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Abstract Using the simplest general equilibrium model incorporating consumption-generated pollution externalities, we identify the condition under which a revenue-neutral tax reform (RNTR), which combines increased consumption tax with reduced income tax, increases pollution emissions. More importantly, we propose a new approach to ecological tax reform, namely carbon-neutral tax reform (CNTR). We show that under plausible conditions, the CNTR raises government revenue and increases economic efficiency without jeopardizing the environment. Furthermore, the CNTR can put a limit on the degree of trade-off, which is frequently accentuated by the RNTR, between environmental and nonenvironmental efficiency. The present paper could herald a new era of tax reform and therefore offers a promising research agenda.

Keywords : Revenue-neutral tax reforms; Carbon-neutral tax reforms; Welfare

JEL classifications: H21, H23, Q58

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1. Introduction

Few issues in recent years have been as hotly debated as the welfare impacts of revenue-neutral ecological tax reform. Some see this reform as a catalyst for an improvement in environmental quality and economic efficiency. Others often see it as harmful to economic efficiency when many distortionary taxes exist. These conflicting positions have been characterized as two well-known effects with the terms coined by Goulder (1995). The first effect is the *revenue-recycling* effect: an environmental tax reform that uses the proceeds from environmental taxes to finance cuts in distortionary taxes can lower the efficiency cost, compared with the case in which the revenues from environmental taxes are returned to consumers (see, for example, Terkla 1984, Lee and Misiolek 1984). It is often argued in this context that environmental taxes render a "double dividend"—by generating not only a cleaner environment but also a less distortionary tax system. The second effect is the *tax- interaction effect*, which posits that a higher environmental tax would compound the distortions associated with preexisting taxes such as labor taxes. In particular, the underlying effect tends to appear when general-equilibrium interactions between environmental taxes and other taxes are operating (see, for example, Bovenberg and de Mooij 1994a, Parry 1995, Bovenberg and Goulder 1996, and Bovenberg and de Mooij 1997b). From these discussions, it should be clear that the relative strength of the above-mentioned opposing effects would play a vital role in determining the welfare consequences of revenue-neutral ecological tax reform.[1]

As briefly reviewed so far, the debate over the welfare effects of reform has revolved around the nonenvironmental component of welfare, and the issue of the environmental impacts of ecological tax reform has received relatively little attention in the literature. The main reason for this seems to be a commonplace belief that ecological tax reform naturally yields environmental benefits because the environmental tax is the centrepiece of the tax reform in question. A more dominant reason has been the idea that nonenvironmental effects (boosted by, for example, reducing prior existing tax distortions) dominates environmental effects—which tends to be difficult to measure. In this regard, Bovenberg (1999, p. 441) notes: "*If the double dividend hypothesis holds, an environmental tax reform would be a so-called 'no-regret' option: even if the environmental benefits are in doubt, an environmental tax reform may be desirable.*" In this way, exploring the environmental consequences of ecological tax reform remains peripheral rather than central in most of the relevant literature. Contrary to this view, some studies have thrown light on the environmental impacts of a revenue-neutral tax reform (RNTR). A notable example is the work of Schöb (1996). He extends the work of Ng (1980) and identifies the conditions under which a revenue-neutral ecological tax reform, that is, a tax cut on the clean good combined with a tax hike on the

[1] It is known that the tax-interaction effect is greater than the revenue-recycling effect if pollution externalities do not affect consumption and leisure, and if the government increases preexisting environmental taxes rather than introducing small environmental taxes (see, Goulder 1995, Bovenberg and Goulder 2002).

dirty good,[2] increases pollution. The important point in Schöb's work is that marginal tax revenue plays a crucial role in determining the environmental impacts of a revenue-neutral ecological tax reform, which is a point missed by Ng (1980). To understand this more clearly, if the marginal tax revenue from taxing the clean good is relatively low compared with that from taxing the dirty good, then the clean tax cuts must be large, which greatly increases the consumption of the dirty good because of the complementary relationship between the dirty good and the clean good. In another vein, Bayindir-Upmann and Raith (1997, 2003) derive the condition under which a revenue-neutral ecological tax reform has a counterproductive effect on environmental protection through involuntary unemployment. Their findings are quite intuitive: an increase in employment following labor tax cuts raises the demand for energy, and this causes the amount of pollution emissions to rise following the tax reform. This insight is consistent with the work of Carraro et al. (1996) who develop the simulation studies of the effect of fiscal reform on the environment in Europe. Interestingly enough, the revenue-neutral tax reform that includes the reduction in payroll taxes induces a higher income for households and in turn raises consumption of all goods, including energy. According to their simulation results, in the long run, this revenue effect can be larger than the higher price-induced emission reduction effect and pollution emissions rise due to the tax reform. Hence, these studies have opened up a Pandora's Box, viz. the environmental impacts of tax reforms, and have offered a useful insight: one must be cautious in implementing revenue-neutral ecological tax reform as a means of environmental protection when considering the price and income changes generated by that tax reform.

Against this background, the purpose of this paper is twofold. First, we aim to clarify the condition under which a revenue-neutral ecological tax reform increases consumption-generated pollution. This aim is similar to that of Bayindir-Upmann and Raith (1997), who develop a model with consumption externalities in which the share of the dirty good and the magnitude of the initial income tax rate play a role in determining the environmental impacts of ecological tax reform. However, our condition is rather in a different form: whether a revenue-neutral ecological tax reform raises pollution emissions hinges critically on information about the consumption of the dirty good as well as on information about the initial labor tax rate. More specifically, as discussed below, if the marginal propensity to consume the polluting good is higher than the price elasticity of the good in question, then the ecological tax reform is detrimental to the environment. In this context, unlike the studies undertaken by Bayindir-Upmann and Raith, we assume a perfectly competitive general equilibrium model, hence disregarding a noncompetitive labor market. In this sense, our analysis is similar to the work of Schöb (1996), although Schöb does not model labor supply and the associated income effects on pollution emissions.

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[2] Ng (1980) points out that emissions unambiguously increase due to a revenue-neutral ecological tax reform if the cross-price elasticity of the clean good is higher than the own-price elasticity of the dirty good.

Second, and more importantly, we propose a new approach to ecological tax reforms, which we term a *carbon-neutral tax reform* (CNTR). As the name implies, the idea and theory behind the CNTR are simple: tax reforms must leave carbon emission levels unchanged.[3] A distinctive and novel feature of this reform is that, unlike the familiar RNTR, governments can increase both economic efficiency and government revenue without jeopardizing the environment. More interestingly, it is found that, under plausible conditions, the proposed CNTR yields both an improvement in welfare and a net increase in government revenue, whereas the RNTR confers neither of these benefits. Hence, the appeal of the CNTR is not confined to its accompanying fiscal benefits but is also related to overall economic efficiency. A related point is that, as discussed later, the CNTR can limit the well-known trade-off between environmental efficiency and nonenvironmental efficiency—which is frequently accentuated by the RNTR. This insight is not merely a theoretical curiosity; rather, it renders the CNTR politically appealing because it is a tax reform that sacrifices neither income nor the environment. Furthermore, given the importance now placed on fiscal and environmental sustainability, the CNTR that yields public revenue without deteriorating the environment is worth considering. One potential counterargument to the CNTR is that it does not reduce pollution emissions and hence the CNTR is generally not appropriate for environmental protection. Yet carbon neutrality (or carbon offset) is omnipresent and widely accepted as environmental protection[4]—in the sense that carbon neutrality can aim at reducing pollution in order to offset increased pollution emissions—so that raising the idea of the CNTR from the perspective of environmental protection seems reasonable, although the CNTR can not be considered as ecological tax reform *sensu stricto*.

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[3] From research in the area of public economics, it has long been known that there is tax reform that keeps the government budget stable and the provision of public goods constant. However, our proposed CNTR need not generate revenue neutrality, even though the CNTR seems to resemble neutrality in public good provision. Moreover, it is well known from the trade literature that tariff cuts combined with consumption tax reform aimed at leaving consumer prices unchanged increases welfare and enhances government revenue (see, for example, Dixit 1985, Hatzipanayotou et al. 1994, and Keen and Lighthart 2002). Our proposed CNTR seems similar to tariff–tax reform in the sense that these tax reforms ensure improved production efficiency and increased government revenue. However, the context and mechanisms at work are quite different: consumer-price-neutral reform does not necessarily generate a cleaner environment, and the CNTR does not achieve price neutrality.

[4] The interested readers should visit the website of Stockholm Environment Institute (http://www.co2offsetresearch.org/index.html) for in-depth analysis and up-to-date information about carbon offset. In addition to this, one can refer to the website of British Colombia for the details of carbon neutral activities undertaken by public sectors (http://www.livesmartbc.ca/government/neutral.html).

In summary, the main contributions of this paper are specified as follows. First, the model and result have the distinct features of simplicity and applicability—so that the general thrust of the paper is accessible to a broader audience. Although the simplified model framework is open to debate, the basic results are clear-cut and will therefore be a useful benchmark for future research. Second, the main results obtained may generate renewed interest in tax reform in general. More specifically, the present paper shows that RNTR—at the heart of which is an increase in consumption tax combined with a reduction in income tax—would not be appropriate on environmental and nonenvironmental grounds. Hence, the proposed tax reform (the CNTR) could potentially end the monopoly position of the RNTR—a long-standing central tenet of tax reform shared by several authors including Corlett and Hague (1953–54).[5] In this sense, the present paper could herald a new era of tax reform and therefore offers a promising research agenda. Third, the proposed CNTR has potentially profound implications for policy, especially in advanced economies in which two key challenges have emerged: increasing government revenue and stabilizing carbon emissions. For these economies, CNTR, which ensures both welfare improvement and revenue enhancement without jeopardizing the environment, would be of considerable value.

The rest of this paper proceeds as follows. Section 2 sets out a simple general equilibrium model in which there are consumption-generated pollution externalities. Regarding this framework, we use a duality theory developed by Dixit and Norman (1980) and Woodland (1982) for the following reasons. First, it enables to derive results in simplest forms, allowing for establishing a useful benchmark outcome. Second, the duality theory characterized by the expenditure function and the revenue function offer the analytical groundwork suitable for the main theme of the paper, viz. income effects on pollution emissions, and as such, these two functions that can easily capture the income effect meets this objective. Among other features of the model, we abstract from the tax interaction effect that is at the heart of most discussions in the ecological tax reform literature. The main reason for this is that, in the spirit of Corlett and Hague (1953–54), the paper aims to offer a pilot model that provides some inspiration for future research. According to this view, the distinct features of the simplicity and applicability of the results are central to the paper: hence, the tax interaction effect, which is complex and controversial, would undermine this. In this respect, it should be emphasized that ignoring the tax interaction effect is not a way of making the CNTR more appealing than the RNTR. Rather, it enables us to highlight clearly the merits and demerits of the CNTR, and for this reason, we disregard the tax interaction effect merely for analytical purposes. Section 3 lays out our basic comparative static results and derives the conditions under which the RNTR increases pollution emissions. Furthermore, we show the desirable and undesirable welfare properties of

[5] Corlett and Hague (1953–54) do not explicitly mention RNTR. However, in their analysis, they address the spirit of revenue neutrality—an increase in indirect tax combined with a decrease in income tax that leads to the same tax revenue being raised from the consumer.

the RNTR and the CNTR. In this context, the limited practical applicability of the CNTR is also discussed. Section 4 shows arguments concerning the main results obtained. Section 5 concludes this paper and outlines suggestions for promising directions for future research.

2. The Model

In this section, we develop a perfectly competitive general equilibrium model of a small open economy. This economy produces two traded goods, *x* and *y*.[6] Good *x* is the polluting good in the sense that consumption of good *x* generates pollution, viz. carbon emissions. Good *y* does not generate pollution and is the untaxed *numeraire*. To tackle pollution, the economy imposes an environmental consumption tax, and hence the resulting consumer price of the nonnumeraire good is $p+\tau$, where p is exogenously given world price and τ denotes the tax level. Hereafter, unless stated otherwise, we refer to the environmental consumption tax τ as the environmental tax.[7]

The representative household's behavior is summarized by the expenditure function $E(1, p, L, z, u)$, where *u* denotes utility (welfare), z is the level of pollution and *L* is an endogenous variable factor such as labor. Utility depends positively on the consumption of goods, hence $u_x > 0$, and negatively on pollution emissions, $u_z < 0$, where subscripts imply partial differentiation in the usual manner. It is well known that the derivatives of the expenditure function with respect to prices give the compensated demands for goods, for example, $E_p = x$, and also that the expenditure function is concave in prices, that is, $E_{pp} < 0$. Furthermore, the derivative of the expenditure function with respect to *u*, that is, $E_u > 0$, measures the reciprocal of the marginal utility of income. In addition, we assume that all goods are normal, that is, $E_{pu} > 0$. The expenditure function is increasing in *z*; that is, $E_z > 0$. This is because an increase in emissions lowers household utility, and thus, expenditure must increase to maintain constant utility. In this sense, $E_z > 0$ is often interpreted as the household's marginal willingness to pay for reduction in pollution or as the marginal damage caused by pollution (Copeland 1994). The derivative of the expenditure function with respect to *L* (that is, $E_L = \tilde{w}$) is considered to be the reservation wage $\tilde{w}$, and $E_{LL} > 0$ is

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[6] Most studies of tax reform consider *n* goods. However, because our pilot model does not focus on interactions between goods, we abstract from the *n*-good generalization. Nevertheless, our results apply to the *n*-good case, of course.

[7] In Europe, the share of environmental consumption tax exceeds that of pure environmental tax, which aims directly at pollution emissions. A notable example of the former is energy consumption tax, which generated more than three-quarters of the environmental tax receipts in 2001 and its taxation base depends on the consumption of energy—up to 80% of the final price for leaded and unleaded petrol (see Albrecht 2006). Against this background, Albrecht (2006) proposes environmentally differentiated consumption taxes such that products with lower environmental impacts bear lower consumption taxes while more environmentally damaging products face higher consumption taxes.

typically assumed.[8] Following standard practice from the literature on ecological tax reforms, we assume that pollution emissions do not affect consumption and leisure (that is, $E_{pz} = E_{Lz} = 0$) under the weakly separable relationship between pollution and consumption in the household's utility function. Furthermore, unlike under conventional settings, we ignore the interaction between leisure and consumption (that is, we assume $E_{pL} = 0$), and between leisure and income (that is, $E_{Lu} = 0$).[9] These assumptions are made apologetically but are essential so that we can abstract from the tax interaction effect.

Let us define pollution externalities:

$$z = \alpha E_p(1, p+\tau, L, z, u), \tag{1}$$

where $\alpha > 0$ is a coefficient of pollution emission. Equation (1) indicates that pollution emission is proportional to the consumption of the non-numeraire good.

The production side of the economy is characterized by the revenue function $R(1, q, L)$, where q represents the producer price of the non-numeraire good. In regard to the revenue function, it is well-known that $R_q = x$ according to the Hotelling's Lemma, and also that the revenue function is convex in prices, i.e., $R_{pp} > 0$ and concave in factors, i.e., $R_{LL} < 0$.

With these preliminaries in hand, we have the following income-expenditure identity:

$$E(1, p+\tau, L, z, u) = (1-\rho)R(1, q, L) + \tau E_p(1, p+\tau, L, z, u), \tag{2}$$

where ρ denotes the income tax rate[10]. The first term on the right-hand side of equation (2) is the net revenue from private production and the second term on the right-hand side indicates environmental tax revenue. We assume that consumption tax revenue is returned to household as lump-sum transfer.

The labor market equilibrium requires that the reservation wage and the net wage received by workers are equal. That is:

$$E_L(1, p+\tau, L, z, u) = (1-\rho)R_L(1, q, L). \tag{3}$$

These three equations (1)-(3) determine the endogenous variables (z, L, u) as functions of the exogenous variables (ρ, τ).

Finally, let us define the government budget constraint as follows:

$$G \equiv \rho R(1, q, L) + \tau E_p(1, p+\tau, z, u), \tag{4}$$

where ρR denotes revenue from income tax and τE_p denotes revenue from environmental tax.

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[8] For detailed discussion of the reservation wage, see Dixit and Norman (1980) and Woodland (1982).

[9] This formulation is due to Diamond (1998) who assumes a quasilinear utility function with respect to goods and leisure in order to simplify the analysis.

[10] Michael and Hatzipanayotou (1999) study the possible effects of trade restrictions on welfare in the presence of income taxation using a general equilibrium model similar to us.

From these settings, it appears that technical contributions involved in the model are quite modest, being a rearrangement of standard tax reforms. However, as discussed below, this rearrangement leads to a quite different way of approaching tax reforms and offers an important novel insight that is worth consideration for future research. Furthermore, the simplest model we have developed here enables us to establish an elegant result, thereby attracting a broader audience including policymakers.

3. Welfare and Environmental Impacts of Tax Reform

The changes in the endogenous variables are as follows (see Appendix):

$$\Delta dL = -R_L \Theta d\rho \,. \tag{5}$$

$$\Delta dz = \alpha E_{pp} E_u M_{LL} d\tau - \alpha E_{pu} R M_{LL} d\rho \,. \tag{6}$$

$$\Delta du = M_{LL}(\tau - \alpha E_z) E_{pp} d\tau - R M_{LL} d\rho \,. \tag{7}$$

Note that $\Delta = M_{LL}\Theta$ is the determinant of the coefficient matrix of the unknown variables, where $M_{LL} = E_{LL} - (1-\rho)R_{LL} > 0$ and $\Theta = [(\alpha E_z - \tau)E_{pu} + E_u]$. As noted earlier, all goods are normal (that is, $E_u - \tau E_{pu} > 0$), so we obtain $\Theta > 0$ and, thereby, $\Delta > 0$. Equation (5) indicates the change in labor supply as the result of changes in income (equivalently, labor) tax. From equation (5), it is clear that an increase in the labor tax reduces labor supply. This could be simply because there is no income effect on labor supply. Analogously, the change in the environmental tax does not affect labor supply when there is no income effect. In this sense, the so-called tax interaction effect, which occurs when an increased environmental tax exacerbates labor market distortions, is not relevant in this context.

Equation (6) shows the change in pollution emissions following tax changes. It reveals that the amount of pollution falls when tax increases. That is, an increase in the environmental tax reduces pollution emissions directly via price hikes that decrease the demand for the polluting good; income tax hikes decrease pollution emissions indirectly by reducing real incomes.

Equation (7) measures the welfare effects of tax changes. On the one hand, an increase in τ lowers the consumption of the polluting good (and therefore pollution emissions), which affects welfare positively, and on the other hand, it lowers environmental tax revenue, which affects welfare negatively. Hence, if the environmental tax rate is smaller (larger) than the marginal damage to the household, that is, if $\alpha E_z > \tau$ ($\alpha E_z < \tau$), then the environmental gain from the increased τ dominates (is dominated by) the environmental tax revenue losses and thus, welfare improves (worsens). It follows that the optimal environmental tax rate coincides with the Pigouvian tax rate, $\tau = \alpha E_z$, provided that income tax is not adjustable. As for the sole change in income tax, an increase in ρ lowers welfare by reducing overall consumer income.

With these basic results in hand, we can now examine the effects of the RNTR, in which environmental taxes are increased to compensate for income tax revenue reduction. By totally differentiating equation (4), then using equations (5) and (7), we obtain:

$$\Delta dG = [(E_p + \tau E_{pp})\Delta + \tau E_{pu} M_{LL}(\tau - \alpha E_z)E_{pp}]d\tau + [R\Delta - \tau E_{pu} RM_{LL} - \rho R_L^2 \Theta]d\rho . \qquad (8)$$

From equation (8), the change in government revenue following increases in tax rates is ambiguous. However, following standard practice from the tax reform literature, we assume (unless stated otherwise), that the tax base does not erode following an increase in each tax rate. Hence, the terms in the brackets on the right-hand side of equation (8) are assumed to be positive. With this in mind, setting $dG = 0$ yields:

$$\left(\frac{d\rho}{d\tau}\right)_{R-N} = -\frac{[(E_p + \tau E_{pp})\Delta + \tau E_{pu} M_{LL}(\tau - \alpha E_z)E_{pp}]}{[R\Delta - \tau E_{pu} RM_{LL} - \rho R_L^2 \Theta]} . \qquad (9)$$

From equation (9), $d\rho / d\tau < 0$. This confirms that the revenue losses resulting from an income tax cut are offset by the revenue gains generated by increased environmental tax. The welfare effects of the tax reform under study can be derived by substituting equation (9) into (7):

$$\Delta(du / d\tau)_{R-N} = M_{LL}(\tau - \alpha E_z)E_{pp} - RM_{LL}(d\rho / d\tau)_{R-N} . \qquad (10)$$

Equation (10) reveals that welfare improves as a result of the RNTR provided that $\alpha E_z > \tau$. Intuition suggests that an increase in the environmental tax rate lowers consumption-generated pollution directly—an increase in τ reduces pollution-inducing consumption (and therefore pollution) via price hikes—and it increases welfare when the marginal damage to the household is high; that is, when $\alpha E_z > \tau$. In addition, a reduction in the income tax rate improves welfare; a fall in ρ raises both labor supply and national income.

Based on these arguments, we proceed to determine the environmental effects of revenue-neutral ecological tax reform.

$$\Delta(dz / d\tau)_{R-N} = \alpha E_{pp} E_u M_{LL} - \alpha E_{pu} RM_{LL}(d\rho / d\tau) . \qquad (11)$$

Furthermore, using equation (9) yields:

$$\Delta\left(\frac{dz}{d\tau}\right)_{R-N} = \frac{\alpha M_{LL} R\Delta E_u E_p p^{-1}(m_x - \varepsilon_x) - \alpha E_{pp} E_u M_{LL} \rho R_L^2 \Theta}{[R\Delta - \tau E_{pu} RM_{LL} - \rho R_L^2 \Theta]} . \qquad (12)$$

where $m_x = pE_{pu} / E_u$ represents the marginal propensity to consume the polluting good, and $\varepsilon_x = pE_{pp} / E_p$ denotes the price elasticity of the good in question. From equation (12), $dz / d\tau > 0$ provided that $m_x > \varepsilon_x$. The key point behind this is that the RNTR brings real income gains via an increase in labor supply and, as a result, the consumption of the dirty good (and therefore pollution emissions) rises. It follows that if the income effect on the dirty good exceeds the substitution effect on the good in question, the net effect on dirty consumption is positive. This situation can arise under the assumption that the marginal propensity to consume the polluting good exceeds the price elasticity of the good in question; that is, $m_x > \varepsilon_x$. Perhaps energy products provide the prime example of the satisfaction of this assumption: both crude oil and natural gas have low price elasticities of demand and high income elasticities of demand (see Krichene 2005).[11] For future reference, we summarize this result as the following proposition.

Proposition 1. *Suppose that the household's marginal propensity to consume the polluting good is higher than the price elasticity of the good in question. Then, the RNTR, under which increased environmental tax is compensated for by reduced income tax, leads to an increase in pollution.*

Proposition 1 crystallizes the result derived previously by several authors, such as Schöb (1996) and Bayindir-Upmann and Raith (1997). As mentioned in the Introduction, Schöb (1996) shows that the marginal revenue effect as well as the relationship between the dirty good and the clean good plays a role in determining the environmental impact of ecological tax reform, although he does not explicitly highlight the income effect on pollution emissions. Bayindir-Upmann and Raith (1997) show that the income effect associated with labor tax cuts represents a rebound effect on consumption of the dirty good (and therefore pollution emissions) if the share of the dirty good and the initial tax rate on labor supply are high. Proposition 1 broadly confirms these findings; that is, the value of the marginal propensity to consume the dirty good is synonymous with the share of the good in question. However, there is one important difference: our results indicate that the RNTR increases pollution emissions as long as $m_x > \varepsilon_x$ holds, even if the initial tax rate on labor supply is low.

The main policy lesson that can be drawn from our discussion is that the environmental dividend of ecological tax reform does not necessarily materialize if there is a substantial feedback effect on pollution emissions following the income tax cut. This feedback effect is theoretically plausible when the polluting good is a normal good: that is, the ecological tax reform generates an improvement in economic efficiency

[11] The expression E_{pu} can be interpreted as the income elasticity of the polluting good.

(and therefore real income) and, thus, the feedback effect may cause pollution emissions to rise.[12] Indeed, this is the primary motivation for this paper: if the RNTR harms the environment, it is worth exploring the tax reform alternative to the RNTR. Hence, in the remainder of this paper, we propose a new approach to ecological tax reform (the CNTR) and then highlight its desirable properties and limitations. As mentioned in the Introduction, the theoretical underpinning of the proposed tax reform is simple: each tax rate is changed to keep the amount of pollution unchanged. That is, we set $dz = 0$ in equation (6) and obtain:

$$\left(\frac{d\rho}{d\tau}\right)_{C-N} = \frac{\alpha E_{pp} E_u}{\alpha E_{pu} R}. \quad (13)$$

Equation (13) exhibits the carbon-neutral swap in which the environmental tax τ replaces the income tax cut, viz. $(d\rho / d\tau)_{C-N} < 0$. This suggests a novel feature of the CNTR; that is, the CNTR is not limited to the curtailment of pollution emissions but also encompasses increases in economic efficiency and government revenue. To see this, by substituting equation (13) into (8), after some rearrangement, we obtain:

$$\Delta(dG / d\tau)_{C-N} = [\alpha E_u E_p R p^{-1} \Delta(m_x - \varepsilon_x) - \alpha E_{pp} E_u \rho R_L^2 \Theta](\alpha E_{pu} R)^{-1}. \quad (14)$$

From equation (14), it is clear that government revenue goes up under the maintained assumption that $m_x > \varepsilon_x$. The question to be addressed in this context is why government revenue rises despite the fact that the pollution level is unchanged. To answer the question, it is instructive to rewrite equation (13) as:

$$\left(\frac{d\rho}{d\tau}\right)_{C-N} = \frac{\alpha E_p \varepsilon_x}{\alpha R m_x}. \quad (13)'$$

Equation (13)′ indicates that the absolute value of $(d\rho / d\tau)_{C-N}$ is low—environmental tax hikes are large whereas income tax cuts are small—when $m_x > \varepsilon_x$. This is because if the marginal propensity to consume the polluting good is high, then the feedback effect on pollution emissions is substantial, and hence, income tax cuts must be small so as not to raise pollution. Furthermore, given the small price elasticity, a higher environmental tax is required to reduce the consumption of the polluting good and thereby pollution emissions. These arguments suggest that the effect of an increase in τ outweighs the

[12] Hoerner and Bosquet (2001) survey the experiences of revenue-neutral ecological tax reform in Europe and found that the reform in question increases emissions relative to baseline. The root cause of this is that the ecological tax reform generates economic growth that, in turn, stimulates pollution emissions, but the improvement in energy efficiency caused by the energy tax is not sufficient to offset the additional growth-related emissions.

effect of a decrease in ρ, which in turn means that the CNTR generates environmental tax revenue gains that are sufficiently large to do more than offset the reduced income tax revenue brought about by the income tax cut. The following proposition sums up this discussion.

Proposition 2. *Suppose that the household's marginal propensity to consume the polluting good is higher than the price elasticity of the good in question. Then, the CNTR, which combines environmental tax hikes and income tax cuts, increases government revenue.*

Propositions 1 and 2 are of particular interest because, under certain plausible conditions, it transpires that the CNTR is a more desirable policy than the RNTR from the fiscal and environmental points of view. These considerations generally have been absent from policy discussions in the tax reform literature. The main reason for this, as explained in the Introduction, is that most previous studies of tax reform have not paid proper attention to its environmental impacts,[13] and therefore, discussions have centered on the extent to which tax reform has improved, or diminished, nonenvironmental efficiency. In this context, several studies referred to in the Introduction have pointed out the deficiencies of the RNTR from the viewpoint of environmental protection, but little has been done to suggest alternative tax reform strategies. In this sense, our proposed CNTR fills this intellectual gap and suggests a novel approach: it represents a first attempt both to raise welfare and to yield a net increase in government revenue without increasing pollution emissions. Moreover, this proposed tax reform strategy is potentially important for many developed countries, in which boosting government revenue and stabilizing carbon emissions are key priorities.

As for government revenue increases, one might argue that consumption hikes alone would be sufficiently desirable to take away the advantage of the CNTR, because increasing the consumption tax raises government revenue without harming the environment. Although this argument is convincing on fiscal and environmental grounds, it is well known that simply increasing environmental tax without making accompanying distortionary tax cuts increases neither labor supply nor economic efficiency. In this respect, the weak form of the double-dividend hypothesis implies that the efficiency costs of environmental tax hikes would exceed the efficiency costs of environmental tax hikes accompanied by distortionary tax cuts, as exemplified by the CNTR and the RNTR.

Up to now, in our analysis, we have assumed that the marginal propensity to consume the polluting good exceeds the price elasticity of that good; that is, $m_x > \varepsilon_x$. Assume that this were not the case, then, the results would be reversed. That is, if $m_x < \varepsilon_x$, the feedback effect on pollution emissions under the

[13] This paper does not attempt to provide a comprehensive survey of the modern theory of tax reform. For detailed discussion of tax reform, see, for example, Dixit (1975), Feldstein (1975), Guesnerie (1977), Hatta (1977), and Auerbach (1985).

RNTR is negligible, and consequently, the RNTR reduces pollution. However, there is an important caveat: if the initial income tax rate is high, then income tax cuts generate a substantial increase in labor supply, which increases the consumption of the polluting good as long as that good is normal. Thus, given the high initial income tax rate required to make the right-hand side of equation (12) positive, along with Proposition 1, it follows that the RNTR can damage the environment despite $m_x < \varepsilon_x$ being the case. This insight is consistent with that of Bayindir-Upmann and Raith (1997, 2003), who show that when initial labor taxes are high, ecological tax reform confers no environmental benefit. However, Bayindir-Upmann and Raith do not consider the relative magnitudes of the price elasticity and the marginal propensity. Similar to Proposition 1, the result of Proposition 2 may hold even when $m_x < \varepsilon_x$. This is mainly because, under the CNTR, the large ρ induces the feedback effect, which serves to increase the consumption of the polluting good and thereby increase government revenue. Nevertheless, it seems fair to point out the case in which the results conveyed by Propositions 1 and 2 are reversed—the RNTR (the CNTR) decreases pollution (government revenue). As can be inferred from the preceding discussion, this case is likely to occur if the initial income tax rate is sufficiently small to be dominated by the price elasticity. In this case, the environmental and fiscal advantages of the CNTR over the RNTR would disappear. Despite this drawback, as discussed below, the welfare properties of the CNTR are more desirable than are those of the RNTR.

Next, we consider another modification to our analysis. So far, we have assumed that the environmental tax rate is small enough to be dominated by the marginal damage to the household; that is, $\alpha E_z > \tau$. Allowing $\alpha E_z < \tau$ generates an intriguing result; that is, there is a sharp contrast between the RNTR and the CNTR from the welfare perspective. To generate further insights, it is instructive to rewrite equation (9) as follows:

$$\left(\frac{d\rho}{d\tau}\right)_{R-N} = -\frac{E_p E_u M_{LL}[(\alpha E_z - \tau)m_x + (1 - \tau p^{-1}\varepsilon_x)]}{[R\Delta - \tau E_{pu} R M_{LL} - \rho R_L^2 \Theta]}. \qquad (9)'$$

The numerator of the right-hand side of equation (9)′ is negative if the value of the environmental tax rate is sufficiently large to ensure that the term in the bracket of the numerator is negative; that is, $\tau > (\alpha E_z m_x + 1)(m_x + p^{-1}\varepsilon_x)^{-1}$. This suggests $(d\rho / d\tau)_{R-N} > 0$ and thus $(du / d\tau)_{R-N} < 0$. The underlying reason for these outcomes can be intuitively explained by invoking the so-called *tax base erosion effect* (see Goulder 1995);[14] that is, given the high initial environmental tax rate, ecological tax

[14] This is also referred to as the *tax level effect* by Bovenberg (1999). It is argued in this context that ecological tax reform erodes the labor tax base; that is, an increase in environmental tax decreases labor supply and therefore labor tax revenue.

reform erodes the pollution tax base considerably and is therefore counterproductive to an increase in labor supply.[15] The reason is that the government cannot reduce income tax sufficiently to offset the adverse effect of a higher environmental tax on its revenue (see, for example, Goulder 1995 and Bovenberg 1999).[16] In relation to this, it is well known that, given the small amount of marginal damage to the household, that is, $\alpha E_z < \tau$, the ecological tax reform confers little environmental gain, and hence, the welfare losses from the revenue reductions more than offset the welfare gains from improved environmental quality. From these discussions, it is intuitively plausible that the RNTR, which imposes income tax hikes, decreases welfare.[17] Indeed, this reflects a fundamental trade-off between, on the one hand, improved environmental efficiency, and on the other hand, favorable nonenvironmental effects such as increased labor supply (see, Bovenberg 1995). By contrast, if the government implements the CNTR, this trade-off is lessened, and as a result, welfare rises whether or not $\alpha E_z < \tau$. To show this more clearly, by substituting equation (13) into (7), we obtain:

$$\Delta(du/d\tau)_{C-N} = \frac{(E_u - \tau E_{pu})RM_{LL}\alpha E_{pp}E_u - \alpha E_z E_{pp}\alpha E_{pu}RM_{LL}}{\alpha E_{pu}R}. \qquad (15)$$

From equation (15), it is clear that $(du/d\tau)_{C-N} > 0$ under the normal good assumption $E_u - \tau E_{pu} > 0$. The intuition behind this result is that under the constraint of carbon neutrality, the fall in ρ must be considerable to increase pollution, thereby offsetting the considerable reduction in pollution emissions associated with large τ. This suggests that any improvement in nonenvironmental efficiency is substantial, more than offsetting the welfare losses from environmental tax revenue reduction. Thus, unlike under the

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However, in our paper, this tax erosion effect is not relevant because we abstract from the interplay between environmental taxes and labor supply.

[15] An increase in environmental tax decreases real income by reducing environmental tax revenue, given that $\alpha E_z < \tau$. Reduced real income lowers the consumption of the polluting good, which further reduces environmental tax revenue.

[16] In contrast to the mainstream theory, in which there is a tax-interaction effect, in this paper, environmental tax hikes do not lower labor supply. Hence, the welfare losses resulting from an increase in the environmental tax rate comprise environmental tax revenue losses and the accompanying labor supply reductions. These effects would arise were the tax-interaction effect to be incorporated because the tax erosion effect accentuates the tax-interaction effect.

[17] Further interpretation of the welfare effects of the RNTR follows. As already noted, the RNTR reduces pollution via pollution tax hikes. The pollution reduction is substantial if the price elasticity ε_X is high. In such a situation, given the small value of the marginal willingness to pay, αE_z, implementing the RNTR lowers welfare because the welfare losses arising from reducing environmental tax revenue more than offset the welfare gains arising from reduced pollution. Note that the large (small) value of ε_X (αE_z) is consistent with the inequality $\tau > (\alpha E_z m_X + 1)(m_X + p^{-1}\varepsilon_X)^{-1}$.

RNTR, the nonenvironmental efficiency improvement induced by the CNTR is greater even if the pollution tax base is reduced because of the higher τ. This implies that given a high initial environmental tax rate, the CNTR is better for welfare than is the RNTR. This gives the following proposition.

Proposition 3. *Suppose that the initial environmental tax rate is high. Then, implementation of the CNTR improves welfare through income tax cuts, whereas implementation of the RNTR reduces welfare through income tax hikes.*

One may argue that Proposition 3 involves an extreme case, in the sense that, contrary to the general thrust of ecological tax reforms, the RNTR calls for labor tax hikes. Nevertheless, Proposition 3, on the one hand, emphasizes the unintended negative effect of the trade-off associated with the RNTR and, on the other hand, sheds light on the desirable welfare effects of the CNTR when compared with the RNTR; that is, unlike implementation of the RNTR, implementation of the CNTR need not erode the pollution tax base. These comments on Proposition 3 apply even in the conventional situation in which the RNTR allows for labor tax cuts. In such circumstances, the welfare effects of the RNTR become ambiguous. The main reason for this ambiguity is that well-known conflicting effects—the gains from an increase in labor supply and the losses from environmental tax revenue reductions—and their relative magnitudes determine the welfare effects of the RNTR. Based on these arguments, compared with those of the CNTR, the welfare prospects of the RNTR are bound to be gloomy if the initial environmental tax rate is high. This suggests use of the CNTR, rather than the RNTR, as an instrument for improving nonenvironmental efficiency. Note that these comments on Proposition 3 would be equally, if not more, valid were we to incorporate the tax interaction effect. This is because the welfare effects of tax erosion and tax interaction move in tandem.

At a practical level, as one can easily imagine, achieving carbon neutrality is a difficult task. However, the direction of the tax changes described by equation (13)′ gives a clue: if the marginal propensity to consume the polluting good is high (low) relative to the price elasticity of the good in question, then the magnitude of the environmental tax hikes is high (low) and the magnitude of the income tax cuts is low (high). To obtain a better understanding of this, let us compare the direction of the tax changes between the RNTR and the CNTR. In doing so, by using equations (9) and (13) and assuming that the initial environmental tax is zero, we obtain:

$$\left(\frac{d\rho}{d\tau}\right)_{C-N} - \left(\frac{d\rho}{d\tau}\right)_{R-N} = \frac{[\alpha E_u E_p R p^{-1}(m_x - \varepsilon_x)\Delta - \alpha E_{pp} E_u \rho R_L^2 \Theta]}{\alpha E_{pu} R[R\Delta - \rho R_L^2 \Theta]}. \tag{16}$$

The right-hand side of equation (16) is positive, which means that $\left|\frac{d\rho}{d\tau}\right|_{R-N} > \left|\frac{d\rho}{d\tau}\right|_{C-N}$, under the maintained assumption $m_x > \varepsilon_x$. Loosely speaking, this suggests that the magnitude of the environmental tax hikes (income tax cuts) is higher (lower) under the CNTR than under the RNTR. This reflects the message conveyed by equation (13)′: if $m_x > \varepsilon_x$, the CNTR calls for a small decrease in the income tax rate. This suggests that the improvement in nonenvironmental efficiency is greater under the RNTR than under the CNTR. However, this does not imply that welfare is higher under the RNTR than under the CNTR. This is because the RNTR generates environmental costs under the assumption that $m_x > \varepsilon_x$. Thus, under the RNTR, as is the case with the high initial environmental tax rate, we face a dilemma—a trade-off between nonenvironmental efficiency and environmental efficiency. A particular facet of this worth emphasizing is that the CNTR can mitigate this trade-off. This is because the CNTR improves nonenvironmental efficiency without increasing pollution.

Suppose we relax the assumption that $m_x > \varepsilon_x$ by assuming that the price elasticity is sufficiently high for the term in the bracket of the numerator of the right-hand side of equation (16) to be negative. Then, as we have already seen, the RNTR leads to a reduction in pollution, whereas the CNTR lowers government revenue. However, the CNTR still has an advantage: the improvement in nonenvironmental efficiency generated by the CNTR is at least as great as the improvement generated by the RNTR; that is, $\left|\frac{d\rho}{d\tau}\right|_{R-N} < \left|\frac{d\rho}{d\tau}\right|_{C-N}$. Thus, given Proposition 3, the CNTR can limit the trade-off between nonenvironmental efficiency and environmental efficiency, which is often accentuated under the RNTR, regardless of the initial magnitude of the environmental tax rate.

Nevertheless, we do not wish to argue against the RNTR for two reasons: first, the RNTR reduces pollution under certain conditions; second, in some cases, the RNTR generates greater improvement in nonenvironmental efficiency than does the CNTR. Thus, it seems fair to conclude that whether the government implements the RNTR or the CNTR depends on the circumstances. In this sense, our proposed CNTR provides the government with a new option for tax reform.

Given our finding in relation to the direction of tax changes under the CNTR, it makes sense to determine the optimal environmental tax rate under the CNTR. To do so, we first substitute equation (13) into (7) and set $du = 0$ to yield:

$$\tau_{C-N}^{opt} = \alpha E_z + \frac{E_u}{E_{pu}}. \qquad (17)$$

From equation (17), $\tau_{C-N}^{opt} > \alpha E_z$. Intuition then suggests that welfare improves under implementation of the CNTR, regardless of the initial value of the environmental tax rate. Hence, it is quite plausible that the optimal environmental tax rate under the CNTR exceeds the Pigouvian rate. The practical implications of implementing the CNTR are summarized by the following proposition.

Proposition 4. (a) *For implementing the CNTR, the magnitude of the environmental tax hikes (the income tax cuts) should be larger (smaller) than under RNTR if the marginal propensity to consume the polluting good is higher than the price elasticity of demand for the good in question.*

(b) *The optimal environmental tax rate under the CNTR is greater than the Pigouvian tax rate.*

The simple rule shown in Proposition 4 gives a theoretical rationale for imposing a large environmental tax from the point of view of carbon neutrality. On the other hand, the RNTR does not necessarily allow for a high environmental tax rate even if the well-known tax interaction effect is absent. To see this, using equations (7) and (9), we examine the optimal environmental tax rate under the RNTR:

$$\tau_{R-N}^{opt} = \alpha E_x - R(d\rho / d\tau)$$

$$= \alpha E_x - \frac{R(E_p - pE_{pp} - E_{1p})}{E_{pp}[R - \rho R_L^2 (M_{LL})^{-1}]}, \tag{18}$$

where we have used the fact that the expenditure function is homogenous of degree one in p; that is, $(p+\tau)E_{pp} + E_{p1} = 0$. If substitutability between the dirty good and the clean good, $E_{1p} > 0$, is sufficiently high for $E_{1p} > E_p + pE_{pp}$, which implies that $\varphi_x > E_p(1+\varepsilon_x)$, where $\varphi_x = E_{p1} / E_p > 0$ denotes the cross price elasticity of the dirty good, then we arrive at the conventional result $\tau_{R-N}^{opt} < \alpha E_x$. The basic point is that if substitutability between the dirty good and the clean good is high, an increase in the environmental tax leads the household to purchase the clean good rather than the dirty good, and as a result, the pollution tax base is eroded. In such a case, government revenue falls, and hence, the optimal environmental tax system prioritizes revenue generation over the internalization of pollution externalities (see, for example, Bovenberg 1999, 2002). According to this view, a low environmental tax rate is required to reap sufficient environmental revenues to offset the fall in income tax revenue. On the other hand, if substitutability between the dirty good and the clean good is negligible, we obtain the opposite result $\tau_{R-N}^{opt} > \alpha E_x$. The basic intuition behind this result is that the optimal environmental tax takes into account the efficiency improvement associated with the income tax cuts; that is, $(dL / d\tau)_{R-N} > 0$. Thus, in what follows, we assume that the optimal tax rate exceeds the benchmark level based on the absence of income tax cuts, $\tau_{R-N}^{opt} = \alpha E_x$. Indeed, this finding is consistent with the results obtained by Terkla (1984) and Lee and Misiolek (1987), who ignore both the tax interaction effect and the tax base erosion effect. Thus, a high optimal environmental tax rate is appropriate.

Consider a situation in which there is a tax interaction effect. One would expect this to leave the main results unchanged: the optimal environmental tax rate under the RNTR would be lower than that under the CNTR. This conjecture is valid because it is well known that the tax base erosion effect exacerbates the tax interaction effect, which lowers the optimal environmental tax rate. Following this logic, the RNTR, which tends to generate tax base erosion, does not allow for a higher environmental tax rate, unlike the CNTR, under which this effect is irrelevant. However, the exact magnitude of the optimal environmental tax rate in the presence of the tax interaction effect is open to debate.

4. Discussion

Before concluding the paper, there are a number of discussions relating to the results obtained thus far. First, we have abstracted from the income effect on leisure; that is, $E_{Lu} = 0$. Incorporating this effect into our modeling may affect the results. To see why, consider the case in which $E_{Lu} > 0$. In this case, one can conjecture that a higher environmental tax rate would reduce labor supply provided that $\alpha E_z > \tau$. This is because real income increases following a reduction in pollution because of the increased τ, and this increases leisure. A related point is that in our analysis, we have ignored the relationship between leisure and consumption. Taking this into account would affect the results;[18] that is, if leisure and consumption of the dirty good are complementary, i.e. $E_{Lp} < 0$, a higher environmental tax increases labor supply and alleviates labor market distortions. On the other hand, if leisure and the consumption in question is a substitute, i.e. $E_{Lp} > 0$, then a hike of environmental tax lowers the consumption and thereby increases leisure, thus reducing national income via a decrease in labor supply. This resonates with the so-called tax-interaction effect: a higher environmental tax exacerbates labor distortions, rendering ecological tax reform welfare-worsening. In such cases, one can expect that pollution emissions fall because the reduced real income leads to a decrease in the dirty consumption, implying that the CNTR becomes less attractive from an environmental point of view. Incorporating these considerations in regard to the tax interaction effect would come at the cost of increasing the model's complexity. To avoid this, as noted earlier, we limited our investigation to analyzing government introduction of a small environmental tax (see, for example, Bovenberg and de Mooij 1994, Bovenberg and Goulder 1996, 2002).[19]

Second, it is worth emphasizing the environmental impacts of the CNTR. As seen, the environmental benefits of CNTR are small because this tax reform would leave pollution levels unchanged, rather than lower. In this respect, implementing the CNTR would be similar to introducing pollution permits because auctioned permits, like the CNTR, would leave pollution levels unchanged. Furthermore, auctioned pollution permits are equivalent *ipso facto* to pollution taxes in the sense that the government can obtain revenues from pollution. However, there is one fundamental difference between the pollution permits of this sort and the CNTR: auctioned pollution permits do not generally cover household pollution emissions,

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[18] In this context, it might be worth exploring how the constraint of carbon neutrality would affect the conventional wisdom represented by the taxation rule developed by Corlett and Hague (1953–54) and Diamond and Mirrlees (1971), under which tax rates on goods that are highly complementary to leisure are efficiency improving.

[19] It is widely recognized that the tax-interaction effect does not appear, if the government introduces small environmental taxes. T his is because the adverse effect of environmental taxes on labor supply is offset by the positive effect of lower taxes on labor income under the circumstances of introducing small environmental taxes. In the present paper, the results shown in Propositions 1 and 2 survive under the assumption that the government introduces a small environmental tax rate; that is, $\tau = 0$.

whereas environmental consumption taxes do apply to household pollution. Hence, for the consumption-generated pollution considered in this paper, auctioned pollution permits are not relevant.

5. Concluding Remarks

Using the simplest possible general equilibrium model incorporating consumption-generated pollution externalities, the paper has proposed a new approach to ecological tax reforms. Although the analysis has abstracted from many important issues, our simple model and its stylized results allow an intuitive grasp of the merits and demerits of the proposed tax reform, termed *carbon-neutral tax reform* (CNTR), and serve as a starting point for discussion. Of the many novel and policy-relevant insights obtained, two aspects deserve further comments. The first of these relates to the environmental consequences of tax reforms. That is, as our discussion indicates, the principles central to most policy advice on traditional tax reform—the revenue-neutral tax reform (RNTR)—would not be appropriate for environmental protection when there is a large income effect on the dirty good. This is the case for energy products: both crude oil and natural gas have low (high) price elasticities (income elasticities) of demand. These discussions imply that revenue neutrality is not the *sine qua non* condition for environmental protection.

The second important lesson that can be drawn from the paper relates to the welfare effects of tax reforms. More specifically, we argued that under a high environmental tax rate, the CNTR can improve nonenvironmental efficiency by, for example, substantially raising labor supply. By contrast, the RNTR may not generate such an improvement and, thus, may fail to increase welfare. The underlying logic is intuitive: the CNTR cuts income tax substantially, whereas the RNTR disallows income tax cuts in order to avoid eroding the environmental tax base. This distinction highlights the novel feature of our tax reform proposal: the CNTR does not necessarily erode tax revenue. In the light of this, the CNTR not only can be considered as a policy for environmental protection but can also be regarded as an instrument for improving nonenvironmental efficiency. In relation to this, it has been argued that the CNTR can help limit the long-standing problem associated with the RNTR—that it induces a fundamental trade-off between beneficial environmental effects and favorable nonenvironmental effects. These discussions would lead some to suggest that the CNTR is a better policy than the RNTR on environmental and nonenvironmental grounds. However, this conclusion is fallacious, mainly because implementation of the CNTR does not guarantee pollution reduction, whereas the RNTR does reduce pollution under certain circumstances. Furthermore, it has been shown that under certain conditions, implementing the RNTR improves nonenvironmental efficiency more than does implementing the CNTR. Based on these arguments, governments should choose between the RNTR and the CNTR on a case-by-case basis; we do not wish to campaign against the RNTR. However, given the current fiscal and environmental pressures, the CNTR, which generates government revenue without jeopardizing the environment, seems timely. Furthermore, because the CNTR can limit the trade-off between environmental efficiency and nonenvironmental efficiency, it might be politically appealing because it is a tax reform that sacrifices neither income nor the environment. However, there is an important caveat: because the CNTR requires a high environmental tax rate, the public may resist its implementation. Nevertheless, given that the message conveyed by the CNTR is that a high environmental tax rate can be offset by a low income tax rate, the CNTR might be justifiable. Moreover, given growing concerns about rising carbon emissions, an environmental tax rate that is sufficiently high to exceed the Pigouvian tax rate might be acceptable. Even if the CNTR cannot be implemented because of the difficulty of introducing a high environmental tax rate, it may be possible to demonstrate the merits of the CNTR by introducing a small environmental tax.

At a practical level, there is a fundamental limitation in relation to the appeal of the CNTR relative to that of the RNTR; that is, demonstrating carbon neutrality is easier said than done. In this respect, the simple taxation rule described in Proposition 4 suggests how to approach carbon neutrality. Nevertheless, the fact that one cannot guarantee complete carbon neutrality should not be used as an argument for abandoning the CNTR; consider the saying that the perfect is the worst enemy of the good.[20] The proposed tax reform gains practical relevance if policy makers gradually achieve carbon neutrality by using information about the price and income elasticities of polluting goods.

Aside from its practical applicability, the CNTR proposed in this paper is far from complete at a theoretical level. This echoes a main motivation of the paper, which is to offer a pilot model that opens up interesting possible extensions. Of the possible extensions to this paper, four are particularly promising. The first of these is to encompass the *n*-good case, which includes the dirty goods and the clean goods. In such circumstances, it is interesting to explore whether the CNTR—an increase in the tax on the dirty goods combined with a decrease in the tax on the clean goods—affects welfare and government revenue. The present model can be used, *mutatis mutandis*, to demonstrate the analysis.

The second involves incorporating the tax interaction effect into our analysis of the CNTR. This would involve including, for example, involuntary unemployment (Bovenberg and van der Ploeg 1998a, 1998b). In this context, one would need to compare the magnitudes of the changes in nonenvironmental efficiency generated by the RNTR and the CNTR. This represents a particularly fruitful direction for extending our proposed CNTR, though this paper has highlighted the situation where the tax-interaction effect either is irrelevant or would reinforce the main results.

A third possible extension involves conducting a dynamic analysis of tax reform. It has long been known that ecological tax reforms affect economic growth, which, in turn, affects pollution emissions (Bovenberg and de Mooij 1997). This suggests that it is worth exploring how the CNTR affects economic

[20] Imperfection applies to the Pigouvian tax, which has well-known implementation difficulties. Moreover, Pigou (1920) does not mention the exact magnitude of the tax rate in question.

growth via capital accumulation and labor supply. In this context, one would need to obtain a numerical solution for the equilibrium of the economy under the CNTR and to compare this with the corresponding solution under the RNTR.

A forth extension relates to a central pillar of tax reform analysis dating back to at least Feldstein (1976); namely, distribution issues. The welfare effects of ecological tax reforms differ between high- and low-income households (Baumol and Oates 1988, Sandmo 2000) and between active (wage-earning) households and inactive households in receipt of government transfers (Bovenberg and Goulder 2002). In this context, because environmental taxes on dirty consumption goods are often argued to be regressive, they tend to harm the poor (from inactive households) more than they do the rich. Hence, the CNTR, which imposes a high environmental tax rate, may aggravate social inequity. However, this argument overlooks one important aspect of the CNTR; that is, unlike the RNTR, the CNTR generates government revenues. If the government uses these revenues to alleviate the welfare costs of environmental taxation on the poor, the CNTR promotes redistribution. Alternatively, the government may pursue carbon neutrality by increasing the prices of pollution-inducing luxuries and reducing the prices of necessities in order to limit the undesirable distributional consequences associated with the CNTR. The distributional issues associated with ecological tax reforms remain a high-profile research topic, and thus, it would be worth exploring whether the CNTR improves equity without impairing economic efficiency.

Finally, we do not argue that the CNTR has more appeal than does the RNTR, which has a long tradition and a venerable pedigree. However, our analysis of the CNTR shows that this reform has far-reaching implications, which suggests that the CNTR provides a promising research agenda and opens the door to a variety of new tax reforms. More specifically, the CNTR is a potential trailblazer for tax reforms, particularly as a tax reform that improves economic efficiency and increases government revenue without jeopardizing the environment. In this sense, the CNTR is not limited to ecological tax reform but encompasses general tax reforms.

Appendix

Totally differentiating equations (1)-(3) yields:

$$dz = \alpha E_{pp} d\tau + \alpha E_{pu} du \,. \tag{A.1}$$

$$(E_u - \tau E_{pu}) du + E_z dz = \tau E_{pp} d\tau - R d\rho \,. \tag{A.2}$$

$$E_{LL} dL = (1-\rho) R_{LL} d\tau - R_L d\rho \,. \tag{A.3}$$

Substituting equation (A.1) into (A.2) yields the following matrix:

$$\begin{bmatrix} \Theta & 0 \\ 0 & M_{LL} \end{bmatrix} \begin{bmatrix} du \\ dL \end{bmatrix} = \begin{bmatrix} (\tau - \alpha E_z) E_{pp} \\ 0 \end{bmatrix} d\tau + \begin{bmatrix} -R \\ -R_L \end{bmatrix} d\rho \,,$$

where $M_{LL} = E_{LL} - (1-\rho)R_{LL} > 0$ and $\Theta = [(\alpha E_z - \tau)E_{pu} + E_u]$.

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