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RESEARCH ARTICLE

Trade liberalization and the choice of pollution abatement

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Abstract

It is well known that a consumer price-neutral reform of consumption taxes and import tariffs is welfare-improving. This paper shows that such price controls are inferior to quantity controls in terms of welfare improvement. The paper next turns to a comparison of different abatement strategies. Whether or not policy changes should fix private abatement or public abatement relates to the level of earmarking, and depends on the relationship between private production and public abatement. There are cases in which increased public abatement *only* improves welfare by more than both increased private and public abatement together. The paper recommends that environmental earmarking in the form of public abatement should be delivered to cushion price hikes and sustain private energy consumption.

Keywords: earmarking; price controls; private abatement; public abatement; quantity controls

JEL classification: F18; H20; Q56

1. Introduction

Many developing countries face three overarching challenges: trade liberalization, revenue mobilization, and environmental protection (including health management). Aslam *et al.* (2022) indicate that the pandemic has added to existing financing pressures in sub-Saharan Africa (SSA), triggering large health spending needs for prevention and treatment, and subsequently for securing vaccines. They also note that revenue mobilization creates fiscal room for all categories of emergency and development spending, including to meet the sustainable development goals (SDGs). In many cases, the tax proceeds can be expected to finance particular purposes, now known as earmarking—or, in fiscal jargon, hypothecation. Examples include the Green Climate Fund (GCF) in South Africa and tobacco tax earmarking in Botswana, Egypt, Iceland, Romania, Poland, the Philippines, Viet Nam, Thailand, and Panama (see Cashin *et al.*, 2017). Developed countries are no exception. In France, Germany, Italy, and the Netherlands, earmarking environmental projects is mostly used with respect to water pollution charges (see Marsiliani and Renström, 2000); e.g., the Dutch water pollution tax is earmarked to finance the activities of sanitation and purification of wastewater.

The economic analysis of earmarking has received substantial attention, from Buchanan (1963) on. Numerous papers since then have studied the pros and cons of earmarking. On the negative side, it is frequently argued that earmarking tax revenues for specific expenditure is harmful inflexibility and thereby introduces economic inefficiency. Earmarking constrains spending on particular items (e.g., pollution abatement), even if there may be a poor match between actual spending needs and the revenues raised (Parry *et al.*, 2014; Carattini *et al.*, 2017). On the positive side, there are many reasons for earmarking. One is based on economic efficiency. Buchanan (1963) shows that earmarking redresses the undesirable distortion of consumption choices that general-fund financing imposes. Pirttilä (1999) shows that spending tax revenues on projects that are beneficial to the losers of environmental tax policy may then alleviate the compensation problems and facilitate more efficient environmental policy. Another reason for earmarking is based on political concerns: earmarking the proceeds to pay for additional emissions reduction reassures voters that the tax will be effective and the environmental objective will be met (e.g., Kallbekken and Sælen, 2011; Baranzini and Carattini, 2017). Sælen and Kallbekken Kallbekken and Sælen (2011) find that earmarking tax revenues for environmental purposes (such as supporting public transport) garnered majority support to increase fuel taxes by up to 15 per cent in their Norwegian study. Brett and Keen (2000) show that green politicians may choose to earmark revenues if the efficiency loss from doing so is outweighed by the value of constraining subsequent and potentially non-green policymakers from wasting the funds raised.[1] Much of the discussion of earmarking revolves around the political economy model, and its effectiveness in the context of revenue mobilization is largely unknown.

The rationale for revenue mobilization is rooted in the production efficiency theorem in Diamond and Mirrlees (1971); i.e., a shift away from trade taxes to domestic taxes improves economic efficiency. The literature has explored two approaches to modeling welfare- and revenue-increasing trade, and domestic tax reforms. The first one represents a price control approach: changes in consumption taxes (resp. production taxes) and tariffs (resp. export taxes) in a way that keeps consumer prices (resp. producer prices) at a constant level (see Hatzipanayotou *et al.*, 1994; Keen and Ligthart, 2002; Emran, 2005; Emran and Stiglitz, 2005, Kreickemeier and Raimondos-Møller, 2008; Hatzipanayotou *et al.*, 2011; Michael and Hatzipanayotou 2013; Fujiwara, 2015; Tsakiris *et al.*, 2019). The second is a quantity control approach[2]: changes in trade and/or domestic taxes to preserve the level of demand or output of taxed commodities (see Haibara, 2012, 2017, 2022a).[3] What is left unanswered by previous studies is the ranking between these two approaches in the presence of environmental earmarking. Michael and Hatzipanayotou (2013) study a price-neutral trade and domestic tax reforms, focusing on pollution externalities.[4] As regards earmarking (for public good provisions), Hatzipanayotou *et al.* (2011) *derive sufficient conditions* under which the price-neutral reform

[1] A related study is that of Marsiliani and Renström (2000): earmarking constraints can act as a commitment mechanism and thereby solve a time-inconsistency problem. Carattini *et al.* (2017) provide a survey of the political rationale for tax revenue earmarking.

[2] Relatedly, Michael *et al.* (1993), Hatzipanayotou *et al.* (2011), and Emran and Stiglitz (2005) study the welfare effects of revenue-neutral tariff tax reforms.

[3] Haibara (2012) labels it as a consumption-neutral tax reform (note that this literature does not study trade tax reforms).

[4] Michael *et al.* (2015) examine the welfare effects of domestic tax reforms without price-neutral conditions.

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increases welfare. The paper closest to ours is Haibara (2022a), albeit being set in a very different framework. This literature compares the two approaches in the presence of pollution externalities without considering environmental earmarking. The present paper therefore seeks to bridge the gap between the literature on environmental earmarking and the literature on trade and domestic tax reforms. Specifically, the paper attempts to rank the above two control measures, focusing on taxes earmarked for public abatement activities. It is shown that price controls are inferior to quantity controls in terms of welfare improvement. The paper also adds a caveat to a reform of trade and domestic taxes: this reform could backfire on the environment and is welfare-worsening when allowing for public pollution abatement.[5]

Another contribution of this paper is that it sheds new light on the choice of pollution abatement activities. This choice is particularly relevant for the quantity control approach. Specifically, private abatement is needed to offset the consumption pollution increase caused by tariff cuts. The private abatement here refers to households' cutback on energy consumption in response to higher taxes or higher prices.[6] Consumption neutrality fixes the level of private abatement because tariff cuts and consumption tax hikes move in the opposite direction. Public abatement is therefore needed to achieve a net reduction in pollution. The problem is that public abatement falls with tariff cuts; i.e., a decrease in the earmarked tariff revenue and/or a reduction in private production (which is complementary with public abatement). The question of interest here is: Which abatement—private abatement or public abatement—should be fixed by policy changes?[7] If the level of private abatement remains unchanged, the reform affects pollution via changes in public abatement. Vice versa, if the level of public abatement remains unchanged, the reform affects pollution via changes in private abatement. Whether or not policy changes should fix private abatement or public abatement relates to the level of earmarking, and depends on the relationship between private production and public abatement. There are cases in which increased public abatement *only* improves welfare by more than *both* increased private and public abatement together. In this context, the present paper provides a novel insight into earmarking: environmental earmarking in the form of public abatement (e.g., wastewater management and reforestation) should be delivered to cushion price hikes and sustain private energy consumption. That might be worth considering because compensating tax cuts or subsidies (against price shocks) hinder revenue mobilization and public abatement. The results here are especially relevant for countries pursuing environmental protection, not sacrificing energy consumption. This might typify a developing country where a certain amount of energy use cannot be avoided.

The layout of this paper is as follows. Section 2 develops the simple general equilibrium perfectly competitive model of a small open economy following Dixit and Norman (1980). Section 3 analyzes the welfare implications of tariff and consumption tax reforms. Here, we focus on the welfare effects of *all* tax changes (but not a selective tax reform): specifically, a reduction of *all* tariffs and a simultaneous increase of *all* consumption

[5] Anderson (1996) argues against a tariff-tax reform in the presence of public goods and non-traded goods.

[6] Hatzipanayotou *et al.* (2005) regard private abatement as a pollution tax-induced emission reduction. For the real-world experiences of private and public abatement, see Lovei (1995) and Francis *et al.* (1999).

[7] Note that offsetting both consumption effects and public abatement effects is not possible because, unlike tariffs, consumption taxes do not affect the production-public abatement linkage.

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taxes.[8] We then compare a price-neutral reform with a consumption-neutral reform. Section 4 turns to a comparison of different pollution abatement activities. Section 5 reconsiders the choice of pollution abatement, taking into account exogenous price hikes. Section 6 concludes this paper.

2. The model

The model is analyzed using the dual approach pioneered by Dixit and Norman (1980). This literature has been extended subsequently to encompass public good provision (Yanase, 2010; Hatzipanayotou *et al.*, 2011) and public abatement activities (Chao and Yu, 1999; Hatzipanayotou *et al.*, 2005). The model structure is a synthesis of the public abatement study of Hatzipanayotou *et al.* (2005) and trade and domestic policy reform of Yanase (2010)[9] and Hatzipanayotou *et al.* (2011). We consider a perfectly competitive general equilibrium model of a Heckscher–Ohlin small open economy. There are a number of commodities.[10] We take one good to be the numeraire, and label it y. Let q be the fixed vector of world prices of the other n goods (which are labelled as x). The numeraire good is assumed to be the clean good and bears no indirect taxes, whereas the non-numeraire good is the dirty good and bears indirect taxes (see Chao and Yu, 1999). The country has a number of fixed factors, which are used in the production of private goods and public abatement provision. Consumer and producer prices are respectively given as

$$q = p^f + \tau + t \text{ and } p = p^f + t,$$

where p^f is the vector of the international relative prices of tradable goods and is exogenous; τ denotes consumption taxes; and t indicates import tariffs. There is a single representative consumer with preferences characterized by the expenditure function

$$E(q, r, u) = \min\{d_y + qd_x : u = \Phi(d_y, d_x) + \phi(r)\}$$

where u denotes utility (welfare), r indicates net pollution emissions, and d_x and d_y are the demand for goods x and y respectively. (Note that implicit in the list of arguments of E is the price of a composite clean good, which we take as numeraire so its price can be set equal to one). By using the linear homogeneity property of the expenditure function, we have $qE_{qq} + 1E_{q1} = 0$, which means the numeraire good and non-numeraire good are a substitute; i.e., E_{q1} is positive. The clean numeraire good has a role here, because a higher tax on the dirty good can trigger consumption substitution toward the clean good, thereby reducing consumption pollution emissions. The function E is concave and homogenous of degree one in all prices. Its derivative with respect to prices gives the compensated demands of x ($E_q = x$) and E_{qq} is negative semidefinite. The derivative E_u indicates the inverse of the marginal utility of income. Since all goods are assumed to be normal, E_{qu} is positive. The partial derivative of the expenditure function with respect

[8] Thus, we do not examine the welfare effects of squeezing of tax rates of any pair of substitutes à la Hatta (1986). This is left for future research.

[9] Yanase (2010) studies an integrated reform of tariffs and consumption taxes in the presence of *production* pollution externalities and a public consumption good. Our paper fundamentally differs from this literature in that we focus on *consumption* pollution externalities. Moreover, the reform of Yanase (2010) is not consumer price-neutral, nor is it consumption-neutral, both of which are at the heart of our paper. The common point is that all pollutants are a substitute for public activities.

[10] For simplicity, no distinction is made in notation between row and column vectors.

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to r ($E_r > 0$) gives the household's marginal willingness to pay for pollution abatement (see Copeland, 1994). For analytical simplicity, we assume that net pollution emissions and consumption are assumed to be separable, i.e., $E_{qr} = 0$.

The consumption of the non-numeraire good generates pollution,

$$z_c = E_q, \tag{1}$$

where z_c is consumption pollution. Here one unit of consumption generates one unit of pollution.

The production side of the economy is characterized by a "restricted revenue function",[11] $R(p, g)$ where g is the level of public pollution abatement (see appendix A). The function R is convex and homogeneous of degree one in producer prices; i.e., R_{pp} is positive and $R_p = y$ where y indicates the vector of supplies. Moreover, $R_g = -C_g$ where C_g is the unit cost of public abatement and $R_{gg} = 0$ under the Heckscher–Ohlin framework. The scaler $R_g < 0$ means that public abatement provision reduces private production.

Net emissions r can be expressed as

$$r = z_c - g. \tag{2}$$

The economy's budget constraint is

$$E(q, r, u) = R(p, g) - gR_g(p, g) + (1 - \alpha)\tau E_q + (1 - \gamma)t(E_q - R_p). \tag{3}$$

The first and second terms on the right-hand side of equation (1) are factor incomes from private production $R(p, g)$ and public abatement activities $-gR_g(p, g)$. The remaining terms are a part of tax revenue returned to consumers in a lump-sum fashion. In this context, the government allocates a fraction of domestic tax revenue for public abatement activities, and this fraction (α, γ) is a policy instrument available to the government. The government budget constraint (B) can thus be written as

$$B = \alpha\tau E_q + \gamma t(E_q - R_p) + gR_g = 0, \tag{4}$$

where $\alpha\tau E_q$ and $\gamma t(E_q - R_p)$, respectively, indicate a fraction of consumption tax revenue and tariff revenue earmarked to finance public abatement.

Equations (1)–(4) contain four endogenous variables (z_c, g, r, u) and five exogenous variables $(\tau, t, \alpha, \gamma, p^f)$. For later reference, the present paper assumes that the international price of p^f is altered by uncontrolled adverse events such as conflicts and/or pandemics. Totally differentiate (1)–(4) yields (see appendix B):

$$\Delta du = A_\tau d\tau + A_t dt + A_p dp^f + A_\alpha d\alpha + A_\gamma d\gamma, \tag{5}$$

Where

$$\Delta = \{E_u + E_{qu}[E_r - (1 - \alpha)\tau - (1 - \gamma)t]\}(\gamma t R_{pg} - R_g) + (\alpha\tau + \gamma t)E_{qu}[R_{pg}(1 - \gamma)t - E_r]^{12},$$

[11]See Abe (1992) and Hatzipanayotou *et al.* (2005) for the derivation of this function.

[12]If the equilibrium is locally stable, then we have $d\dot{B}/dg < 0$ where B indicates the government budget constraint. From (1)–(3), we obtain $d\dot{B}/dg = -\Delta/\{E_u + E_{qu}[E_r - (1 - \alpha)\tau - (1 - \gamma)t]\} < 0$, which means that the signs of Δ and $\{E_u + E_{qu}[E_r - (1 - \alpha)\tau - (1 - \gamma)t]\}$ are both positive.

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$$
\begin{aligned}
A_\tau &= (\gamma t R_{pg} - R_g)\{-\alpha E_q + E_{qq}[(1-\alpha)\tau + (1-\gamma)t - aE_r]\}\\
&\quad - \{R_{pg}(1-\gamma)t - E_r\}(\alpha E_q + \alpha\tau E_{qq} + \gamma t E_{qq}),\\
A_t &= (\gamma t R_{pg} - R_g)\{-\gamma(E_q - R_p)\\
&\quad + E_{qq}[(1-\alpha)\tau + (1-\gamma)t - aE_r] - R_{pp}(1-\gamma)t - gR_{gp}\}\\
&\quad - \{R_{pg}(1-\gamma)t - E_r\}[\gamma(E_q - R_p) + \alpha\tau E_{qq} + \gamma t E_{qq} - \gamma t R_{pp} + gR_{gp}],\\
A_p &= -R_g[R_p - E_q + E_{qq}(\tau - E_r)]\\
&\quad + (E_r + R_g)[\alpha\tau E_{qq} + \gamma t(E_{qq} - R_{pp}) + gR_{gp}] + t(E_{qq} - R_{pp}),\\
A_\alpha &= \tau E_q(E_r + R_g - tR_{pg}),\ A_\gamma = t(E_q - R_p)(E_r + R_g - tR_{pg}).
\end{aligned}
$$

As regards changes in public pollution abatement, we have:

$$
\Delta dg = g_\tau d\tau + g_t dt + g_\alpha d\alpha + g_\gamma d\gamma, \tag{6}
$$

where

$$
\begin{aligned}
g_\tau &= \{E_u + E_{qu}[aE_r - (1-\alpha)\tau - (1-\gamma)t]\}(\alpha E_q + \alpha\tau E_{qq} + \gamma t E_{qq})\\
&\quad + (\alpha\tau + \gamma t)E_{qu}\{-\alpha E_q + E_{qq}[(1-\alpha)\tau + (1-\gamma)t - aE_r]\},\\
g_t &= \{E_u + E_{qu}[aE_r - (1-\alpha)\tau - (1-\gamma)t]\}\\
&\quad \times [\gamma(E_q - R_p) + \alpha\tau E_{qq} + \gamma t E_{qq} - \gamma t R_{pp} + gR_{gp}]\\
&\quad + (\alpha\tau + \gamma t)E_{qu}\{-\gamma(E_q - R_p) + E_{qq}[(1-\alpha)\tau + (1-\gamma)t - E_r]\\
&\quad - R_{pp}(1-\gamma)t - gR_{gp}\},\\
g_p &= [(E_u - tE_{qu})\alpha\tau E_{qq} + (\alpha\tau + \gamma t)E_{qu}(R_p - E_q)] + gR_{gp}[E_u - tE_{qu} + (E_r - \tau)E_{qu}]\\
&\quad + t[(E_{qq} - R_{pp})(E_u + \alpha\tau E_{qu}) - \gamma R_{pp}(E_r - \tau)E_{qu}],\\
g_\alpha &= \tau E_q[E_u + (E_r - \tau)E_{qu}],\ g_\gamma = t(E_q - R_p)[E_u + (E_r - \tau)E_{qu}].
\end{aligned}
$$

3. Reforms of import tariffs and consumption taxes

We start with the environmental effects of a consumer price-neutral reform of tariff cuts and consumption tax hikes (i.e., $dt < 0,\ d\tau > 0$, and $dq = dt + d\tau = 0$). We assume, unless stated otherwise, that all tariff revenue is returned to households in a lump-sum fashion ($\gamma = 0$).

Totally differentiating (2) yields

$$
\begin{aligned}
\left.\frac{dr}{dt}\right|_{dq=0} &= \left.\frac{dx}{dt}\right|_{dq=0} - \left.\frac{dg}{dt}\right|_{dq=0},\\
&= \left[\frac{E_{qu}(A_t - A_\tau)}{\Delta}\right] - \left.\frac{dg}{dt}\right|_{dq=0}\\
&= \left[\frac{E_{qu}(A_t - A_\tau)}{\Delta}\right] - \frac{g_t - g_\tau}{\Delta}.
\end{aligned} \tag{7}
$$

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Note that g_τ, g_t, A_τ, and A_t now become (assuming that $\gamma = 0$)

$$\begin{aligned}
g_\tau &= E_u(\alpha E_q + \alpha\tau E_{qq}) + E_{qu}\alpha E_q(E_r - \tau - t),\\
g_t &= E_u(\alpha\tau E_{qq} + gR_{gp}) + E_{qu}gR_{gp}(E_r - \tau - t) - \alpha\tau E_{qu}tR_{pp},\\
A_\tau &= (\alpha E_q + \alpha\tau E_{qq})(E_r + R_g - tR_{pg}) - R_gE_{qq}(\tau + t - E_r),\\
A_t &= (\alpha\tau E_{qq} + gR_{gp})(E_r + R_g - tR_{pg}) - R_gE_{qq}[(\tau + t - E_r) - tR_{pp}],\\
A_t - A_\tau &= (gR_{gp} - \alpha E_q)(E_r + R_g - tR_{pg}) + R_gtR_{pp}.
\end{aligned}$$

The sign of g_τ is positive if $E_r > \tau + t$,[13] while the sign of g_t is negative under the assumption of $R_{gp} < 0$. The reform has conflicting effects on r. The first term on the right-hand side of (7) indicates that the real income gains from reduced tariff distortions increase the demand for the dirty good and therefore pollution emissions $E_{qu}(A_t - A_\tau)\Delta^{-1} < 0$. In this case, the reform has a negative impact on private abatement $dx/dt|_{dq=0} < 0$. The second term on the right-hand side captures public abatement effects. A reduction in tariffs raises the level of the dirty consumption and therefore the level of g if environmental benefits are sufficiently large relative to initial tax levels $E_r > \tau + t$. Namely, real income gains increase the demand for taxed commodities (which are normal in demand) and thereby increase earmarked revenue. This is reinforced by the substitutability of private production and public abatement; i.e., tariff cuts lower the production of importables and thereby increase public abatement provision.

We turn to the quantitative approach following Haibara (2017, 2022a, 2022b). *Consider* the reform that keeps the consumption of taxed goods at a constant level. Let $x = E_q(q, r, u)$ be the total consumption for taxed commodities and differentiate it,

$$\Delta dx = (\Delta E_{qq} + E_{qu}A_\tau)d\tau + (\Delta E_{qq} + E_{qu}A_t)dt. \tag{8}$$

Here, we make a natural assumption that tax hikes (cuts) reduce (increase) consumption due to sufficiently large substitution effects ($|E_{qq}|$), so the sign of the coefficients of the tax changes is negative. By setting $dx = 0$, we obtain

$$\left.\frac{d\tau}{dt}\right|_{dx=0} = -\frac{(\Delta E_{qq} + E_{qu}A_t)}{(\Delta E_{qq} + E_{qu}A_\tau)}. \tag{9}$$

From (2), we obtain

$$\begin{aligned}
\left.\frac{dr}{dt}\right|_{dx=0} &= -\left.\frac{dg}{dt}\right|_{dx=0},\\
&= -\left[g_\tau\left(\frac{d\tau}{dt}\right)_{dx=0} + g_t\right].
\end{aligned} \tag{10}$$

The right-hand side is positive under the assumptions of $g_\tau > 0$, $g_t < 0$, and $d\tau/dt|_{dx=0} < 0$. It is important to notice that, unlike in equation (7), private abatement effects (i.e., dx/dt) vanish. This is why the policy of $dx = 0$ affects pollution mainly

[13]The inequality $\alpha E_q + \alpha\tau E_{qq} > 0$ can be guaranteed if the consumption tax rate to be changed is revenue increasing.

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via public abatement. We then subtract equation (7) and (10) and, noting that initially $\tau = 0$,[14] obtain

$$\left.\frac{dr}{dt}\right|_{dx=0} - \left.\frac{dr}{dt}\right|_{dq=0} = \frac{E_{qu}g_{\tau}(A_t - A_{\tau})}{(\Delta E_{qq} + E_{pu}A_{\tau})\Delta} - \left[\frac{E_{qu}(A_t - A_{\tau})}{\Delta}\right]. \tag{11}$$

Since the sign of $(A_t - A_\tau)$ is negative under the assumptions of $E_r + R_g > 0$ and $R_{gp} < 0$, the sign of the right-hand side of (11) is positive. It thus suggests that the trade liberalization reform of $dx = 0$ reduces pollution by more than that of $dq = 0$. The basic point is that the price-control approach increases the demand for the dirty consumption (and therefore pollution emissions), whereas the quantity control approach keeps the dirty consumption at a constant level. The latter approach can increase earmarked revenue and therefore public abatement because the tax base does not fall with the reform. The quantity controls pursued here can be an alternative to a cap-and-trade system which does not apply to household emissions.

With these preliminaries in hand, we now examine the welfare effects of the two reforms,

$$\begin{aligned}\left.\frac{du}{dt}\right|_{dq=0} &= \frac{(A_t - A_{\tau})}{\Delta} \\ &= \frac{(gR_{gp} - \alpha E_q)(E_r + R_g - tR_{pg})}{\Delta},\end{aligned} \tag{12}$$

which says that welfare improves with a simultaneous reduction in t and increase in τ if public pollution abatement is under-provided (i.e., $E_r + R_g > 0$) and if the production of the imported goods is a substitute for public abatement $R_{gp} < 0$. A reduction in private goods production through tariff cuts lowers private production subsidies and thereby increases production efficiency (see Diamond and Mirrlees, 1971; Hatzipanayotou *et al.*, 1994; Keen and Ligthart, 2002). This desired effect can be reinforced by an increase in public abatement which lowers private production and therefore its subsidies. Admittedly increased g raises social costs (R_g), but they can be more than offset by the benefits of g when the costs are small enough to ensure $E_r + R_g > 0$.

We turn to the reform of Haibara. By substituting (9) into (5), we get

$$\begin{aligned}\left.\frac{du}{dt}\right|_{dx=0} &= \frac{(A_t - A_{\tau})E_{qq}}{(\Delta E_{qq} + E_{pu}A_{\tau})}. \\ &= \frac{E_{qq}(gR_{gp} - \alpha E_q)(E_r + R_g - tR_{pg})}{(\Delta E_{qq} + E_{pu}A_{\tau})}.\end{aligned} \tag{13}$$

Thus, the reform improves welfare under the assumptions of $E_r + R_g > 0$ and $R_{gp} < 0$ (or a small value of $R_{gp} > 0$). The interpretation of (13) is analogous to that of (12). We now compare the welfare effects of a marginal price-neutral reform of a tariff and

[14] We compare different tax reforms starting at the same initial equilibrium and thereby assume $\tau = 0$ initially (see Kreickemeier and Raimondos-Møller, 2008).

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consumption tax, to those of a consumption-neutral tax reform.

$$\left.\frac{du}{dt}\right|_{dx=0} - \left.\frac{du}{dt}\right|_{dq=0} = \frac{-E_{qu}A_\tau(gR_{gp} - \alpha E_q)(E_r + R_g - tR_{pg})}{(\Delta E_{qq} + E_{pu}A_\tau)}, \tag{14}$$

where $A_\tau = \alpha E_q(E_r + R_g - tR_{pg}) - R_g E_{qq}(t - E_r)$. Consumption taxation yields environmental benefits but at the same time it exacerbates tax distortions. This taxation entails a positive impact on welfare if environmental gains outweigh these distortions $E_r > t$. This, together with the assumptions of $E_r + R_g > 0$ and $R_{gp} < 0$, ensures that $A_\tau > 0$. Equation (14) then suggests that the welfare improvement of a consumption-neutral tax reform is higher than is that of a price-neutral tax reform. The reasoning behind this is that the magnitude of offsetting consumption tax hikes is greater under the reform of $dx = 0$ than it is under the reform of $dq = 0$.[15] This is so because tariff cuts raise production efficiency—an effect which is lacking in consumption tax hikes. It makes the level of increased τ large compared to that of decreased t in order to achieve consumption neutrality. We have the following proposition.

Proposition 1 : *Suppose that consumption tax revenue only is earmarked to finance public pollution abatement. Then, the magnitude of a welfare improvement is higher under a consumption-neutral combination of tariff cuts and consumption tax hikes than it is under a price-neutral combination of these tax changes if: (i) public abatement provision and private goods production are a substitute; and (ii) marginal environmental damages are larger than the cost of pollution abatement.*

A consumer price-neutral tax reform has a number of potential benefits. First, it can help to increase economic efficiency by reducing distortions in the market. Second, it can raise net revenue, which can be used to finance important government programs. However, this price-control, albeit standard in the literature, has some potential drawbacks. The increase in real income resulting from tariff cuts could lead to increased consumption, which could lead to increased environmental degradation.

The empirical literature suggests that the relationship between trade liberalization and consumption pollution is context-specific, meaning that the effects of trade liberalization on consumption pollution can vary depending on the specific country or region being studied. With regard to Mexico and the United States in particular, Davis and Kahn (2010) find that trade decreases average emission levels in the United States and increases average emission levels in Mexico for carbon dioxide. The reasoning is that trade gives new life to vehicles that otherwise would have been scrapped. The lower vehicle retirement rates of Mexico can have a large impact on lifetime carbon emissions from vehicles. Chen *et al.* (2019) contradict their results, showing that used vehicle imports decrease aggregate pollution emissions in Mexico. This is mainly due to the technique effect (that is, vehicles imported from the United States to Mexico are cleaner than domestic vehicles in Mexico). These studies, however, address the trade and environment issue from a single-country perspective. In a multi-country context, Hu and McKitrick (2016) show that international trade will be likely to increase the total consumption-generated emissions.

[15]The absolute value of the denominator is smaller than that of the numerator of (9) under the assumption of $A_t - A_\tau < 0$; i.e., a sufficient condition for the welfare improvement of the reform $dx = 0$.

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On this showing, the relationship between trade liberalization and consumption pollution is complex and multifaceted, which can make it difficult to establish a clear causal relationship between the two. Proposition 1 suggests that trade liberalization policy packages, if well designed, can reduce the level of consumption pollution: the consumption-neutral policy mix fixes the level of dirty consumption while increasing public abatement. However, the welfare ranking of proposition 1 reverses if pollution externalities and public abatement are absent. This is so because a consumption-neutral reform does not increase the demand for the clean consumption good,[16] whereas a price-neutral reform increases it. Note also that even though pollution externalities are present, a consumption-neutral reform is not necessarily superior to a price-neutral reform in terms of welfare improvements. This will be the case when income effects on taxed commodities are absent (i.e., $E_{qu} = 0$); in this special case, the two reforms are equivalent (see (12) and (13)). The reason: the price-neutral reform does not raise the dirty-good consumption via real income gains, and a tariff cut is offset point-for-point by an increase in consumption tax under the two reforms. It follows from the above that the presence of pollution externalities and income effects renders quantity controls more appropriate than price controls.

Note, however, that the two reforms reported in proposition 1 share common drawbacks. That is, welfare falls if private production and public abatement provision is a complement (i.e., $R_{gp} > 0$) and its complementarity is sufficiently large, whereas the level of earmarking is very small (i.e., $\alpha E_q < gR_{gp}$). In these circumstances, trade liberalization decreases public abatement. A consumption tax hike increases the level of public abatement, but it cannot offset the decreased g when an earmarked consumption tax is sufficiently small. In this case, the reform generates a net decrease in g ($g_t > g_\tau$) and an increase in r. This negative impact of environmental degradation outweighs the positive impact of decreased production distortions under the assumption of $E_r + R_g - tR_{pg} > 0$. In this way, tariff-tax reforms could backfire on the environment and potentially reduce welfare when allowing for public abatement. This is a point that has been missed in the previous literature of tariff tax reforms in the presence of pollution externalities (e.g., Michael and Hatzipanayotou, 2013; Tsakiris *et al.*, 2019; Haibara, 2022a, 2022b). The next section explores a reform strategy that improves welfare under the assumption of $\alpha E_q < gR_{gp}$.

4. The choice of pollution abatement

As noted in the introduction, many economists have proposed a number of tariff tax reforms, with the goal of increasing economic efficiency and increasing government revenue. The problem with these reforms is that welfare can go down when public abatement and private production are a complement and when public abatement is under-provided. The question to be addressed in this context is as follows. Which abatement—private abatement or public abatement—should be fixed by policy changes? To answer this question, we consider a reform to preserve public abatement; i.e., a public abatement-neutral reform ($dg = 0$). From (6), we have

$$\left.\frac{d\tau}{dt}\right|_{dg=0} = -\frac{g_t}{g_\tau}. \tag{15}$$

[16] It does not mean that the demand for the numeraire good remains constant: it can be increased through real income gains.

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This, together with (2), yields

$$\left.\frac{dr}{dt}\right|_{dg=0} = \left.\frac{dx}{dt}\right|_{dg=0},$$

$$= (\Delta E_{qq} + E_{qu}A_\tau)\left(\frac{d\tau}{dt}\right)_{dg=0} + (\Delta E_{qq} + E_{qu}A_t)$$

$$= \Delta E_{qq}\left(1 + \left.\frac{d\tau}{dt}\right|_{dg=0}\right) + E_{qu}\left(A_t + A_\tau \left.\frac{d\tau}{dt}\right|_{dg=0}\right). \tag{16}$$

Note that, unlike equations (7) and (10), public abatement effects (i.e., dg/dt) vanish. That is why the policy of $dg = 0$ affects pollution mainly via private abatement. Suppose that $R_{gp} > 0$, then the signs of g_τ and g_t are both positive, meaning that $d\tau/dt|_{dg=0} < 0$. The difference between the denominator and numerator is

$$g_\tau - g_t = E_u(\alpha E_q - gR_{gp})[E_u + E_{qu}(E_r - \tau - t)] + \alpha\tau E_{qu}tR_{pp},$$

which is negative under the large (resp. small) value of $R_{gp} > 0$ (resp. α). This suggests that $|d\tau/dt|_{dg=0} > 1$, meaning that $dr/dt|_{dg=0} > 0$ under the large value of $|E_{qq}|$. The intuition is that a reduction in t lowers the level of g, thus requiring an offsetting increase in τ to achieve $dg = 0$. The level of consumption pollution falls as a result.

Turning now to the welfare effects of a public abatement-neutral policy, we use (15) and (5) to obtain

$$\left.\frac{du}{dt}\right|_{dg=0} = \frac{R_g[(t - E_r)E_{qq}(gR_{gp} - \alpha E_q) + tR_{pp}\alpha E_q]}{\alpha E_q}, \tag{17}$$

where we have used $\tau = 0$ to simplify. Compare (17) with (13). The reform of $dg = 0$ is welfare-improving, whereas the reform of $dx = 0$ is welfare-worsening, provided that $gR_{gp} > \alpha E_q$ and $E_r > t$. As noted earlier, tariff cuts reduce both private and public production activities under the assumption of $R_{gp} > 0$. In order to achieve $dg = 0$, the level of consumption tax hikes must be greater than that of tariff cuts, because consumption taxes have a small effect on g due to the small level of earmarking α. It is the relative largeness of increased τ which causes a substantial consumption pollution reduction. The welfare differences between the policy of $dx = 0$ and that of $dg = 0$ are summarized as follows.

Proposition 2 : *In the reforms of import tariffs and consumption taxes, a reform to fix public abatement (resp. a reform to fix private abatement) raises (resp. decreases) welfare if: (i) public abatement provision and private goods production are a complement and the initial level of earmarking is very small; and (ii) marginal environmental damages are larger than the cost of pollution abatement.*

Here again, price controls, albeit standard in the tariff-tax reform literature, are inferior to quantity controls in terms of welfare improvements because proposition 2 gives conditions under which the reform of $dg = 0$ improves welfare, whereas the reform of $dq = 0$ worsens welfare. But we must look at the *other side of the coin*. Suppose that $R_{gp} < 0$ and initial tax levels are small enough, then the sign of g_τ (resp. g_t) is

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positive (resp. negative), meaning that $d\tau/dt|_{dg=0} > 0$ and $dr/dt|_{dg=0} < 0$ under a sufficiently large value of $|E_{qq}|$. A tariff cut reduces private production and thereby increases public abatement. It requires a reduction in consumption taxes (and therefore public abatement provision) to achieve public abatement neutrality. The upshot: the reform of $dg = 0$ increases consumption pollution emissions (i.e., decreased private abatement) and worsens welfare. By contrast, the reform of $dq = 0$ (and $dx = 0$) improves welfare (see proposition 1).

As regards the choice of pollution abatement, Hatzipanayotou *et al.* (2005) show that a shift from public to private abatement increases welfare in the presence of *production* pollution emissions. However, they do not study integrated reforms of trade and domestic taxes. Nor do they compare between price and quantity controls in the presence of *consumption* pollution emissions. In the tariff-tax reform literature with public good provision, Hatzipanayotou *et al.* (2011) indicate that the substitutability between private production and public good provisions is a sufficient condition for welfare-improving (i.e., $R_{gp} < 0$).[17] Proposition 2 identifies a welfare-improving reform strategy even under the complementarity assumption (i.e., $R_{gp} > 0$).[18]

Thus far, we have assumed that all tariff revenue is returned to consumers in a lump-sum fashion (i.e., $\gamma = 0$). This assumption is reasonable, in view of the fact that trade tax revenue is a strong decreasing trend in many countries and also that environmental tax revenue (but not trade tax revenue) is a main source of public pollution abatement. Introducing both an earmarked tariff revenue and an earmarked domestic tax revenue complicates the analysis but, as discussed below, the added complication would not alter the main results presented in previous sections. The expressions A_τ, A_t, g_τ, and g_t now become

$$\begin{aligned}
A_\tau &= (\alpha E_q + \alpha\tau E_{qq} + \gamma t E_{qq})(E_r + R_g - tR_{pg}) + (\gamma t R_{pg} - R_g E_{qq})(\tau + t - E_r),\\
A_t &= [\gamma(E_q - R_p) + \alpha\tau E_{qq} + \gamma t E_{qq} - \gamma t R_{pp} + gR_{gp}](E_r + R_g - tR_{pg})\\
&\quad + (\gamma t R_{pg} - R_g)[E_{qq}(\tau + t - E_r) - tR_{pp}],\\
g_\tau &= E_u(\alpha E_q + \alpha\tau E_{qq} + \gamma t E_{qq}) + E_{qu}\alpha E_q(E_r - \tau - t),\\
g_t &= E_u[\gamma(E_q - R_p) + \alpha\tau E_{qq} + \gamma t E_{qq} - \gamma t R_{pp} + gR_{gp}]\\
&\quad + E_{qu}[\gamma(E_q - R_p) - \gamma t R_{pp} + gR_{gp}](E_r - \tau - t) - E_{qu}(\alpha\tau + \gamma t)tR_{pp}.
\end{aligned}$$

We reproduce the welfare effects of the reform of $dx = 0$,

$$\left.\frac{du}{dt}\right|_{dx=0} = A_\tau\left(\frac{d\tau}{dt}\right)_{dx=0} + A_t = \frac{(A_t - A_\tau)E_{qq}}{(\Delta E_{qq} + E_{pu}A_\tau)},$$

[17] More exactly, Hatzipanayotou *et al.* (2011) show that welfare improves with a consumer price-neutral tariff tax reform (i) if the total production subsidy cost of all imported goods is nonnegative instead of the total consumption subsidy cost on all exported goods being nonnegative, and (ii) the additional requirement that the imported goods are substitutes in production to the public good.

[18] Dawood and Francois (2018) show that private and government consumption are a substitute, so an increase in government consumption crowds out private consumption which in turn negatively affects output. Jalles and Karras (2021) show that an increase in government spending is found to strongly and robustly complement private consumption, thereby "crowding in" private spending and leading to a higher output multiplier.

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where the signs of A_t and A_τ are positive[19] given a large tax base and therefore earmarked tariff revenue (i.e., $\gamma(E_q - R_p) > 0$). Then we have

$$A_t - A_\tau = (E_r + R_g - tR_{pg})[\gamma(E_q - R_p) - \alpha E_q - \gamma t R_{pg} + gR_{gp}] - tR_{pp}(\gamma t R_{pg} - R_g).$$

If: (a) a fraction of tariff revenue for public abatement activities is smaller or equal to that of consumption tax revenue for public abatement (i.e., $\gamma(E_q - R_p) - \alpha E_q \leq 0$), (b) public abatement is a substitute for private goods production (i.e., $R_{gp} < 0$); and (c) marginal environmental damages are very large, whereas initial tariff levels are small, then the sign of $A_t - A_\tau$ is negative which means the trade liberalization reform of $dx = 0$ is welfare-improving. Under the assumption of (a), an increase in earmarked consumption tax revenue outweighs a decrease in earmarked tariff revenue. In addition, the magnitude of offsetting consumption tax hikes is greater than that of tariff cuts (see footnote 13), so we have $|d\tau/dt|_{dx=0} > 1$. On net, public abatement rises with the reform.

Turning to the reform of $dg = 0$, we have

$$\left.\frac{du}{dt}\right|_{dg=0} = A_\tau \left(\frac{d\tau}{dt}\right)_{dg=0} + A_t,$$

where

$$\left.\frac{d\tau}{dt}\right|_{dg=0} = -\frac{g_t}{g_\tau}.$$

Here, we assume that the signs of g_t and g_τ are positive: i.e., tariff cuts (resp. consumption tax hikes) reduce (resp. increase) the level of g, i.e., earmarked tariff revenue and therefore the level of g inevitably fall with trade liberalization. Then we have to compare the degree of offsetting consumption tax hikes among the three different reform strategies,

$$g_t - g_\tau = E_u[\gamma(E_q - R_p) - \alpha E_q - \gamma t R_{pp} + gR_{gp}][E_u + E_{qu}(E_r - \tau - t)] \\ - E_{qu}(\alpha\tau + \gamma t)tR_{pp}.$$

Thus, we obtain $g_t < g_\tau$ under the aforementioned three assumptions: (a) $\gamma(E_q - R_p) - \alpha E_q \leq 0$, (b)$R_{gp} < 0$, and (c)$t \cong 0$. In contrast to the reform of $dx = 0$, the magnitude of offsetting consumption tax hikes is smaller than that of tariff cuts, so we have $|d\tau/dt|_{dg=0} < 1$. In case of the reform of $dq = 0$, we have $|d\tau/dt|_{dq=0} = 1$. Summing up, we have the following proposition.

Proposition 3 : *Suppose that a large fraction of tariff revenue and consumption tax revenue is earmarked to finance public abatement. Then, a reform to fix private abatement improves welfare by more than a reform to fix public abatement if: (i) a fraction of tariff revenue for public abatement activities is smaller or equal to that of consumption tax revenue for public abatement, (ii) public abatement is a substitute for private goods production; and (iii) marginal environmental damages are larger than the cost of pollution abatement. The welfare improvement from a consumer price-neutral reform ranks in between the above partial abatement strategies.*

[19]It means that welfare-improving tariff imposition is possible. This is consistent with the result of Haibara (2009): the optimal tariff rate is positive in the presence of public pollution abatement. (Note that the literature does not consider integrated reforms of trade taxes and domestic taxes.)

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Note that the above welfare improvement ranking reverses if $\gamma(E_q - R_p) - \alpha E_q > 0$ and $R_{gp} > 0$; in this case, we have $|d\tau/dt|_{dx=0} < 1$ and $|d\tau/dt|_{dg=0} > 1$. Proposition 3 indicates that welfare improves even when tariff revenue is financed for public activities and these activities are under-provided initially (i.e., $E_r + R_g > 0$). This result is consistent with Yanase (2010): there is revenue (here, consumption tax revenue) other than tariff revenue for financing public activities (here, public abatement). One important difference from this literature is that tax bases (here, the consumption of the non-numeraire good) remain unchanged even when changing tax rates. Proposition 3 is especially relevant for countries where trade tax revenue is financed for environmental protection. An example of this is the National Clean Energy Fund (NCEF) Act, 2010, in India. This act states that the NCEF will be funded by the Clean Energy cess, an excise duty on both domestic and imported coal. The purpose of this cess was financing and promoting clean energy initiatives, funding research in the area of clean energy, or any other purpose relating thereto (see International Institute for Sustainable Development, 2018).

5. Exogenous price shocks

This section considers a post-trade liberalization world with no tariffs and examines the welfare effects of exogenous price shocks. The quantity control measures presented in the previous section are particularly relevant here. To understand why, consider exogenous foreign price hikes $dp^f > 0$. In this case, governments need not lower consumption tax rates. Instead, they can alter the level of earmarking α. This makes sense: a consumption tax cut could backfire on the environment through a reduction in public abatement; i.e., a consumer price-neutral reform cannot be appropriate. What is more, compensating tax cuts or subsidies (against price shocks) create pressures on budgets already strained by the pandemic and hinder revenue mobilization. Look back at equations (5) and (6) where we saw that

$$g_p = [E_u \alpha \tau E_{qq} + \alpha \tau E_{qu}(R_p - E_q)] + g R_{gp}[E_u + (E_r - \tau) E_{pu}],$$
$$A_p = -R_g[R_p - E_q + E_{qq}(\tau - E_r)] + (E_r + R_g)(\alpha \tau E_{qq} + g R_{gp}).$$

(Note that we assumed $t = 0$ to derive the above equations). Thus, exogenous price hikes increase g when the initial level of earmarking α is small and the production of the imported good and public abatement are a complement (i.e., $R_{gp} > 0$). Exogenous price hikes erode earmarked consumption tax revenue; however, this undesired environmental effect must be negligible under the low value of α.

It is unclear, a priori, whether an increase in p^f is likely to be welfare-worsening. On the one hand, if the country is a net importer of tradable goods (i.e., $E_q - R_p > 0$), then exogenous price hikes worsen the country's terms of trade and entail a negative impact on welfare. On the other hand, the price hikes lower consumption pollution emissions and thereby increase welfare provided $E_r > \tau$ and small values of α. It should be emphasized here that increased p^f raises both private and public sector pollution abatement, because a price hike encourages households to save energy and at the same time increases public abatement under the complementarity assumption. Now suppose that welfare rises with increased p^f through the dominance of environmental gains over terms of trade losses (i.e., $A_p > 0$). The remaining question then is as follows. Does increased public abatement *only* (i.e., $dx = 0$) improve welfare by more than both increased private and public abatement together? To answer this question, we again differentiate the compensated demand function x and obtain (keeping in mind that $dx = 0$)

$$\left.\frac{d\alpha}{dp^f}\right|_{dx=0} = -\frac{(\Delta E_{qq} + E_{qu}A_p)}{E_{qu}A_\alpha}, \tag{18}$$

where $d\alpha/dp^f|_{dx=0} > 0$ if consumption substitution effects (E_{qq}) are sufficiently large. We then obtain welfare effects

$$\left.\frac{du}{dp^f}\right|_{dx=0} = A_\alpha\left(\frac{d\alpha}{dp^f}\right)_{dx=0} + A_p = -\frac{E_{qq}}{E_{qu}}. \tag{19}$$

Equations (18) and (19) indicate that the welfare improvement from a consumption-neutral policy must be greater than the welfare improvement from a price hike alone (A_p). The intuition justifying this result is that a terms of trade loss can be translated into increased public abatement when implementing the policy of $dx = 0$. This is because, under consumption neutrality, the degree of earmarking (and real income gains) is higher the larger a terms of trade loss (and a real income loss).To see this more clearly, we compare the pollution effects of the policy of $dx = 0$, and that of increased p^f only (noting that $\alpha = 0$ initially),

$$\begin{aligned}\left.\frac{dr}{dp^f}\right|_{dx=0} - \frac{dr}{dp^f} &= \frac{\tau E_q[(R_p - E_q)E_{qu} + E_uE_{qq}]\Delta}{E_{qu}A_\alpha\Delta} \\ &\quad - \left\{\frac{gR_{gp}\Theta - R_g[(R_p - E_q)E_{qu} + E_uE_{qq}]}{E_{qu}A_\alpha\Delta}\right\} \\ &= \frac{\tau E_q\Theta\{R_g[(R_p - E_q)E_{qu} + E_uE_{qq}] - E_{qu}gR_{gp}(E_r + R_g)\}}{E_{qu}A_\alpha\Delta},\end{aligned} \tag{20}$$

where $\Theta = [E_{qu}R_g - (E_u - \tau E_{qu})] < 0$.[20] Equation (20) says that the assumption of imports (i.e., $E_q - R_p > 0$) makes it more likely that $|dr/dp^f|_{dx=0} > |dr/dp^f|$. As noted above, a rise in p^f entails terms of trade deterioration and so the magnitude of offsetting α must be large. This, coupled with the result that increased p^f only induces terms of trade loss, ensures the welfare improvement ranking $du/dp^f|_{dx=0} > du/dp^f$.

We now consider the welfare and pollution effects of a public abatement-neutral policy (i.e., $dg = 0$). From (6), we have

$$\left.\frac{d\alpha}{dp^f}\right|_{dg=0} = -\frac{g_p}{g_\alpha} = -\frac{[E_u\alpha\tau E_{qq} + \alpha\tau E_{qu}(R_p - E_q)] + gR_{gp}[E_u + (E_r - \tau)E_{pu}]}{\tau E_q[E_u + E_{qu}(aE_r - \tau)]}, \tag{21}$$

which says $d\alpha/dp^f|_{dg=0} < 0$ when $gR_{gp} > 0$ and the value of α is small. The reason is simply that increased public abatement is offset by decreased α. By using (5) and (21),

[20] This is due to linear homogeneity of the expenditure function, i.e., $E_u = (p^f + \tau)E_{qu} + E_{1u}$. Thus, $E_u - (p^f + \tau)E_{qu} = E_{1u} > 0$ under the normal good assumption.

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we have

$$\left.\frac{du}{dp^f}\right|_{dg=0} = A_\alpha \left(\frac{d\alpha}{dp^f}\right)_{dg=0} + A_p = -\frac{R_g[R_p - E_p + (\tau - E_r)E_{qq}]}{\Delta}.$$

Welfare thus rises under the assumption which says that pollution abatement effects (as indicated by the term $|E_r E_{qq}|$) outweigh a terms of trade loss—the assumption ensuring $A_p > 0$. However, the magnitude of a welfare improvement is lower than increased p^f only, $du/dp^f|_{dg=0} < du/dp^f$, due to the offsetting reduction in public abatement $d\alpha/dp^f|_{dg=0} < 0$. We also obtain

$$\left.\frac{du}{dp^f}\right|_{dx=0} - \left.\frac{du}{dp^f}\right|_{dg=0} = \frac{R_g[(R_p - E_p)E_{qu} + E_u E_{qq}]}{E_{qu}\Delta}.$$

Overall, the welfare improvement ranking is $du/dp^f|_{dg=0} < du/dp^f < du/dp^f|_{dx=0}$ if: (a) the country is a net importer of the polluting good, and (b) private goods production and public abatement are a complement. Here, the offsetting policy of $dx = 0$ (resp. $dg = 0$) ensures public abatement *only* (resp. private abatement *only*), while increased p^f ensures both private and public abatement under the positive sign of R_{gp}.

Proposition 4 : *Suppose that the country experiences exogenous terms of trade shocks. Suppose also that public abatement is a complement to private goods production, and that abatement effects outweigh terms of trade deterioration effects. Then, it is possible that a welfare improvement from increased public abatement only is higher than it is from both increased private and public abatement together. Increased public abatement only improves welfare by more than increased private abatement only regardless of the relationship between private goods production and public abatement.*

Proposition 4 can provide a new rationale for earmarking. Specifically, a consumption-neutral increase in the level of earmarking is introduced to mitigate adverse effects of higher energy prices on households, recognizing that certain amounts of energy use (i.e., basic needs) cannot be avoided. In this context, proposition 4 offers pollution abatement strategies without altering taxes; i.e., a change in the level of earmarking *only*. An implication is that offsetting α applies to domestic environmental policy reforms—such as a combination of increased consumption taxes and the level of earmarking to achieve $dx = 0$. This is so because the consumer price rises in both cases (i.e., exogenous terms of trade shocks and consumption tax hikes). Again, it is possible that public abatement *only* improves welfare more than both private and public abatement (i.e., increased τ alone). The point is that environmental earmarking acts as shock absorber for small open economies facing domestic and external shocks.

Another important point to make is that, unlike the results reported in the previous sections, the sign of R_{gp} is irrelevant for the ranking between $dx = 0$ and $dg = 0$. To understand why, suppose that public abatement and private goods production are a substitute. In this case, increased p^f facilitates private abatement under the public abatement-neutral policy. However, the policy of $dg = 0$ cannot offset terms of trade loss, whereas the policy of $dx = 0$ translates these negative income effects into increased public abatement. Moreover, unlike indirect tax changes, a policy variable α does not have consumption substitution effects. So, a large increase in α is needed to offset the substitution effects (caused by increased p^f) under the consumption-neutral policy (see equation (18)). Public abatement thus rises with the policy of $dx = 0$. A caveat is that, in case of terms of trade improvements (i.e., $dp^f < 0$), the role of offsetting α becomes a blunt instrument to protect the environment, because the policy requires a reduction in α to achieve $dx = 0$. In this case, consumption tax rates should be increased to reduce consumption, as shown by the results in the previous sections. To summarize, the choice of pollution abatement matters in a free trade regime prone to terms of trade shocks.

6. Conclusions

Existing studies suggest that a price-neutral reform or a consumption-neutral reform is welfare increasing in the presence of pollution externalities. The present paper has cast doubt on the validity of these two reforms: they are counterproductive to the environment and are welfare-worsening when allowing for public abatement. Thus, the choice of pollution abatement matters before and after trade liberalization. Think of tariff cuts. An increase in private abatement *only* raises welfare when public abatement is a complement to private production. Think of exogenous import price hikes. An increase in public abatement *only* improves welfare by more than an increase in both private and public abatement. The quantity control adjustments presented here (i.e., the consumption-neutral or the public abatement-neutral policy) pursued here are flexible enough to address both domestic policy and international shocks when compared with price-neutral adjustments.[21] Holding private consumption constant does not mean a constant level of pollution due to the presence of public abatement.

There has been long-standing disagreement and debate concerning environmental earmarking. The consumption-neutral reform suggests a new rationale for earmarking: environmental earmarking should be delivered to compensate for rising energy prices and for sustaining energy use. It would have the twin merits of reducing pollution and helping to reduce the social cost of higher energy prices. The paper can thus contribute to environmental protection and economic development in countries where certain amount of energy use cannot be avoided. While we have focused on consumption pollution externalities, our analysis, *mutatis mutandis*, applies to production pollution externalities.[22] In this case too, we can rank different quantity approaches, one based on a constant output policy, the other based on a constant public abatement policy. In this context, it is possible to include endogenous factor supplies and examine the choice of pollution abatement. Testing whether earmarking in the way proposed achieves distributional goals and is politically optimal is a theme for future research. Also, it would be

[21] Herweg and Schmidt (2022) argue that price regulation (i.e., a carbon tax) encourages voluntary efforts to reduce emissions and encourages consumers to consume less of the polluting good, whereas quantity regulation (i.e., cap-and-trade) discourages morally motivated consumers from reducing emissions and may even induce them to pollute more. This is mainly due to the fact that the total amount of emissions is fixed by the number of emission permits issued by the regulator. While moral behavior lies beyond the scope of our paper, the present paper fundamentally differs from their paper in terms of policies. Unlike Herweg and Schmidt (2022), the present paper does not introduce a cap-and-trade but taxes *alone* to fix households' consumption. In real-world situations, our tax-based quantity controls seem more appropriate than a cap-and-trade, especially since it is difficult for the latter to address households' emissions in developing countries (even in developed countries).

[22] For a producer price-neutral reform in the presence of public abatement, see Haibara (2022b). This literature does not study the welfare effects of exogenous price shocks.

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an interesting topic of future work to see if the results here continue to hold in the presence of untaxable informal sectors.[23] Finally, note that although the focus of our paper is on public pollution abatement, the results could fruitfully be applied to pure public good provision; here again, the choice of larger public goods or larger private goods matters.

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Appendix A

Following Abe (1992), we obtain the restricted revenue function.

The full employment condition requires that

$$v^p + v^g = v, \tag{A1}$$

where v denotes the vector of total factor endowments (which are fixed), and v^p and v^g indicate the amounts of factors used in the production of private goods and in the public abatement activities.

The factor markets are in equilibrium when

$$w = R_v^*(p, v^p), \tag{A2}$$

where w is the factor price vector and the subscript denotes a partial derivative. The unit cost of public abatement, denoted $C^g(w)$, is homogenous of degree one and concave in w (i.e., $wC_w^g = C^g$ and $wC_{ww}^g = 0$). Using the properties of the unit cost function, the demand vector for public abatement is given by

$$v^g = gC_w^g(w). \tag{A3}$$

By substituting equation (A2) and (A3) into (A1), we get the restricted revenue function that contains information for the private and public production:

$$v^p + gC_w^g(R_v^*(p, v^p)) = v. \tag{A4}$$

Equation (A4) gives v^p as a function of $p,\ q,\ g$ and v. Because v is constant, v^p can be written as

$$v^p = v^p(p, g). \tag{A5}$$

By substituting equation (A5) into $R^*(p, v^p)$, we define the restricted revenue function:

$$R(p, g) = R^*[p, v^p(p, g)]. \tag{A6}$$

It is well known that in the two-traded good, one-nontraded good, two factor Heckscher–Ohlin model, changes in factor supplies do not affect factor rewards under incomplete specialization. That is, R_{vv}^*=0. If R_{vv}^*=0, then the $R(p, v^p)$ function has the following properties: (a) $R_g = -C_w^g(w)$, (b) $R_p = R_p^*$; and (c) $R_{pp} = R_{pp}^* - gR_{pv}^* C_{ww}^g R_{vq}^* > 0$. Then we obtain $C_g^g = -R_{gg} = 0$ under the H–O model.

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Appendix B

Total differentiation of (1)–(4) yields:

$$dz_c = E_{qq}d\tau + E_{qq}dt + E_{qq}dp^f + E_{qu}du, \tag{B1}$$

$$\begin{aligned} dr &= E_{qq}d\tau + E_{qq}dt + E_{qq}dp^f + E_{qu}du - dg \\ &\quad \times [E_u - (1-\alpha)\tau E_{qu} - (1-\gamma)tE_{qu}]du + E_r dr + (1-\gamma)tR_{pg}dg \\ &= [-\alpha E_q + (1-\alpha)\tau E_{qq} + (1-\gamma)tE_{qq}]d\tau \\ &\quad + [-\gamma(E_q - R_p) + (1-\alpha)\tau E_{qq} + (1-\gamma)tE_{qq} - (1-\gamma)tR_{pp} - gR_{gp}]dt \quad \text{(B2)} \\ &\quad - \tau E_q d\alpha - t(E_q - R_p)d\gamma + [R_p - E_q - gR_{gp} + (1-\alpha)\tau E_{qq}]dp^f, \\ &\quad - (\alpha\tau + \gamma t)E_{qu}du + (\gamma tR_{pg} - R_g)dg \\ &= (\alpha E_q + \alpha\tau E_{qq} + \gamma tE_{qq})d\tau + [\gamma(E_q - R_p) + \alpha\tau E_{qq} + \gamma tE_{qq} - \gamma tR_{pp} + gR_{gp}]dt \quad \text{(B3)} \\ &\quad + \tau E_q d\alpha + t(E_q - R_p)d\gamma + (\alpha\tau E_{qq} + gR_{gp})dp^f. \quad \text{(B4)} \end{aligned}$$

Substituting (A2) into (A3) yields the following matrix:

$$\begin{aligned} &\begin{bmatrix} \{E_u + E_{qu}[E_r - (1-\alpha)\tau - (1-\gamma)t]\} & [R_{pg}(1-\gamma)t - E_r] \\ -(\alpha\tau + \gamma t)E_{qu} & (\gamma tR_{pg} - R_g) \end{bmatrix} \begin{bmatrix} du \\ dg \end{bmatrix} \\ &= \begin{bmatrix} \{-\alpha E_q + E_{qq}[(1-\alpha)\tau + (1-\gamma)t - E_r]\} \\ \alpha E_q + \alpha\tau E_{qq} + \gamma tE_{qq} \end{bmatrix} d\tau \\ &\quad + \begin{bmatrix} \{-\gamma(E_q - R_p) + E_{qq}[(1-\alpha)\tau + (1-\gamma)t - E_r] - R_{pp}gR_{gp}\} \\ \gamma(E_q - R_p) + \alpha\tau E_{qq} + \gamma tE_{qq} - \gamma tR_{pp} + gR_{gp} \end{bmatrix} dt \\ &\quad + \begin{bmatrix} -\tau E_q \\ \tau E_q \end{bmatrix} d\alpha + \begin{bmatrix} -t(E_q - R_p) \\ t(E_q - R_p) \end{bmatrix} d\gamma. \\ &\quad + \begin{bmatrix} \{R_p - E_q - gR_{gp} + E_{qq}[(1-\alpha)\tau - E_r] + \gamma t(E_{qq} - R_{pp})\} \\ \alpha\tau E_{qq} + gR_{gp} + \gamma t(E_{qq} - R_{pp}) \end{bmatrix} dp^f. \end{aligned} \tag{B5}$$

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