2017), and in the presence of consumption generated pollution see, e.g., Beghin *et al.*(1997), 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), Lahiri and Symeonidis (2017).

is written as:

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

where $e(q, z, u)$ denotes the minimum expenditure on commodities to achieve a level of utility u at consumer prices q and consumption pollution z.[7] 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, thus 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. The country's Gross Domestic Product function (GDP) is given by $r(p)$ and denotes the maximum value of output produced at producers prices p, given the country's fixed factor supplies and production technologies.[8] 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, thus r_p is the vector of the country's supply functions of the traded 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. An element of this vector can be 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 pollution per unit of consumption of imports, and, a_j be 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:

---

[7] 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, homothetic and concave, and h is increasing and convex. The $e(.)$ function implies complete separability between consumption and pollution, ensuring that relative demands are independent of the environmental damage.

[8] 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.

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

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

The first bracketed right-hand-side term in 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.[9] Equations (1), (2) and (3) constitute the system characterizing the equilibrium of this economy.

3 Optimal trade and consumption taxes

Equations (1), (2) and (3) are used to 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 j^{th} commodity, and noting that $dq_i = dt_i + d\tau_i$ and $dp_i = dt_i$, yields:[10]

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

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

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

[9] 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 $z = a_2^* e_{q_2} + a_1 e_{q_1} + (a_2 - a_2^*) r_{p_2}$.

[10] Hereon, for analytical clarity we assume that demand for traded goods and clean environment are independent in consumption, i.e., $e_{q_j z} = 0$, and $e_{q_j u} > 0$, $\forall\ j = 1, ...N$. A preferences strucutre supporting such an analytical conjecture can be of the form of the expenditure function $g(q)\,\overline{u} + z$.

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

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

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

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:

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

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:

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

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

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

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

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:

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

The following conclusions emerge from equations (9) and (11). First, an import tariff (subsidy) is the optimal trade policy for the importable goods, and a zero trade tax (subsidy) is the optimal policy for exportable ones. 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. These first-best policy recommendations are more practical and easier to implement relative to optimal policy combinations proposed thus far in the relevant literature.[11]

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 a subsidy, or free trade for an importable good if the pollution per unit of imports consumption 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 consumption pollution. The idea of BTA measures in the trade-cum-environment literature is not a new one. Recently, for example, 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. Here, we show that in the absence of emission taxes, a form of BTA

[11]It can be argued, however, that while emission taxes constitute widespread instruments adopted when pollution is a by-product of production, rarely are implemented when pollution emanates from consumption activities. Instead, consumption taxes are frequently used to regulate consumption pollution emissions, e.g., OECD (2014) and Fullerton and West (2002).

(subsidies/tariffs) is required when consumption pollution is local and the rates of pollution per unit of consumption between imported and domestically produced quantities of the same good differ.

4 Piecemeal reforms under consumption pollution

4.1 Selective consumer-price-neutral reform

We examine the welfare, tax revenue and pollution implications of a marginal consumer-price-neutral *trade-cum-consumption 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 revenue 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:

$$\begin{aligned}\Omega du &= -\left[t_n + e_z\left(a_n - a_n^*\right)\right] r_{p_n p_n} dt_n - \sum_{j\neq n}\left[t_j + e_z\left(a_j - a_j^*\right)\right] r_{p_j p_n} dt_n \Rightarrow \\ \Omega\frac{du}{dt_n} &= \sum_{j\neq n}\left(\gamma_n - \gamma_j\right) p_j r_{p_j p_n}, \end{aligned} \tag{12}$$

where $\gamma_i = \frac{t_i + e_z\left(a_i - a_i^*\right)}{p_i}$, for $i = j, n$ when the i^{th} commodity is an importable, and $\gamma_i = \frac{t_i}{p_i}$ when the i^{th} commodity is an exportable. We call γ_i the *total welfare burden ratio of a trade tax.* In the case of importable commodities it consists of two parts. The first, i.e., $\frac{t_i}{p_i}$, captures the direct welfare burden of the import tariff as a fraction of domestic producers' price. The second, i.e., $\frac{e_z\left(a_i - a_i^*\right)}{p_i}$, captures the welfare burden due to the difference in pollution per unit of consumption between the imported and the domestically produced quantities of the i^{th} good as a fraction of p_i. Thus, for the importable goods, γ_i is positive provided that $a_i > a_i^*$. Else, it can be negative. For the exportable goods, γ_i is negative.

Observing equation (12) the following results emerge. When consumption pollution is absent, or when pollution per unit of consumption of imported and domestically produced quantities of the same good are the same, i.e.., $a_j = a_j^*$, $\forall j$, equation (12) reduces to $\Omega\left(du/dt_n\right) = \sum_{j\neq n}\left(\frac{t_n}{pn} - \frac{t_i}{pi}\right) p_j r_{p_j p_n}$. This is the standard result of the literature in *consumer-price-neutral piecemeal reforms* of trade -cum-consumption taxes. That is,this reform policy is welfare improving when it brings the *trade taxes towards uniformity.*

Sufficient, but 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.

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 brings towards uniformity the *total welfare burden ratios of trade taxes.* That is, in the present framework, for the particular piecemeal 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 $\blacksquare$ ratio. Thus, for example, a *consumer-price-neutral piecemeal reform* of tariffs-cum-consumption taxes is welfare improving if in addition to the above standard conditions (i) and (ii) it 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, in absolute terms, total welfare burden is an exportable, then by reducing this export tax improves welfare if this good is a substitute in production to all other goods.

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

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

where $\mu_i = \frac{\left(a_i - a_i^*\right)}{p_i}$, for $i = j, n$, if the i^{th} good is importable, and $\mu_i = 0$ if the i^{th} good is exportable. If the i^{th} good is importable, μ_i captures the excess pollution burden, as a fraction of producers' price, of consuming a unit of domestically produced output of the importable, relative to consuming one unit of imports of the same commodity. Recall from equation (12) that the sufficient conditions under which the particular *consumer-price-neutral* trade-cum-consumption taxes piecemeal reform improve welfare, also lead to an ambiguous effect on the overall level of consumption pollution. The intuition of the result is straighforward. 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-cum-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, if the n^{th} good (i) carries the highest tariff rate, (ii) exhibits the highest positive difference in pollution per unit of consumption between domestically and foreign produced quantities of the importable goods per unit of price 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-cum-consumption tax reform

We now compare the welfare effects of a marginal *consumer-price-neutral piecemeal reform* of tariff-cum-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:

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

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

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:

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

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 exhibits the lowest pollution per unit of consumption as a fraction of its consumer price relative to all other imported and exportable goods, then the right hand side of the equation is positive (sufficient but not necessary conditions). 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 which 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 decrease in the tariff we have also increase in consumption tax, the previous effect does not exists since the consumer price, the consumption of goods and pollution does not change. Reversing condition (ii) above, however, i.e., letting the imported quantities of the n^{th} commodity exhibits the highest rate of pollution per unit of consumption as a fraction of its consumer price relative to all other goods imported quantities and exported goods, 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 equa-

[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.

tion (16) from (12), and noting that initially $\tau - 0$, to obtain:

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

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

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 exhibits the lowest rate of pollution per unit of consumption as a fraction of its consumer price, relative to all other imported and exported quantities, i.e., a negative pollution distortion.[13] If, however, (i) its imported quantities exhibits the highest rate of pollution per unit of consumption as a fraction of its consumer price relative to all other imported and exported quantities, i.e., a positive pollution distortion, and (ii) this positive pollution externality outweights the trade distortion, then reducing the tariff rate and increasing its consumption tax is a welfare superior policy than reducing only the tariff rate. Note that in the absence of consumption generated pollution, or when pollution per unit of consumption per price is the same for goods, imported and domestically produced, then the second term in equation (18) is zero. In this case we get the well know result that a marginal reduction of the tariff rate on the n^{th} good only is a welfare superior policy compared to the case where the tariff rate is reduced and its consumption tax is increases as to keep its consumer price constant if conditions the above (i) and (ii) hold. e.g., Kreickemeier and Raimondos-Møller (2008). Thus, in the presence framework, if the n^{th} imported commodity exhibits a sufficiently strong positive pollution externality, then we have a reversal of the well known result and reducing the tariff rate and increasing its consumption tax as to keep its price constant is welfare superior policy than reducing only the tariff rate.

Proposition 3 *Consider a small open economy where the consumption of goods gener-*

[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.

ates pollution. If the n^{th} imported commodity is (i) a substitute to all other goods in consumption and (ii) has the highest tariff rate per unit of price. Then, if its imported quantities exhibits the lowest (highest) rate of pollution per unit of consumption as a fraction of its consumer price, relative to all other goods imported quantities and exported goods, then, reducing the tariff rate on this good is a superior (can be inferior) welfare policy relative to a consumer-price-neutral tariff-cum-consumption tax, tariff reduction.

5 Consumer-price-neutral reforms under consumption pollution

The standard indirect tax reform literature has concluded that a radial reduction in trade taxes accompanied by an adjustment in consumption taxes, leaving all consumer prices unchanged is a welfare improving reform. 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:

$$\begin{aligned} dG &= (t' + \tau')e_{qu}du - \left(t'r_{pp} + r_p'\right)dt, \text{ and} && (19) \\ \Omega du &= -[t + e_z\left(a - a^*\right)]'r_{pp}dt. && (20) \end{aligned}$$

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 specific consumer-price-neutral radial reform of trade-cum-consumption taxes has an ambiguous impact on the country's levels of government tax revenues and welfare. 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.

In the present context, a consumer-price-neutral reform of trade-cum-consumption taxes which is welfare improving is the following. Let $dt = -\lambda\gamma$, where γ is a an $(N \times 1)$ vector, whose j^{th} element is $\gamma_j = t_j + e_z\left(a_j - a_j^*\right)$ if the j^{th} good is an importable, and it is $\gamma_j = t_j$ when the j^{th} good is an exportable one. Note that even for the importable goods γ_j can be negative. Thus, if we adjust trade taxes according to the following rule $dt = -\lambda\left[t + e_z\left(a - a^*\right)\right]$, then welfare improves. We call this the *total welfare burden rule* that includes the direct burden due to trade taxes and the pollution burden. 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 othe goods. That is, assuming that all $t_j s$ are the same, the total welfare burden 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 γ_j is positive we reduce the tariff rate. For the importables for which γ_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 bring the total welfare burden ratio on each good towards uniformity.

Using equations (20) and (19) it can be shown that the consumer-price-neutral reduction in trade taxes according to this *total welfare burden rule* is welfare improving. That is:

$$\Phi du = \lambda \gamma' r_{pp} \gamma. \tag{21}$$

Thus, welfare improves if we have a consumer-price-neutral reduction of trade taxes according to the total welfare burden rule which in addition of the standard trade distortion, it also includes the pollution distortion. 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 by different firms in different countries can generate different pollution per unit of consumption. Recognizing this real world phenomenon, this 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, a subsidy or free trade on an imported good if the pollution per unit of its consumption of the imported quantities is higher, lower or the same with that of the quantities of the same good that are domestically produced.

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 total welfare burden of goods due to the tariffs, which besides the trade tax burden includes the pollution burden, move towards uniformity. We identifies the conditions under which the reduction of the tariff rate on a good is a welfare superior policy relative to the case where we reduce the tariff rate and increase its consumption tax as to keep its consumer price constant. We show that reducing the tariff rate on a good is a welfare superior policy if it curries 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 i.e., negative pollution externality. We show, however, that if the pollution externality is positive (i.e., its imported quantities generate the highest pollution per unit of consumption relative to all imported and exported quantities) and 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 brings the total welfare burden ratios on all goods towards uniformity, is welfare improving.

Appendix

Writing equations (4), (5) and (6) in a vector format we get:

$$\begin{aligned} dz &= \left(a_I^{*\prime} e_{q_I u} + a_E^{\prime} e_{q_E u}\right) du + \left(a_I^{*\prime} e_{q_I z} + a_E^{\prime} e_{q_E z}\right) dz + \left(a_I^{\prime} - a_I^{*\prime}\right) r_{p_I p} dt \Rightarrow \\ \delta dz &= \left(a_I^{*\prime} e_{q_I u} + a_E^{\prime} e_{q_E u}\right) du + \left(a_I^{\prime} - a_I^{*\prime}\right) r_{p_I p_I} dt, \end{aligned} \tag{A.1}$$

$$\begin{aligned} dG \;&=\; \left(t' + \tau'\right)\left[\left(e_{q_I u} + e_{q_E u}\right) + \delta^{-1}\left(e_{q_I z} + e_{q_E z}\right)\left(a_I^{*\prime} e_{q_I u} + a_E^{\prime} e_{q_E u}\right)\right] du \\ &\quad + \left[\delta^{-1}(t' + \tau')\left(e_{q_I z} + e_{q_E z}\right)\left(a_I^{\prime} - a_I^{*\prime}\right) r_{p_I p_I} - t' r_{pp} - r_p\right] dt, \quad \text{and} \end{aligned} \tag{A.2}$$

$$\begin{aligned} e_u du &= r_p dt + dG - e_z dz \Rightarrow \\ \Delta du &= -\left[t' r_{pp} + \left(e_z - \left(t' + \tau'\right)\left(e_{q_I z} + e_{q_E z}\right)\right)\left(a_I^{\prime} - a_I^{*\prime}\right) r_{p_I p_I} \delta^{-1}\right] dt, \end{aligned} \tag{A.3}$$

where $\Delta = e_u - (t' + \tau')\left(e_{q_I u} + e_{q_E u}\right) + \left[e_z - (t' + \tau')\left(e_{q_I z} + e_{q_E z}\right)\right]\left(a_I^{*\prime} e_{q_I u} + a_E^{\prime} e_{q_E u}\right)\delta^{-1}$. To facilitate the analysis we assume that $e_{q_I z} = e_{q_E z} = 0$, thus $\delta = 1$. That is, commodities and clean-environment are independent in consumption. Applying the *trade-cum-consumption taxes* radial reform $dt < 0$ and $d\tau > 0$, $d\tau = -dt = -\theta t$, so that $dq = dt + d\tau = 0$, we obtain equations (**??**), (19) and (20) in the text.

References

[1] Abe, K., 1995, The target rates of tariff and tax reform, *International Economic Review* 36, 875-885.

[2] Beghin, J., D. Roland-Holst, and D. van der Mensbrugghe, 1997, Trade and pollution linkages: piecemeal reform and optimal intervention, Canadian Journal of Economics 30, 442-455.

[3] Boadway, R., and M. Sato, 2009, Optimal Tax Design and Enforcement with an Informal Sector," American Economic Journal: Economic Policy 1, 1-27.

[4] Chao C-C., Laffargue, J-P. and P. Sgro, 2012, Tariff and environmental policies with product standards, Canadian Journal of Economics 45, 978-995.

[5] Copeland, B., 1994, International trade and the environment: Policy reform in a polluted small open economy, Journal of Environmental Economics and Management 26, 44-65.

[6] Haibara, T., 2012, Alternative approaches to tax reform, *Economics Letters* 117, 408-410.

[7] Hatzipanayotou, P., Michael S.M., and S.M. Miller, 1994, Win-win indirect tax reform. *Economics Letters* 44, 147-151.

[8] Hu, B., and R. McKitrick 2016, Decomposing the Environmental Effects of Trade Liberalization: The Case of Consumption-Generated Pollution, Environmental and Resource Economics 64, 205-223.

[9] Emran, M.S., and J.E. Stiglitz. 2005. On selective indirect tax reform in developing countries. *Journal of Public Economics* 89: 599-623.

[10] Emran, M.S. 2005, Revenue-increasing and welfare-enhancing reform of taxes on exports. *Journal of Development Economics* 77: 277-292.

[11] Fulerton, D., and S. West, 2002, Can taxes on cars and on gasoline mimic an unavailable tax on emissions? *Journal of Environmental Economics and Management* 43, 135-157.

[12] Jones, C., Morrissey, O., and Nelson, D., 2011, Did the World Bank Drive Tariff Reforms in Eastern Africa?, *World Development* 39, 324-335.

[13] Kayalica, O. and O. Kayalica, 2005, Transboundary pollution from consumption in a reciprocal dumping model, Global Economy Review 5, Article 7.

[14] Keen, M., and J.E. Ligthart, 2002, Coordinating tariff reduction and domestic tax reform. *Journal of International Economics* 56: 489-507.

[15] Kreickemeier, U., and P. Raimondos-Møller, 2008, Tariff–tax reforms and market access. *Journal of Development Economics* 87: 85-91.

[16] McAusland, C., 2005, Harmonizing tailpipe policy in symmetric countries: Improve the environment, improve welfare?, Journal of Environmental Economics and Management 50, 229-251.

[17] Metcalfe, M., and J., Beghin, 2015, Piecemeal reform of trade and environmental policy when consumption also pollutes, *Economics Bulletin* 35, 2282-2287.

[18] Michael, S.M., P. Hatzipanayotou, and S.M. Miller, 1993, Integrated reforms of tariffs and consumption taxes. *Journal of Public Economics* 52, 417-428.

[19] Michael, M., and P. Hatzipanayotou, 2013, Pollution and reforms of domestic and trade taxes towards uniformity, I*international Tax and Public Finance* 20, 753-768.

[20] Michael S.M., S. Lahiri, and P., Hatzipanayotou, 2015. "Piecemeal Reform of Domestic Indirect Taxes toward Uniformity in the Presence of Pollution: with and without a Revenue Constraint," Journal of Public Economic Theory, Association for Public Economic Theory, vol. 17(2), pages 174-195, 04.

[21] Neary, P., 2006, International trade and the environment: Theoretical and policy linkages, Environmental and Resource Economics 33, 95-118.

[22] Turunen-Red, A. and A. Woodland, 2004, Multilateral reforms of trade and environmental policy, Review of International Economics 12, 321-336.