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Three tax reforms with and without public pollution abatement

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Abstract

The literature has explored three strategies for reforming tariffs and consumption taxes: price-neutral tax reforms, revenue-neutral tax reforms, and consumption-neutral tax reforms. In the presence of private pollution abatement only, consumption-neutral tax reforms rank first in terms of welfare improvements. With the presence of both private and public pollution abatement, welfare-improving tariff protection reform packages occur. Unless income effects are zero, price-neutral tax reforms do not rank first regardless of the type of pollution abatement.

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1. Introduction

There are two approaches to reforming tariffs and consumption taxes: a price-neutral tax reform (see Hatzipanayotou et al. 1994; Keen and Ligthart 2002; Emran and Stiglitz 2005a Kreickemeier and Raimondos-Møller 2008; Fujiwara 2015; Tsakiris et al. 2019) and a revenue-neutral tax reform (see Michael et al. 1993; Emran and Stiglitz 2005b). A new approach has recently been advanced: tax rates should be altered to leave the consumption of taxed goods unchanged—so called a consumption-neutral tax reform (see Haibara 2012). A key issue not addressed adequately in the literature thus far is the welfare implications of the above three tax reforms in the presence of consumption pollution externalities[1]. A notable exception is the work of Chao et al. (2012) and Michael and Hatzipanayotou (2013): they establish sufficient conditions for welfare-improving price-neutral tax reforms when consumption pollution exists. The present paper differs from these studies in two respects. First, we consider earmarking domestic tax revenue for public pollution abatement[2]. By doing so, the paper focuses on the environmental effect which is not taken up by Chao et al. (2012) and Michael and Hatzipanayotou (2013); that is, tax reforms reduce pollution emissions via changes in the revenue allocated to public pollution abatement. Of particular relevance here is a consumption-neutral tax reform, whereby the level of consumption and therefore pollution emissions remain unchanged. The reform involves two pollution abatement measures. Specifically, private abatement is needed to offset the consumption pollution increase caused by tariff cuts or consumption tax cuts. (Note that the private abatement in this paper refers to households cut back on energy consumption in response to higher taxes). In order to achieve a net reduction in pollution emissions, public abatement will be necessary. As this example shows, public and private abatement are needed simultaneously when implementing trade and domestic tax reforms. Second, and more importantly, the present paper is the first effort to rank three tax reforms with and without public pollution abatement. In the presence of private pollution abatement only, consumption-neutral tax reforms rank first in terms of welfare improvements. With the presence of both private and public pollution abatement, welfare-improving tariff protection reform packages occur. Unless income effects are zero, price-neutral tax reforms do not rank first regardless of the type of pollution abatement.

The present paper makes two distinct contributions. First, we show that the type of pollution abatement affects the welfare improving conditions of three tax reforms[3]. Here, the paper provides a theoretical qualification on the efficiency of a price-neutral tax reform—a standard practice in the literature. Second, the paper contradicts the traditional view that tariffs should be replaced by consumption taxes. Public pollution abatement, if financed by tariff revenue only, allows for the unconventional reform packages of tariff hikes and consumption tax cuts.

The layout of this paper is as follows. Section 2 develops the simple general equilibrium model following Dixit and Norman (1980). Section 3 analyses the welfare implications of the three tax reforms without public pollution abatement. Section 4 considers public abatement and re-examined the results reported in the previous section. Section 5 concludes this paper.

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[1] Aside from neutrality conditions, Beghin et al. (1997) and Metcalfe and Beghin (2015) examine coordinated trade liberalization and environmental policy reforms in a small open economy with consumption pollution externalities. They show that a proportional decrease of tariff distortions accompanied by a proportional decrease of pollution distortions increases welfare.

[2] Anderson (1996) identifies a simple sufficient condition under which price-neutral tariff-tax reforms increase welfare in the presence of public good. Hatzipanayotou et al. (2005) show that a shift from public abatement increases welfare in the presence of cross-border production pollution externalities.

[3] Michael and Hatzipanayotou (2013) show that the type of pollution externalities (i.e., consumption pollution or production pollution) affects the welfare-improving conditions of price-neutral tax reforms.

2. The Model

Consider a small open economy, consuming and producing n tradable goods which are subject to a vector of trade taxes, t. All other goods can be aggregated into a single composite commodity whose price is set equal to unity by choice of numeraire and omitted from the list of arguments of the behavioral functions for convenience. The consumer price relationships in the economy are as follows: $p = p^* + \tau + t$. The expression p is the vector of the domestic relative prices of taxed goods; p^* is the vector of the international relative prices of tradable goods and assumed to be fixed; τ denotes a vector of consumption taxes, while t represents the vector of trade taxes. I describe the production side of the economy as the revenue function $R(p)$: R_p denotes the output of good x, and R_{pp} is positive. The behavior of the representative household can be compactly expressed as the following expenditure function, $E(p,r,u)$, where u denotes utility (welfare). From the properties of the expenditure function, its derivatives with respect to prices (i.e., $x = \partial E / \partial p$) are the economy's Hicksian net demand functions where x is the vector of tradable goods. E is concave in prices (i.e., E_{pp} is negative) and the scaler E_u is the inverse of the marginal utility of income and is strictly positive. Since all goods are assumed to be normal, E_{pu} is positive. The expression r is the net emission of pollution.

$$r = z - g, \tag{1}$$

where $z = E_p$ denotes consumption pollution externalities and g is the level of public abatement. Note that one unit of consumption generates one unit of pollution. The partial derivative of the expenditure function with respect to r ($E_r > 0$) gives the household's marginal willingness to pay for pollution abatement (see Copeland 1994). It is assumed throughout the paper that pollution and consumption are assume to be separable, i.e., $E_{pr} = 0$

The economy's budget constraint is as follows:

$$E(p,r,u) = R(p) + (1-\alpha)\tau E_p + (1-\beta)tM_p, \tag{2}$$

where $M_p = E_p - R_p$ is positive and indicates net imports; if we consider exports and export taxes, then M_p and t are both negative. The first right-hand side of Eq. (2) is factor income from private production. The remaining terms indicate tax revenue. Since a fraction of tax revenue (i.e., $\alpha\tau E_p$ and $\beta t M_p$) is earmarked for public abatement, the remaining fraction of consumption tax revenue $(1-\alpha)\tau E_p$ and tariff revenue $(1-\beta)tM_p$ is returned to consumers in a lump-sum fashion.

The government's budget constraint is as follows:

$$P_g g = \alpha\tau E_p + \beta t M_p, \tag{3}$$

where P_g indicates the cost of public abatement which is imported from abroad (see Hadjiyiannis et al. 2009). Equations (1)-(3)contain three endogenous variables (z, g, u) and two tax policy instruments (τ, t).

3. The absence of public pollution abatement

As a benchmark for comparison, we first compare the welfare effects of three tax reforms without pollution externalities. Totally differentiating (1) keeping in mind that $dr = dg = 0$ leads to :

$$\Delta du = A_\tau d\tau + A_t dt, \tag{4}$$

where $\Delta = E_u - (\tau + t)E_{pu}$, $A_\tau = (\tau + t)E_{pp}$, and $A_t = (\tau E_{pp} + tM_{pp})$ both of which are negative. Consider a price-neutral reform of tariff cuts and consumption tax hikes (i.e., $d\tau = -dt$):

$$\left.\frac{du}{dt}\right|_{P-N} = \frac{-tR_{pp}}{\Delta}. \tag{5}$$

This leads to a familiar result of Hatzipanayotou et al. 1994; Keen and Ligthart 2002: a tariff tax reform improves welfare via decreased production distortions. The abbreviation "P-N" indicates price neutrality.

It is also possible to implement the reform to keep the consumption of taxed goods at a constant level (i.e., $dx = 0$): we refer to it as consumption neutrality (abbreviated as "C-N"). Totally differentiate $x = E_p$ yields:

$$\left.\frac{d\tau}{dt}\right|_{C-N} = -\frac{(\Delta E_{pp} + E_{pu}A_t)}{(\Delta E_{pp} + E_{pu}A_\tau)}. \tag{6}$$

Here, we make a natural assumption that tax hikes (cuts) reduce (increase) consumption; so the signs of the denominator and numerator of (6) are negative. It means that the increased consumption

by a decrease in t can be offset by the decreased consumption by an increase in τ. By substituting (6) into (4), we get:

$$\left.\frac{du}{dt}\right|_{C-N} = -\frac{-E_{pp}tR_{pp}}{(\Delta E_{pp} + E_{pu}A_{\tau})}. \tag{7}$$

Consider next a revenue-neutral tax reform (the abbreviation of revenue neutrality is "R-N" . Totally differentiate government revenue $G = \tau E_p + tM_p$ yields:

$$\left.\frac{d\tau}{dt}\right|_{R-N} = -\frac{\Delta(M_p + \tau E_{pp} + +tM_{pp}) + (\tau + t)E_{pu}A_t}{\Delta(E_p + \tau E_{pp} + +tE_{pp}) + (\tau + t)E_{pu}A_{\tau}}. \tag{8}$$

If the tax rates to be changed are revenue increasing—as will often be the case—then the sign of the right-hand side of (8) is negative: the revenue loss (resp. gain) from tariff cuts (resp. hikes) can be compensated by the revenue gain (resp. loss) from consumption tax hikes (resp. cuts). From (8) and (4), we obtain:

$$\left.\frac{du}{dt}\right|_{R-N} = -\frac{R_p A_{\tau} - tR_{pp}E_p}{(\tau + t)E_{pu}A_{\tau} + \Delta(E_p + \tau E_{pp} + +tE_{pp})}. \tag{9}$$

Eqs. (6) and (8) confirm that a combination of tariff cuts and consumption tax hikes improves welfare. The interpretation is analogous to that of (5). Now compare (5), (7) and (8)[4], assuming that $\tau = 0$ initially.

$$\left.\frac{du}{dt}\right|_{P-N} - \left.\frac{du}{dt}\right|_{C-N} = -\frac{\overbrace{tR_{pp}E_{pu}A_{\tau}}^{(-)}}{\underbrace{(\Delta E_{pp} + E_{pu}A_{\tau})\Delta}_{(-)}}. \tag{10}$$

$$\left.\frac{du}{dt}\right|_{P-N} - \left.\frac{du}{dt}\right|_{R-N} = -\frac{\overbrace{tR_pE_{pp}\Delta}^{(-)} + \overbrace{tR_{pp}(tE_{pp}\Delta + tE_{pu}A_{\tau})}^{(-)}}{\underbrace{[(\tau + t)E_{pu}A_{\tau} + \Delta(E_p + \tau E_{pp} + +tE_{pp})]\Delta}_{(+)}}. \tag{11}$$

$$\left.\frac{du}{dt}\right|_{C-N} - \left.\frac{du}{dt}\right|_{R-N} = \frac{\overbrace{-\Delta t(E_{pp})^2(R_{pp} + R_p)}^{(-)}\overbrace{-tE_{pp}R_{pp}tE_{pu}A_{\tau}}^{(-)}\overbrace{-E_{pu}A_{\tau}t(R_pE_{pp} - tR_{pp}E_p)}^{(-)}}{(\Delta E_{pp} + E_{pu}A_{\tau})[(\Delta(E_p + \tau E_{pp} + +tE_{pp}) + (\tau + t)E_{pu}A_{\tau}]}. \tag{12}$$

Eq. (10) indicates that the magnitude of a welfare improvement is higher when implementing price-neutral reforms than consumption-neutral reforms. The reason: the former reforms increase the level of consumption of taxed goods via real income gains, whereas the latter keep it at a constant level. So, if income effects on the non-numeraire commodities are zero (i.e., $E_{pu} = 0$), then price-neutral reforms are equivalent to consumption-neutral reforms. Eqs. (11) and (12) show that revenue-neutral tax reforms increase welfare by more than other tax reforms. As compared to other tax reforms, the magnitude of consumption tax hikes is lower. This is because tariff cuts reduce production subsidies. So, the revenue loss from tariff cuts is negligible, allowing little room for consumption tax hikes. It places revenue-neutral reforms at a relative advantage over other tax reforms. We have the following proposition.

Proposition 1: *Suppose that the country reduces tariffs and simultaneously increases consumption taxes in the absence of pollution externalities. Then,*
(i) The ranking of a welfare improvement is R-N > P-N > C-N.
(ii) If income effects on non-numeraire commodities are zero, the ranking is R-N > P-N = C-N.

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[4] Throughput the analysis we compare the three tax reforms starting at the same initial equilibrium and thereby assume $\tau = 0$ initially (see Kreickemeier and Raimondos-Møller (2008)).

The intellectual underpinning for the shift away from trade taxes to VAT has been provided by the production efficiency theorem in Diamond and Mirrlees (1971). Yet no consensus has been reached concerning the proper approach to reforming indirect tax structures. Pursuing this approach is the motivation for the present paper.

We next compare three tax reforms in the presence of pollution externalities with private pollution abatement *only* (i.e., $g = 0$). By totally differentiating (1) and (2), we obtain after some manipulation:

$$\Delta du = A_\tau d\tau + A_t dt, \tag{4}'$$

Note the coefficients now become $\Delta = E_u + [E_r - (\tau + t)E_{pu}]$, $A_\tau = (\tau + t - E_r)E_{pp}$, and $A_t = (\tau + t - E_r)E_{pp} - tR_{pp}$. The introduction of pollution externalities does not alter the fundamental results of (5) and (7). But the welfare improvement ranking could reverse:

$$\left.\frac{du}{dt}\right|_{P-N} - \left.\frac{du}{dt}\right|_{C-N} = -\underbrace{\frac{tR_{pp}E_{pu}A_\tau}{(\Delta E_{pp} + E_{pu}A_\tau)\Delta}}_{(-)}. \tag{13}$$

Unlike the earlier result of no pollution externalities, the sign of A_τ now becomes positive if marginal environmental damages are higher than the tax rates ($E_r > \tau + t$). As said before, a price-neutral trade liberalization reform increases welfare (in other words, real income) by more than a consumption-neutral liberalization reform. This suggests that the degree of consumption pollution increase is larger under the former reform than it is under the latter—C-N preserves the dirty good consumption[5].

Turning to revenue-neutral reforms, we obtain by using (8):

$$\left.\frac{du}{dt}\right|_{R-N} = \frac{R_p(\tau + t - E_r)E_{pp}A_\tau - tR_{pp}(E_rE_{pp} + E_p)}{\Delta(E_p + \tau E_{pp} + + tE_{pp}) + (\tau + t)E_{pu}A_\tau}. \tag{14}$$

It says that a revenue-neutral combination of tariff cuts and consumption tax hikes lowers welfare when $E_rE_{pp} + E_p$ is negative and $E_r > \tau + t$. A tariff cut lowers production subsidies and thereby mitigates the revenue loss. This lowers the magnitude of consumption tax increase and the resulting pollution abatement. On net, the level of pollution rises and welfare falls with the reform. We have the following proposition.

Proposition 2: *Suppose that the country reduces tariffs and simultaneously increases consumption taxes in the presence of consumption pollution. Then if marginal environmental damages are very large, the ranking of a welfare improvement is C-N > P-N. Welfare falls with R-N if* $E_rE_{pp} + E_p$ is *negative, sufficient but not necessary condition.*

This—together with Proposition 1 suggests that there is a sharp welfare difference between revenue-neutral tax reforms and other tax reforms. Also note that, unlike much of the existing tariff-tax reform literature, price neutrality is not *a sine qua non*. The question is whether the results obtained so far continue to hold in the presence of public pollution abatement.

4. The presence of both private and public pollution abatement

Differentiating (2), (3) and using (1) to eliminate *dr* gives the following (see Appendix):

$$\Delta du = A_\tau d\tau + A_t dt, \tag{4}'$$

The coefficients now become

$$\Delta = P_g\{E_u + E_{pu}[E_r - (\tau + t)E_{pu}]\} - E_r(\alpha\tau E_{pu} + \beta t E_{pu}),$$
$$A_\tau = P_g(\tau + t - E_r)E_{pp} + (E_r - P_g)(\alpha E_p + \alpha\tau E_{pp} + \beta\tau E_{pp}), \text{ and}$$
$$A_t = P_g(\tau + t - E_r)E_{pp} + (E_r - P_g)(\beta M_p + \alpha\tau E_{pp} + \beta t M_{pp}) - P_g tR_{pp}$$

Note that Δ is the determinant of the matrix of the coefficient of the unknown variables and positive by stability[6]. The signs of A_τ and A_t are both positive if private abatement costs ($\tau + t$) and public

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[5] That is why consumption neutrality is also called "environmental preservation rule" (see Haibara (2021)).

[6] The government budget constraint can be written as $B = \alpha\tau E_p + \beta t M_p - P_g g$. If the equilibrium is locally stable, then we have

abatement costs(P_g) are sufficiently small (i.e., $E_r > \tau + t$ and $E_r > P_g$).

We now examine the welfare effects of price-neutral and consumption-neutral reforms in the presence of both private and public abatement. By a similar series of steps to those which led to Eq. (5) we obtain the followings.

$$\left.\frac{du}{dt}\right|_{P-N} = \frac{(E_r - P_g)[(\beta-\alpha)E_p - \beta(R_p + tR_{pp})] - P_g tR_{pp}}{\Delta}, \tag{15}$$

$$\left.\frac{du}{dt}\right|_{C-N} = \frac{E_{pp}\{(E_r - P_g)[(\beta-\alpha)E_p - \beta(R_p + tR_{pp})] - P_g tR_{pp}\}}{(\Delta E_{pp} + E_{pu}A_\tau)}, \tag{16}$$

The two tax reforms improve welfare to the extent $E_r > P_g$, $\alpha > 0$, and $\beta = 0$. A reduction in *t* lowers the tariff revenue earmarked for public pollution abatement and thereby entails a welfare loss under the assumption of $E_r > P_g$. However, this undesired environmental effect does not appear when consumption tax revenue only is earmarked for public abatement ($\beta = 0$).We then make a comparison of the magnitude of the welfare improvements.

$$\left.\frac{du}{dt}\right|_{P-N} - \left.\frac{du}{dt}\right|_{C-N} = \frac{\{(E_r - P_g)[(\beta-\alpha)E_p - \beta(R_p + tR_{pp})] - P_g tR_{pp}\}E_{pu}A_\tau}{\underbrace{(\Delta E_{pp} + E_{pu}A_\tau)\Delta}_{(-)}}. \tag{17}$$

It says that the impact of C-N is of a greater magnitude compared to the impact of the P-N. As noted earlier, C-N is superior to P-N in terms of pollution abatement, remembering that P-N increases consumption pollution emissions mainly via income effects, whereas C-N avoids increasing these emissions. Even in terms of public abatement, C-N is a superior policy. This is because the magnitude of consumption tax hikes is larger than that of tariff cuts[7]. Tariff cuts induce positive income effects due to a reduction in production subsidies—effects which are lacking to consumption taxation. To offset this, the magnitude of increased τ must be higher than that of decreased *t*. In case of P-N, however, the magnitude of these tax changes are equivalent. In this summing up, a net reduction in pollution emission is higher under C-N than it is under P-N. This explains why C-N improves welfare by more than P-N provided $E_r > P_g$.

Turning now to a revenue-neutral tax reform in the presence of *g*, we obtain:

$$\left.\frac{du}{dt}\right|_{R-N} = \frac{(E_p + \tau E_{pp} + tE_{pp})(A_t - A_\tau) + A_\tau(R_p + tR_{pp})}{\Delta(E_p + \tau E_{pp} + +tE_{pp}) + (\tau + t)E_{pu}A_\tau}, \tag{18}$$

where $A_t - A_\tau = \{(E_r - P_g)[(\beta-\alpha)E_p - \beta(R_p + tR_{pp})] - P_g tR_{pp}\}$. Welfare does not necessarily rise given the assumption of $\beta = 0$ (i.e., the sign of $A_t - A_\tau$ is negative). The reason for this is analogous to that of (14): a decrease in production subsidies lowers the magnitude of increased τ and of pollution emission reductions. However, unlike the previous result of (14), welfare does not necessarily fall even under the large value of E_r : because *g* reinforces the consumption tax-induced pollution abatement. Suppose that welfare rises with the reform by assuming the large initial consumption of taxed goods (E_p): which means revenue gains and the resulting public abatement effect are very large. We then compare this with (15) and (16).

$$\left.\frac{du}{dt}\right|_{P-N} - \left.\frac{du}{dt}\right|_{R-N} = \frac{A_\tau[(A_t - A_\tau)E_{pu} - (R_p + tR_{pp})]}{[\Delta(E_p + \tau E_{pp} + +tE_{pp}) + (\tau + t)E_{pu}A_\tau]\Delta}. \tag{19}$$

$$\left.\frac{du}{dt}\right|_{C-N} - \left.\frac{du}{dt}\right|_{R-N} = -\frac{\{(A_t - A_\tau)E_{pu}A_\tau[(E_p + tE_{pp}) - tE_{pp}] + (R_p + tR_{pp})A_\tau(\Delta E_{pp} + E_{pu}A_\tau)\}}{(\Delta E_{pp} + E_{pu}A_\tau)[\Delta(E_p + \tau E_{pp} + +tE_{pp}) + (\tau + t)E_{pu}A_\tau]}. \tag{20}$$

The right-hand sides of (18) and (19) are negative under the assumptions of, $E_r > \tau + t$, $E_r > P_g$,

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$d\dot{B}/dg < 0$. From (1), (2), and (3), we obtain $d\dot{B}/dg = -\Delta/\{E_u + E_{pu}[E_r - (1-\alpha)\tau - (1-\beta)t]\} < 0$ It means that the signs of Δ and $E_u + E_{pu}[E_r - (1-\alpha)\tau - (1-\beta)t]$ are both positive.

[7] Eq. (6) indicates that if signs of A_τ and A_t are positive and if in addition $A_t < A_\tau$, then the magnitude of increased τ is larger than that of decreased *t*.

and $\beta = 0$: which means non-revenue-neutral combination of tariff cuts and consumption tax hikes improve welfare by more than revenue-neutral tax reforms.

Now suppose that only tariff revenue is earmarked for public pollution abatement (i.e., $\alpha = 0$ and $\beta > 0$) and also assume that $E_r > \tau + t$ and $E_r > P_g$. Then, if the initial consumption of taxed goods (E_p) is very large, then the sign of $A_t - A_\tau$ becomes positive. It allows for the unconventional reform packages of tariff hikes and consumption tax cuts. In this case, both P-N and C-N improve welfare by more than R-N (notice that the signs of Eqs. (19) and (20) now become positive) if E_{pu} is very large. The magnitude of offsetting tax cuts is greater the larger (resp. the smaller) value of E_{pu} under R-N (resp. C-N)[8]. Since tax cuts induce pollution increases, revenue-neutral tax reforms are plausibly inferior to other tax reforms in terms of welfare improvements. Conversely, if the value of E_{pu} is very small, then the ranking reverses: the welfare improvements of revenue-neutral reforms are greater than other tax reforms.

Proposition 3: *Suppose that tariff revenue only is earmarked for public pollution abatement. Suppose also that the initial consumption of taxed goods is very large. Then, the welfare-improving unconventional reform packages of tariff hikes and consumption tax cuts occur. The ranking of a welfare improvement is C-N > P-N > R-N (resp. R-N > C-N > P-N) if pollution abatement is under-provided initially and if income effects on non-numeraire commodities are very large (resp. small).*

Two points have to be noted. First, the presence of public pollution abatement provides a rationale for tariffs in a small open economy[9], the reason being that a reduction in consumption pollution distortions could outweigh the production distortions induced by tariffs. The situation in mind here is that environmental tariff revenue (e.g. border tax revenue) is earmarked to finance public abatement. Second, and more importantly, unless income effects are zero, price-neutral reforms do not rank first regardless of the type of pollution abatement.

The question addressed is: Which approach, a tariff plus offsetting tax cut or a tariff only, is the appropriate one?[10] Subtracting (15), (16), and (17) from the equation when only tariffs are increased gives (note that that $\tau = 0$ initially) :

$$\left.\frac{du}{dt}\right|_{P-N} - \left.\frac{du}{dt}\right|_{tariffs-only} = -\frac{\Omega}{\Delta}, \tag{21}$$

$$\left.\frac{du}{dt}\right|_{C-N} - \left.\frac{du}{dt}\right|_{tariffs-only} = -\frac{(\Omega E_{pp}\Delta + E_{pu}A_\tau\Theta)}{\Delta(\Delta E_{pp} + E_{pu}A_\tau)}, \tag{22}$$

$$\left.\frac{du}{dt}\right|_{R-N} - \left.\frac{du}{dt}\right|_{tariffs-only} = \frac{-\Omega(E_p + tE_{pp})\Delta + (R_p + tR_{pp})A_\tau\Delta - tE_{pu}A_\tau\Theta}{\Delta[\Delta(E_p + tE_{pp}) + tE_{pu}A_\tau]}, \tag{23}$$

where

$\Omega = (E_r - P_g)\beta tE_{pp} + P_g(t - E_r)E_{pp}$, $\Theta = E_{pp}P_g(t - E_r) + (E_r - P_g)(\beta M_p + \beta tM_{pp}) - P_g tR_{pp}$.

Suppose that public abatement costs (P_g) are sufficiently small whereas the level of earmarking (β) is sufficiently large. Then it is possible that the sign of Ω (Θ) is negative (positive) under the assumptions of $E_r > \tau + t$ and $E_r > P_g$. From Eqs. (21) and (22), we can find the superiority of reform packages in terms of welfare improvements. This seems a *curiosum*, since offsetting consumption tax cuts raise pollution externalities. But remember: tariff revenue only is earmarked for public

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[8] Eqs. (6) and (8) indicates that if signs of A_τ and A_t are positive (and $A_t > A_\tau$), then the magnitude of offsetting τ is larger (resp. smaller) the larger the value of E_{pu} under R-N (resp. C-N).

[9] In large open economies, tariffs (or border tax adjustments) can be justified to address pollution emissions abroad (see, for example, Markusen (1975) Keen and Kotsogiannis (2014)). Tsakiris et al. (2019) show that environmental tariffs can be appropriate in a small open economy, showing that with presence of consumption pollution externalities, the first-best policy combination calls for consumption taxes on all polluting goods, and import tariffs: Border Tax Adjustment (BTA) measures. The present paper differs from the studies referred to above in that the presence of public pollution abatement justifies tariffs and consumption tax cuts.

[10] Kreickemeier and Raimondos-Møller (2008) and Tsakiris et al. (2019) show tariff cuts alone improve welfare by more than tariff cuts plus consumption tax hikes.

pollution abatement. In this case, decreased τ raises consumption and therefore tariff revenue, thus reinforcing public abatement. It could more than offset the increased pollution if (β) is sufficiently large. Regarding revenue-neutral reforms, one additional condition is in order. That is, the value of E_{pu} is very small: because otherwise the magnitude of tax cuts (and therefore pollution increases) must be very large via real income and revenue gains. We have the following proposition.

Proposition 4: *If the public abatement cost is sufficiently small whereas the level of tariff revenue earmarking is sufficiently large, then both P-N and C-N improve welfare by more than tariffs alone. R-N improves welfare by more than tariffs alone if income effects on non-numeraire commodities are very small.*

Thus, if β is very small, then the above unconventional reform packages are inferior to tariffs alone in terms of welfare improvements. In this case, the conventional reform packages (i.e., tariff cuts plus consumption tax hikes) become a particularly policy relevant. There are some exceptions. Eq. (22) indicates that C-N improves welfare by more than tariffs alone if E_{pu} (P_g) is very large (small). Tariffs alone increase real income and thereby attenuate the emission reduction by tariffs. This undesired income effect on pollution emissions does not appear in case of C-N. Another exception occurs in case of R-N. Eq. (23) suggests that revenue-neutral reform packages could improve welfare by more than tariffs alone provided the initial level of output and its price responsiveness are sufficiently large[11]. The large value of $R_p + tR_{pp}$ entails a significant revenue loss and thereby leaves little room for offsetting tax cuts; so tariff-induced private abatement could outweigh the reduction in public abatement under the sufficiently small value of β .

Though not explicitly analyzed above, a consumption-neutral reform appears relevant to the autarky case where only consumption tax is used to finance public abatement. In this case, the degree of earmarking α becomes a policy variable. Specifically, an increase in τ and α to achieve $dx = 0$ is welfare-improving through increased public abatement. In this way, C-N is likely to be of wider relevance, as many countries implement public abatement activities. Even leaving aside abatement issues, consumption neutrality may be worth considering because certain amount of energy consumption (i.e., a basic need) cannot be avoided.

5. Conclusions

It is well known that second-best policy rankings are circumstance-dependent (see. Bhagwati and Ramaswami (1963)). While consumption-neutral tax reforms rank first in case of private pollution abatement only, price-neutral tax reforms, albeit standard in the literature, do not rank first regardless of the type of pollution abatement. Of particular interest is the finding that public pollution abatement, if financed by tariff revenue only, allows for the unconventional reforms of tariff hikes and consumption tax cuts. There are cases in which revenue-neutral tax reforms improve welfare more than the two tax reforms. The results obtained provide novel insights into public finance analysis: environmental earmarking creates a distinction among three tax reforms. A more general analysis would include multiple pollution externalities (including production pollution) and multiple tax rates[12]. This is a theme for future research.

Appendix

Differentiating (1)-(3) and using (1) to eliminate dr gives the following:

$$\begin{bmatrix} E_u + E_{pu}[E_r - (1-\alpha)\tau - (1-\beta)t] & -E_r \\ -(\alpha\tau + \beta t)E_{pu} & P_g \end{bmatrix} \begin{bmatrix} du \\ dg \end{bmatrix} = \begin{bmatrix} (\tau + t - E_r)E_{pp} - (\alpha E_p + \alpha\tau E_{pp} + \beta t E_{pp}) \\ \alpha E_p + \alpha\tau E_{pp} + \beta t E_{pp} \end{bmatrix} d\tau$$

$$+ \begin{bmatrix} (\tau + t - E_r)E_{pp} - (\beta M_p + \alpha\tau E_{pp} + \beta t M_{pp} + tR_{pp}) \\ \beta M_p + \alpha\tau E_{pp} + \beta t M_{pp} \end{bmatrix} dt$$

The absence of public abatement (i.e., $g = 0$, $\alpha = \beta = 0$) leads to Eq. (4)'.

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[11] It is possible that the sign of the RHS of (18) is positive if the value of β is sufficiently small.

[12] Here, one can examine the welfare effects of "squeezing" of tax rates of some pair of substitutes à la Hatta (1986).

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