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Quantity control reforms and the green transition

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Abstract

The present paper offers an unconventional reform strategy that can mitigate the trade-off between the green transition and economic shocks. There are cases in which double tax cuts encourage a shift toward clean production without jeopardizing employment and/or overall taxed production. While the results depend on factor intensities, it can be argued that preserving output is more desirable than preserving employment, especially when implementing double tax cuts. The findings of this paper are particularly relevant for small open economies, where the scope for taxing dirty production is severely limited.

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1. Introduction

The green transition, while essential for combating climate change, may trigger adverse supply and employment shocks (see Ciccarelli and Marotta (2024)). On the supply side, the accelerated obsolescence of carbon-intensive technologies and products may lead to contractions in certain sectors, particularly those related to fossil fuels. Additionally, mitigation policies could increase costs for carbon-intensive industries, potentially disrupting established supply chains. In terms of employment, workers in industries like coal mining, oil and gas extraction, and traditional power generation face displacement. It is against this background that the recent article of Stern and Stiglitz (2023, p298) notes; "Because of the presence of a host of market failures, simply relying on a carbon price will not suffice. There needs to be a package of policies, aimed at inducing the green transition and protecting workers who would otherwise be adversely affected". It is this that the present paper seeks to provide policies that *directly* address the shocks emanating from the green transition. The quantity control reforms recently proposed by Haibara (2024) may be good candidates for achieving this objective; specifically, tax rates should be adjusted to keep the overall level of taxed goods or labor supply at a constant level[1]. The present paper extends such reforms to allow for production pollution externalities. This extension not only better reflects the green transition affecting employment[2], but also brings a new research agenda. That is, the choice between different quantity control reforms (labor supply-neutral and production-neutral reforms) in the presence of production pollution. The comparison of the two reforms lie in its response to a fundamental question in green transition strategies: whether to prioritize the protection of output or employment during the transition phase. While the results depend on factor intensities, it can be argued that preserving output is more desirable than preserving employment, especially when implementing double tax cuts[3]. The findings of this paper are particularly relevant for small open economies, where the scope for taxing dirty production is severely limited.

The layout of this paper is as follows. Section 2 describes the simple general equilibrium model, using the dual approach of Dixit and Norman (1980). The framework for analyzing labor supply within the context of duality theory presented here draws heavily on Mayer (1991), Hatzipanayotou and Michael (1995), Michael and Hatzipanayotou (1999), Anderson and Neary (2016). However, this model distinguishes itself by incorporating pollution externalities and concentrating on domestic tax reforms rather than tariff adjustments. Section 3 examines the welfare effects of non-conventional reforms in the presence of production pollution. Section 4 concludes this paper.

2. The model

Consider a competitive small open economy which produces three groups of commodities using many factors of production (note that the small open economy's assumption is to fix world prices and thereby isolate the domestic policy impact on output and labor supply). The first group, indexed by "d", is a composite of an energy service; while the second group, indexed by "c", is a composite of the clean good (note that only "d" generates pollution). The third group represents an untaxed composite numeraire good. The economy is endowed with a number of fixed factors and an additional factor, labor L whose work hours are variable owing to endogenous supply adjustments. All factors are internationally immobile but intersectorally mobile. Pollution z is modeled as a by-product of goods production. z does not affect the cost of any firms, but does affect the utility of consumers (see Copeland 1994)). Let the world prices of traded goods be fixed by p_c and p_d, the domestic prices for producers are $p_c - s_c$ and $p_d - s_d$, where s represents the production tax rate. Let $E(p_c, p_d, L, z, u)$ be the minimum expenditure necessary for attaining the utility level u given employment L and pollution z. The function

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[1] Guesnerie and Roberts (1984) study quantity control reforms such as a rationing system aimed at fixing consumption. The celebrated Mirrlees Review (2011) advocates reforms that avoids worsening work incentives. Haibara (2012) focuses on reforms to fix the level of taxed consumption. In the international trade literature, several scholars have explored reforms that maintain constant consumer prices while adjusting tariffs and taxes. Examples include the works of Hatzipanayotou et al. (1994), Keen and Ligthart (2002), Emran (2005), Kreickemeier and Raimondos-Møller (2008), Michael and Hatzipanayotou (2013), and Haibara (2022, 2023). In the field of public economics, Kaplow (2006) examines how changes in consumption and labor taxes could be implemented while keeping utility levels unchanged. However, none of these authors explicitly compare different (non-revenue) neutral conditions in the presence of production pollution externalities and endogenous labor supply, which is central to the present paper.

[2] Bergant et al. (2022) explores the neural mechanisms of industrial decarbonization, documenting how regulatory interventions like the Clean Air Act prompted significant labor reallocation. The study reveals a structural reconfiguration of the workforce, with employees migrating across industrial boundaries, yet maintaining a consistent aggregate employment landscape.

[3] The results here are not directly comparable with the revenue-neutral environmental tax reform literature, first because, we employ non-revenue-neutral reform strategies, and second because, we examine the effects of clean taxes-only on the environment. For the discussion of the revenue-neutral environmental tax reform, see, for, example, Goulder (1995, 2013); Bovenberg (1999).

E is concave and homogenous degree one in all prices. Its price derivatives give the economy's Hicksian net demand functions ($E_q = x$) and with respect to L ($E_L = \hat{w}$) gives the reservation wage (see Dixit and Norman (1980)). The expenditure function is assumed to be strictly concave in prices (i.e., E_{pp} is negative) and strictly convex in L (i.e., $E_{LL} > 0$). E_u is the inverse of the marginal utility of income and is strictly positive (note that $E_u = 1$ by suitable choice of units). We assume that all goods are normal (i.e., $E_{qu} > 0$) but there are no income effects on labor supply $E_{Lu} = 0$ (see Diamond 1988)[4]. The expression z indicates pollution externalities lowering utility; so the minimum cost of achieving a given utility level rises with z; i.e., $E_z > 0$ (see Copeland 1994). For simplicity it is assumed that pollution externalities do not affect endogenous labor-leisure choice (i.e., $E_{Lz} = 0$).

The economy's production side is represented by the revenue function $R(p_c - s_s, p_d - s_d, L)$, which gives the economy's maximum value of output production, with producer's price $p_c - s_c$ and $p_d - s_d$,and the domestic supply of labor L. Fixed domestic endowment factors are omitted from the revenue function. The revenue function is convex, linearly homogenous in producer prices and assumed to be twice continuously differentiable. The derivatives of $R(.)$ function with respect to prices denote the supply function of the composite non-numeraire good, and with respect to L (i.e., R_L) represent the marginal revenue product of labor. In this context, $R_{p_d} = y_d$ denotes the output of dirty production, while $R_{p_c} = y_c$ indicates that of clean production. The revenue function is strictly convex in p (i.e., $R_{p_c p_c}$ and $R_{p_d p_d}$ is positive) and concave in L (i.e., $R_{LL} < 0$). The country's income-expenditure identity is as follows:

$$E(p_c, p_d, L, z, u) = R(p_c - s_c, p_d - s_d, L) + s_d R_p + s_c R_q \, . \qquad (1)$$

It says that the country's expenditure equals the revenue from overall production and the revenue from taxed production (which is lump-sum distributed in the domestic household)[5].

Equilibrium in the labor market requires that the reservation wage equals the net wage received by workers. The net wage equals the marginal revenue product of labor (R_L) minus the wage tax ρ .

$$E_L(p_c, p_d, L, z, u) = R_L(p_c - s_c, p_d - s_d, L) - \rho \, . \qquad (2)$$

Finally, we make the following pollution equation.

$$z = R_p(p_c - s_c, p_d - s_d, L) \, . \qquad (3)$$

Here, one unit of production generates one unit of pollution. Equations (1) to (3) contain three endogenous variables (L, z, u) and two policy variables ($s_c \rho$).

3. Welfare effects of tax packages

Differentiating (1), (2) and (3) with respect to (s_c, ρ), we obtain (see Appendix): (note that the good in the third sector is not taxed.)

$$\Delta dL = L_d ds_d + L_c ds_c + L_\rho d\rho \, . \qquad (4)$$

$$\Delta dy = -[(R_{p_d p_d} + R_{p_d p_c})\Delta + (R_{p_d L} + R_{p_c L})R_{pL}]ds_d - [(R_{p_c p_c} + R_{p_c p_c})\Delta + (R_{p_d L} + R_{p_c L})R_{p_c L}]ds_c$$

$$-(R_{p_d L} + R_{p_c L})d\rho \, . \qquad (5)$$

$$\Delta du = A_d ds_d + A_c ds_c + A_\rho d\rho \, . \qquad (6)$$

where $y = R_{p_d} + R_{p_c}$, $\Delta = M_{LL} > 0$, $L_d = -R_{Lp_d}$, $L_c = -R_{Lp_c}$, $L_\rho = -1$

$A_d = (E_z - s_d)[M_{LL} R_{p_d p_d} + (R_{p_d L})^2] - s_c(R_{Lp_d} R_{Lp_c} + R_{p_d p_c} M_{LL}) - \rho R_{Lp_d}$

$A_c = (E_z - s_d)(R_{Lp_d} R_{Lp_c} + R_{p_d p_c} M_{LL}) - s_c[M_{LL} R_{p_c p_c} + (R_{p_c L})^2] - \rho R_{Lp_c}$,

$A_\rho = (E_z - s_d)R_{Lp_d} - s_c R_{Lp_c} - \rho$

Eq. (4) indicates the labor supply effects of tax changes. A reduction in production taxes raises the level of labor supply if clean production is labor intensive $R_{Lp_c} > 0$, and a reduction in labor tax raises the level of L. Eq. (5) shows the production effects of taxation. A decrease in production taxes or labor taxes raises the level of taxed output when own price effects (i.e., $R_{p_d p_d}, R_{p_c p_c}$) are large enough and when overall production is labor intensive (i.e., $R_{p_d L} + R_{p_c L}$ is positive). Eq. (6) captures the welfare effects of tax changes. Suppose that dirty-production is labor intensive and also that marginal environmental damages (E_z) are very large, whereas initial level tax levels are very small. Then welfare improves with increased environmental tax on dirty-production $A_d > 0$. In terms of clean tax changes, a reduction in s_c improves welfare if in addition to the above conditions $R_{Lp_c} > 0$ and $E_z > s_d$, it is also required that the substitutability between dirty and clean production is large enough to yield

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[4] Tsakiris et al. (2019) employ a duality framework and simplify their model by disregarding the effects of income on labor supply.

[5] In line with Hatzipanayotou and Michael (1995), labor taxes (whose revenue is lump-sum distributed to households) are not included on the right-hand side of equation (1)..

$R_{Lp_d} R_{Lp_c} + R_{p_d p_c} M_{LL} < 0$. On the one hand, the level of dirty production (and therefore pollution emissions) falls via substitution effects. On the other hand, dirty production rises with increased labor supply. On net, production tax cuts should have a negative impact on dirty production due to large substitution effects. It can thus improve welfare via pollution abatement. As regards labor tax changes, decreased ρ entails a negative impact on welfare when $R_{Lq} > 0$ and $E_z > s_d$: because such tax cuts increase labor-intensive dirty production and pollution emissions. The question arises as to whether the magnitude of welfare improvements is higher under environmental taxation-only than it is under a reform package involving offsetting labor tax adjustments.

We first consider the reform package that keeps overall taxed production or labor supply at a constant level. Let y be the aggregate production for taxed goods $y = R_{p_d} + R_{p_c}$. Totally differentiating it leads to:

$$\Delta dy = -[(R_{p_d p_d} + R_{p_d p_c})\Delta + (R_{p_d L} + R_{p_c L})R_{p_d L}]ds_d - [(R_{p_c p_c} + R_{p_d p_c})\Delta + (R_{p_d L} + R_{p_c L})R_{p_c L}]ds_c$$

$$-(R_{p_d L} + R_{p_c L})d\rho . \tag{7}$$

Note that the ds_c , ds_d and $d\rho$ are all positive, assuming that the tax rates to be increased are production decreasing (i.e., own price effects are very large). By setting $dy = 0$, we obtain:

$$\left.\frac{d\rho}{ds_d}\right|_{dy=0} = -\frac{[(R_{p_d p_d} + R_{p_d p_c})\Delta + (R_{p_d L} + R_{p_c L})R_{p_d L}]}{(R_{p_d L} + R_{p_c L})} . \tag{8}$$

With regard to a labor-supply neutral reform ($dL = 0$), we obtain from (4):

$$\left.\frac{d\rho}{ds_d}\right|_{dL=0} = -R_{Lp_d} . \tag{9}$$

The welfare effects of these tax packages are:

$$\left.\frac{du}{ds_d}\right|_{di=0} = A_d + A_\rho \left.\frac{d\rho}{ds_d}\right|_{di=0} \qquad i = y, L . \tag{10}$$

Suppose first that taxed goods are labor intensive (i.e., $R_{Lp_d} > 0$ and $R_{Lp_c} > 0$) and also that marginal environmental damages (E_z) are large enough to yield $A_\rho > 0$. Then we obtain $d\rho / ds_d|_{dy=0} < 0$, and $d\rho / ds_d|_{dL=0} < 0$. The intuition is that increased s_d lowers dirty production and thereby labor supply. To offset the reductions in both y_d and L , decreased ρ must be in order. It entails a negative impact on welfare because increased labor supply following labor tax cuts raises labor-intensive dirty production. Suppose instead that taxed goods are capital intensive (i.e., $R_{Lp} < 0$ and $R_{Lq} < 0$). In this case too, an offsetting labor tax adjustment has a negative impact on welfare $d\rho / ds_d|_{dy=0} > 0$ and $d\rho / ds_d|_{dL=0} > 0$. This is because induced labor tax hikes raise the level of capital-intensive dirty production. Thus, the reforms considered above are inferior to environmental taxation alone (i.e., $A_d > 0$) in terms of welfare improvements.

The more interesting case is that in which R_{Lp_d} and R_{Lp_c} have the opposite signs. For example, if dirty production (resp. clean production) is labor intensive $R_{Lp_d} > 0$ (resp. capital intensive $R_{Lp_c} < 0$) and overall tax production is capital intensive $R_{p_d L} + R_{p_c L} < 0$. In this case, we obtain $d\rho / ds_d|_{dy=0} > 0$ and $A_\rho > 0$ (assuming that own price effects R_{pp} and marginal environmental damages E_z are both very large). It suggests that the double tax hikes magnify the welfare improvement creased by higher environmental taxation. In this case, increased capital-intensive clean production following labor tax hikes can exactly match the decreased dirty production ($y_d \downarrow = y_c \uparrow$) caused by environmental taxation. Consider next the case where dirty production (resp. clean production) is capital intensive $R_{Lp_d} < 0$ (resp. labor intensive $R_{Lp_c} > 0$) and overall tax production is labor intensive $R_{p_d L} + R_{p_c L} > 0$. In this case, we have $d\rho / ds_d|_{dy=0} < 0$ and $A_\rho < 0$. The intuition is that offsetting labor tax cuts raise labor-intensive clean production[6], which can match decreased capital-intensive dirty production ($y_d \downarrow = y_c \uparrow$). These environmentally desired replacement contributes to a welfare gain under the reform of $dy = 0$. We have

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[6] We obtain $dL / ds_d|_{dy=0} = (R_{p_d p_d} + R_{p_c p_d})(R_{p_d L} + R_{p_c L})^{-1}$. Thus, dirty-production tax hikes (which lowers capital intensive dirty-production) plus labor tax cuts increases labor supply under the assumption of $R_{p_d L} + R_{p_c L} > 0$. It implies that labor tax cuts lower capital intensive dirty production and reinforces pollution abatement.

the following proposition.

Proposition 1. *Suppose that that own price effects and marginal environmental damages are both very large, while initial tax levels are very small. Suppose also that dirty production (resp. clean production) is labor intensive (resp. capital intensive) and overall tax production is capital intensive. Then, the reform of increasing both environmental taxes and labor taxes to preserve the level of overall taxed production is higher than environmental taxation alone. Suppose instead that dirty production (resp. clean production) is capital intensive (resp. labor intensive) and overall tax production is labor intensive. Then, the reform of increasing environmental taxes and decreasing labor taxes to preserve the level of overall taxed production is higher than environmental taxation alone.*

The problem of the unconventional reforms of (8) and (9) is that they are inferior to environmental taxation alone in terms of welfare improvements when R_{Lp_d} and R_{Lp_c} have the same signs. I must now examine whether the same is true for clean tax changes. From (4) and (5), we have:

$$\left.\frac{d\rho}{ds_c}\right|_{dy=0} = -\frac{[(R_{p_cp_c} + R_{p_dp_c})\Delta + (R_{p_dL} + R_{p_cL})R_{p_cL}]}{(R_{p_dL} + R_{p_cL})\Delta}, \tag{11}$$

$$\left.\frac{d\rho}{ds_c}\right|_{dL=0} = -R_{Lp_c}, \tag{12}$$

The welfare effects are:

$$\left.\frac{du}{ds_c}\right|_{di=0} = A_c + A_\rho \left.\frac{d\rho}{ds_d}\right|_{di=0} \qquad i = y, L. \tag{13}$$

Substituting (11) and (12) into Eq. (13) leads to the welfare effects of the tax packages:

$$\left.\frac{du}{ds_c}\right|_{dy=0} = A_c + A_\rho \left.\frac{d\rho}{ds_c}\right|_{dy=0}$$

$$= \frac{(E_z - s_d + s_c)(R_{p_cL}R_{p_dp_c} - R_{p_cp_c}R_{p_dL}) + \rho(R_{p_cp_c} + R_{p_dp_c})}{(R_{p_dL} + R_{p_cL})}. \tag{14}$$

$$\left.\frac{du}{ds_c}\right|_{dL=0} = A_c + A_\rho \left.\frac{d\rho}{ds_c}\right|_{dL=0}$$

$$= (E_z - s_d)R_{p_dp_c} - s_cR_{p_cp_c}. \tag{15}$$

Suppose that own price effects ($R_{p_cp_c}$) and marginal environmental damages are sufficiently high. Then the signs of A_ρ, $d\rho/ds_c|_{dy=0}$, and $d\rho/ds_c|_{dL=0}$ depend on factor intensities. Suppose also that dirty production and clean production exhibit substitutability to ensure a welfare improvement under the reform of $dL = 0$. We next turn to a welfare improvement comparison of the reform of $dy = 0$ and the reform of $dL = 0$. We have the following cases.

(i) $R_{Lp_d} > 0, R_{Lp_c} > 0, R_{Lp_d} + R_{Lp_c} > 0$: $\underbrace{A_\rho}_{(+)}\underbrace{(d\rho/ds_c)_{dy=0}}_{(-)}$, $\underbrace{A_\rho}_{(+)}\underbrace{(d\rho/ds_c)_{dL=0}}_{(-)}$

(ii) $R_{Lp_d} < 0, R_{Lp_c} > 0, R_{Lp_d} + R_{Lp_c} > 0$: $\underbrace{A_\rho}_{(-)}\underbrace{(d\rho/ds_c)_{dy=0}}_{(-)}$, $\underbrace{A_\rho}_{(-)}\underbrace{(d\rho/ds_c)_{dL=0}}_{(-)}$

(iii) $R_{Lp_d} < 0, R_{Lp_c} > 0, R_{Lp_d} + R_{Lp_c} < 0$: $\underbrace{A_\rho}_{(-)}\underbrace{(d\rho/ds_c)_{dy=0}}_{(+)}$, $\underbrace{A_\rho}_{(-)}\underbrace{(d\rho/ds_c)_{dL=0}}_{(-)}$

(iv) $R_{Lp_d} > 0, R_{Lp_c} < 0, R_{Lp_d} + R_{Lp_c} > 0$: $\underbrace{A_\rho}_{(+)} \underbrace{(d\rho / ds_c)_{dy=0}}_{(-)}$, $\underbrace{A_\rho}_{(+)} \underbrace{(d\rho / ds_c)_{dL=0}}_{(+)}$

(v) $R_{Lp_d} > 0, R_{Lp_c} < 0, R_{Lp_d} + R_{Lp_c} < 0$: $\underbrace{A_\rho}_{(+)} \underbrace{(d\rho / ds_c)_{dy=0}}_{(+)}$, $\underbrace{A_\rho}_{(+)} \underbrace{(d\rho / ds_c)_{dL=0}}_{(+)}$

(vi) $R_{Lp_d} < 0, R_{Lp_c} < 0, R_{Lp_d} + R_{Lp_c} < 0$: $\underbrace{A_\rho}_{(-)} \underbrace{(d\rho / ds_c)_{dy=0}}_{(+)}$, $\underbrace{A_\rho}_{(-)} \underbrace{(d\rho / ds_c)_{dL=0}}_{(+)}$

Thus, a potentially welfare-improving clean production tax cut ($s_c \downarrow$) corresponds to (i), (iii), (iv), and (vi). Among them, (i) and (vi) have room for a welfare improvement comparison: because in case of (iii) and (iv), offsetting labor tax cuts under the reform of $dL = 0$ are inferior to clean tax cuts-only in terms of welfare improvements. In case of (i), the reform allows for offsetting labor tax hikes. The intuition justifying $d\rho / ds_c|_{dy=0} < 0$ is that decreased s_c raises labor-intensive clean production, which in turn increases dirty production via increased *L*. It requires labor tax hikes to reduce dirty production and thereby achieve overall production neutral (i.e., $y_d \downarrow = y_c \uparrow$). This environmentally desired production replacement also occurs under the reform of $dL = 0 : d\rho / ds_c|_{dL=0} < 0$. This is because the increased *L* following reductions in s_c can be offset by the decreased *L* caused by a higher ρ. The case (vi) represents the reverse side to the case (i). The intuition justifying $d\rho / ds_c|_{dy=0} > 0$ is that decreased s_c raises clean production, which can match the decreased (capital-intensive) dirty production caused by lowered ρ. The intuition behind $d\rho / ds_c|_{dL=0} > 0$ is that a reduction in s_c lowers the level of *L*, which can match the increased *L* following reductions in ρ. Now compare the welfare improvement ranking by examining the magnitude of offsetting labor tax changes (evaluated at $\rho = 0$ initially).

$$\underbrace{\left.\frac{d\rho}{ds_c}\right|_{dy=0}}_{(+)} - \underbrace{\left.\frac{d\rho}{ds_c}\right|_{dL=0}}_{(+)} = \frac{-(R_{p_c p_c} + R_{p_d p_c})}{(R_{p_d L} + R_{p_c L})}, \tag{16}$$

which says that $d\rho / ds_c|_{dy=0} > d\rho / ds_c|_{dL=0}$. Note that this welfare improvement ranking continues to hold even when both dirty-and clean-production are labor intensive (i.e., $R_{Lp_d} > 0$, $R_{Lp_c} > 0$); in this case, the reform allows for a welfare improving labor tax hikes $d\rho / ds_c|_{dy=0} < 0$ and $d\rho / ds_c|_{dL=0} < 0$ (i.e., $s_c \downarrow \rho \uparrow$). The reason for the ranking $|d\rho / ds_c|_{dy=0} > |d\rho / ds_c|_{dL=0}$ is that labor tax changes do not have the price effects (i.e., $R_{p_c p_c}, R_{p_d p_d}$) inherent in production tax changes. So, the magnitude of labor tax changes must be very high to achieve overall production neutrality. It is the relative largeness of offsetting labor tax changes (and therefore pollution abatement) which renders the welfare improvement ranking; $dy = 0 > dL = 0$. We have the following proposition.

Proposition 2. *Suppose that (a) marginal environmental damages and own price effects are both very large, while initial tax levels are very small. Suppose also that (b) taxed goods exhibit strong substitutability and that (c) dirty production and clean production are capital intensive. Then the reform of decreasing both clean-production taxes and labor taxes to preserve the level of overall taxed production improves welfare by more than the reform to preserve labor supply. Suppose instead that dirty production and overall production are labor intensive. Then the reform of decreasing clean-production taxes and increasing labor taxes to preserve the level of overall taxed production improves welfare by more than the reform to preserve labor supply.*

Unlike the previous reforms of (8) and (9), the reforms here magnify the welfare improvement from environmentally related tax changes even when R_{Lp} and R_{Lq} have the same signs. Note that the assumption of (b) can be relaxed without changing the basic intuition of the result. To understand why, consider the case where dirty production is a complement to clean production (i.e., $R_{p_d p_c} > 0$). Look back at Eq. (14). There we saw that welfare improves with the double tax cuts ($s_c \downarrow \rho \downarrow$) to the extent taxed production is capital intensive and own price effects are very large. By contrast, the single tax cut ($s_c \downarrow$) decreases welfare (i.e., $A_\rho > 0$). We have the following result.

Corollary. *In the circumstances of Proposition 2, if taxed goods exhibit complementarity, then clean tax cuts-only worsen welfare, whereas the double tax cuts to preserve the level of overall taxed production improve welfare.*

As Schöb (1996) puts it: "focusing on the environmental dividend only, the best policy recommendation would be to avoid tax rate cuts for all complements to the dirty good and to look for strong substitutes" (Schöb1 1996, p545)[7].Corollary provides a counterexample for this view; i.e., tax cuts, if well-designed, ensure a welfare improvement even though taxed goods exhibit complementarity. To the extent own price effects dominate other effects, offsetting tax cuts raise clean production. This increase in capital-intensive clean production is balanced by a reduction in capital-intensive dirty production—which can be a result of increased labor supply following labor tax cuts[8]. Note that such an exact production replacement does not occur when implementing the reform of $dL = 0$.

Fullerton and Metcalf (2001) show that the subsidy to the clean good can have the same environmental effects as a tax on pollution to the extent that labor taxes are adjusted. Specifically, the welfare effects of the subsidy to the clean good plus labor tax hikes are equivalent to those of the tax on the dirty good plus labor tax cuts. The reforms reported in Proposition 1 show the "two-part instrument" not highlighted in their paper; the subsidy to the clean good plus labor tax cuts.

Finally, we examine changes in labor supply and the composition of outputs. From (11) and (4), we obtain $dL/ds_c\big|_{dy=0} = (R_{p_c p_c} + R_{p_d p_c})(R_{p_d L} + R_{p_c L})^{-1}$. The right-hand-side of this equation is negative when overall production is capital intensive. Even though tax cuts on capital intensive clean production lower the level of L, this can be more than offset the increased L obtained through labor tax cuts. Remember: the magnitude of offsetting labor tax cuts must be larger than that of clean production tax cuts.

As for the change in output, we obtain it by differentiating $R_{p_d} = y_d$ and $R_{p_c} = y_c$ yields:

$$dy_d = -\Delta^{-1}(R_{p_d p_c}\Delta + R_{p_d L}R_{p_c L})ds_c - \Delta^{-1}R_{p_d L}d\rho \,. \tag{17}$$

$$dy_c = -\Delta^{-1}[R_{p_c p_c}\Delta + \left(R_{p_c L}\right)^2]ds_c - \Delta^{-1}R_{p_c L}d\rho \quad . \tag{18}$$

The sign of the coefficient of $d\rho$ in Eq. (17) is positive when dirty production is capital intensive (e.g., steel manufacturing and chemical manufacturing), while that in Eq. (18) is negative when clean production is labor intensive (e.g., organic farming, and solar panel installation). This corresponds to the case (iii). In this case, offsetting labor tax cuts magnify the substitution towards clean production (following clean production tax cuts). We have the following Proposition.

Proposition 3. *Suppose that clean production is labor intensive but overall taxed production is capital intensive. Then the double tax cuts to preserve overall taxed production increases labor supply and is more effective for the green transition than clean production tax cuts alone.*

The above tax relief package could be aptly termed "Moderate Green Transition.", in the sense that reforms can mitigate the trade-off between the green transition and economic shocks. Both Propositions 2 and 3 have important implications for environmental subsidies (i.e., $s_c = 0$ initially) whose rationale can be traced back to Sandmo (1975): subsidizing substitutes for the polluting good might be desirable when governments are unable to tax emissions directly. A well-known related point is that environmental taxes and subsidies have very different effects on market entry (see Baumol and Oates (1988)). Taxes can create a financial burden that may deter market entry, especially for firms with low productivity or those engaging in polluting activities. By contrast, subsidies encourage market entry as firms seek to qualify for these benefits. The problem is that the entry of new firms could dampen the potential reductions in emissions by subsidies. Our quantity control reform $dy = 0$ has a role here: environmental subsidies, if implemented with overall output controls, need not allow the entry of

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[7] Note that the complementarity between dirty goods and clean goods does not per se make a reform pollution increasing even under a revenue-neutral reform. If the marginal tax revenue effect dominates the degree of complementarity, then the reform lowers the level of pollution (see Schöb 1996).

[8] By totally differentiating Eq. (3) and using (4), we obtain the change in pollution $dz/ds_c\big|_{dy=0} = (R_{p_c p_c}R_{p_d L} - R_{p_c L}R_{p_d p_c})(R_{p_d L} + R_{p_c L})^{-1}$. Suppose that own price effects are large enough and R_{Lp_d} and R_{Lp_c} have the same signs, then the double tax cuts lower the level of pollution even when taxed goods exhibit complementarity $R_{p_d p_c} > 0$.

polluting firms.

Our findings are consistent with real world examples. In developing countries, labor-intensive industries are dominant, with significant pollution emissions (see Hettige et al. (2000)). Typical industries include textiles, food processing, and pollution in these countries is mostly in the form of untreated wastewater. These countries have ample room for increasing environmental taxation on production (see Proposition 1). In developed countries, capital-intensive industries are dominant, but pollution continues. Heavy and chemical industries (steel, petrochemicals, heavy machinery) dominate the economy. Some developed countries such as EU have already imposed stringent climate policies. Ireland carbon tax is considered relatively high by international standards (€63.50 per ton of CO2 emissions in 2025). Thus, there remains limited room for increasing tax rates: which means the double tax cuts reported in Proposition 2 seem appropriate.

4. Conclusions

The paper has shown a moderate tax reform proposal designed to facilitate the green transition while safeguarding output or employment. As seen, the double tax cuts to fix total output can improve welfare even though dirty production and clean production are a *complement*. Make no mistake: I have no particular liking for double tax cuts. Our reform allows for double tax hikes, or the conventional mix of increasing environmental taxes and decreasing clean taxes (see Proposition 1). The overall message: during the transition process, it is the preservation of total output, rather employment, that should be maintained and prioritized. The next step is to include public pollution abatement activities (see Hatzipanayotou et al. 2005, Haibara 2023) and re-examine the results here.

As Stern and Stiglitz (2023, p289) put it: "*new, more productive technologies are embodied in new capital goods, so that an increase in the pace of investment, as old capital goods of the old economy are replaced by new capital goods of the new economy, will increase the rate of growth*." Such desired replacement occurs under the reform to fix total output. In practice, such output control reforms may not achieve a complete replacement of dirty production with clean production. However, this partial replacement can be advantageous in certain scenarios. The rationale lies in the potential for the growth of renewable energy production to outpace the decline of fossil fuels. Thus, even without full replacement, our policy appears important incremental steps along the way towards the green transition.

Appendix

Totally differentiating (1)-(3) leads to:

$$E_u du + E_z dz - \rho dL = -(s_d R_{p_d p_d} + s_c R_{p_c p_d})ds_d - (s_d R_{p_d p_c} + s_c R_{p_c p_c})ds_c, \qquad \text{(A.1)}$$

$$E_{Lu} du + E_{Lz} dz + M_{LL} dL = -R_{Lp_d} ds_d - R_{Lp_c} ds_c - d\rho, \qquad \text{(A.2)}$$

$$dz = R_{p_d p_d} ds_d - R_{p_d p_c} ds_c + R_{p_d L} dL, \qquad \text{(A.3)}$$

where $M_{LL} = E_{LL} - R_{LL} > 0$. By substituting (A.3) into (A.1) and (A.2), we have the following matrix.

$$\begin{bmatrix} 1 & (E_z - s_d)R_{p_d L} - s_c R_{p_c L} - \rho \\ 0 & M_{LL} \end{bmatrix} \begin{bmatrix} du \\ dL \end{bmatrix}$$

$$= \begin{bmatrix} (E_z - s_d)R_{p_d p_d} - s_c R_{p_c p_d} \\ -R_{Lp_d} \end{bmatrix} ds_d + \begin{bmatrix} (E_z - s_d)R_{p_d p_c} - s_c R_{p_c p_c} \\ -R_{Lp_c} \end{bmatrix} ds_c + \begin{bmatrix} 0 \\ -1 \end{bmatrix} d\rho, \qquad \text{(A.4)}$$

where we haves used the assumptions of $E_{Lu} = E_{Lz} = 0$ and $E_u = 1$.

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