Environmental Tax Reform and Growth: Income Tax Cuts or Profits Tax Reduction

Nakada, Minoru

Graduate School of Environmental Studies, Nagoya University

June 2010

Environmental Tax Reform and Growth: Income Tax Cuts or Profits Tax Reduction

Minoru Nakada*

January 2009
Revised: June 2010

This study investigates how recycling revenues, which are generated by environmental taxes, affect growth through different types of tax cuts. A growth model with creative destruction (Aghion and Howitt 1992, 2009) is modified to include the production of final output as a source of pollution. This paper demonstrates that introducing an environmental tax, accompanied by either an income tax cut or a profits tax reduction, increases the output growth rate. The analysis also shows that, if technological change is resulted from deliberate activities of economic agents, the reduction of the profits tax rate for an intermediate monopolist is more growth-enhancing than an income tax cut since a profits tax reduction directly promotes R&D activities.

JEL classification: H23, O41, Q58

Keywords: Environmental Policy, Environmental Tax Reform, Endogenous Growth

*Address for correspondence: Graduate School of Environmental Studies, Nagoya University, Furo, Chikusa, Nagoya 464-8601, Japan; Tel: +81-52-789-4733, Fax: +81-52-789-4820, E-mail: mnakada@cc.nagoya-u.ac.jp

1 Introduction

Over the last four decades, numerous arguments have been raised about the relationship between economic growth and the environment. One of these issues is whether environmental policies affect economic growth negatively or positively. Environmental policies, which positively affect the quality of the environment, may have a negative impact on growth because they tend to require additional costs of production. In empirical analyses such as Christainsen and Haveman (1981), and Gollop and Roberts (1983), environmental regulations have frequently been regarded as the main source of productivity slowdown. However, Porter and van der Linde (1995) claim that an environmental policy promotes innovations and that long-term benefits overtake short-run losses in the economy. They call this phenomena "innovation offsets" (Porter and van der Linde 1995). From a theoretical perspective, Bovenberg and Smulders (1995) reveal that by incorporating an endogenous growth model, the implementation of a green tax not only improves the quality of the environment but also increases the total factor productivity of the economy when environmental quality is one of the factors of production. On the one hand, by applying a growth model with expanding product variety (Romer 1990), Grimaud (1999) demonstarates that environmental policies have a negative impact on growth. On the other hand, Verdier (1995) shows that environmental taxation promotes growth if the environmental tax rate is low enough for there to be no need to conduct R&D to improve the quality of the environment. Elbasha and Roe (1996) demonstrate that a greener preference increases the growth rate if the elasticity of intertemporal substitution is small. On the basis of the quality-upgrading model of Aghion and Howitt (1992), Ricci (2007) constructed a model with a continuum of intermediate goods differentiated in pollution intensity, and analyzed the possibility of the "green crowding-out effect," in which environmental taxation crowds-out old and dirty intermediates. In Ricci's model, environmental taxation has a negative impact. In contrast, Hart (2004) analyzed the impact of environmental sales taxes on growth by employing a model with production vintages. Hart then shows the possibility that such sales taxes enhance growth while improving the environment, with some conditions. Nakada (2004) examined the issue through a simpler model, focusing on the "profitability effect," which is the loss or gain in the profits of the intermediate sector, caused by taxation. Nakada reveals that environmental taxation has a positive impact on growth. This paper employs the quality-upgrading model of Aghion and Howitt (1992) for investigating how recycling revenues affects growth, which has not been addressed in these models.

The analysis is, therefore, linked to the issue of "double dividend," that is, how growth is affected by recycling revenues that are generated by environmental taxes through different types of tax cuts. Double dividend has been extensively investigated in both static (e.g., Bovenberg and de Mooij (1994), Oates (1995) and Parry (1995)) and dynamic frameworks (see Gerlagh and van der Zwaan (2001) and Ono (2007) for the framework of overlapping generations). Bovenberg and Smulders (1995, 1996) and Bovenberg and de Mooij (1997) introduced an endogenous growth model for analyzing the issue in a dynamic framework. They demonstrate that incorporating the production externalities of the environment makes a double-dividend more likely. Hettich (1998) analyzed various types of tax reforms within an endogenous growth model with elastic labor supply by employing an Uzawa-Lucas model with leisure. Hettich shows that a pollution tax boosts growth without such externalities. Fullerton and Kim (2008), by re-examining Bovenberg and Smulders (1995), analyzed the effect of a pollution tax and income tax on capital with production externalities of the environment. They display that a higher pollution tax may increase or decrease growth depending on both the absorption and the regenerative capacities of the environment. Greiner (2005), by modifying Futagami et al. (1993), analyzed the effects of fiscal policy on long-run growth and proves that pollution tax has a positive impact on growth because revenue from a higher pollution tax increases the stock of public capital, which, in turn, affects growth positively. The present analysis extends the above models by introducing a growth model with creative destruction (Aghion and Howitt 1992). This model has been used because it is essential to incorporate a full endogenous growth model for examining the potential positive impact of environmental tax reform on growth without including the production externalities of the environment.

Many articles have already examined the impact of environmental tax reform on growth; however, while most analysis focuses on an income tax cut, only a few articles study the impact of a profits tax reduction. This is partly because, as Bovenberg and van der Ploeg (1998) and Koskela and Schöb (1999) indicate, the levels of unemployment in EU countries have been quite high for decades. According to the OECD Main Economic Indicators, the EU member countries had an average unemployment rate of 8.9% in 2009, compared to 5.1% in Japan. Hence, economists tend to argue that the revenues generated by pollution taxes should be used to reduce the distortionary tax rate on labor in order to reduce the rate of unemployment. Furthermore, from the theoretical perspective, profits tax is not distortionary in a traditional growth model with perfect competition because it has no impact on the decision-making of producers. Hence, profits tax cuts do not have a positive impact on output growth.

Bovenberg and de Mooij's (1997) elaborate study is an exception. They first assumed a Cobb-Douglas production function; second, they permitted the substitution elasticities between production factors to be smaller than unity. The present paper is similar to their second case because a producer can earn positive profits. However, in the abovementioned model, a shift in the tax burden from capital to profits, i.e., a higher profits tax, boosts growth for two reasons. First, although growth is endogenous, the main engine of growth is capital accumulation and not innovative activities. Second, a profits tax is not distortionary because it has no impact on the decision-making of producers. As a result, shifting the tax burden away from a distortionary capital tax toward a non-distortionary profits tax enhances growth.

In contrast, profits tax reducion may affect growth differently in an economy with technological change resulted from deliberate activities of economic agents (such as in Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992)). This study explores the possibilities of profits tax reduction by employing a growth model of Aghion and Howitt (1992). In this analysis, although the profits tax for an intermediate monopolist has no impact on its output decision, it will act as a distortionary tax on the R&D behavior of research firms because it changes the expected present value of innovation. As a result, a profits tax reduction may boost growth by encouraging R&D activities.

The paper is organized as follows. Section 2 develops the macroeconomic model. Section 3 determines the balanced growth path. Section 4 analyzes the impact of an environmental tax reform. Section 5 concludes.

2 Model

A decentralized economy has a competitive final sector that produces a consumption good using labor and an intermediate good. The intermediate good is provided by a monopolistic supplier that employs final output. It is assumed that the intermediate supplier purchases a patent from a research firm and obtains a technology for supplying an intermediate good. The consumption and the supply of labor are determined by a representative household maximizing its positive utility derived from consumption and leisure, and its negative utility derived from pollution.

2.1 Final Sector

The final producer provides an output by employing labor and an intermediate good[1]. The Cobb-Douglas production function with an intermediate input is expressed as

$$Y_t = (A_t L_t)^{1-\alpha} x_t^{\alpha}, \tag{1}$$

where A_t is the productivity parameter, L_t is the level of labor input, x_t is an intermediate input, and $\alpha \in (0, 1)$. For the pollution function, following Michel and Rotillon (1995) and Aghion and Howitt (2009) and focusing on an environmental tax reform on growth[2], the aggregate level of pollution P_t is assumed to depend positively on the final output. An intermediate good is assumed to be an essential input for production, i.e., $x_t > 0$. There is no population growth in this economy. The government is assumed to impose an environmental tax on pollution, an income tax on wages earned by the workers in the final production sector and by the researchers in the research sector, and a corporate tax on the profits of the intermediate monopolist. In turn, the government gives a transfer payment to a representative consumer. The environmental tax is levied in proportion to the level of pollution caused by the final production sector, which depends on the final output, i.e., $h_t P_t = h_t Y_t$ and $h_t \in [0, 1)$.

The profit function of the final production sector in the presence of environmental taxation is given by the following equation:

$$\Pi_t = (1 - h_t)(A_t L_t)^{1-\alpha} x_t^{\alpha} - w_t L_t - p_t x_t,$$

where the final good is chosen as the numeraire and p_t denotes the price of an intermediate input, assuming $p_t > h_t$. Since the final market is competitive,

[1] The author thanks Reyer Gerlagh (associate editor) and two anonymous referees for their contribution to the argument in this subsection.

[2] Alternatively, as in Grimaud (1999, 2000), pollution abatement can be incorporated as follows. The production function with an intermediate input is expressed as $Y_t = (A_t L_t)^{1-\alpha} x_t^{\alpha}$. The level of abatement is given as $M_t = Y(1 - z_t)$ and the aggregate level of pollution is given as $P_t = (Y_t - M_t)^{1+\zeta} Y_t^{-\zeta} = Y_t z_t^{1+\zeta}$ $(\zeta \geq 0)$. The profit of the final sector is given as $\Pi_t = (1 - z_t^{\zeta} h_t)(A_t L_t)^{1-\alpha} x_t^{\alpha} - w_t L_t - p_t x_t$; hence, the first-order conditions are $z_t = \left[\frac{1}{h_t(\zeta+1)}\right]^{\frac{1}{\zeta}}$, and $w_t = \left[\frac{1}{h_t(\zeta+1)}\right]^{\frac{1}{\zeta}} \frac{\zeta}{1+\zeta}(1-\alpha)Y_t/L_t$. The profit of the intermediate monopolist is $\pi_t = (1 - \tau_t)\left[\frac{1}{h_t(\zeta+1)}\right]^{\frac{1}{\zeta}} \frac{\zeta}{1+\zeta}(1 - h_t)\alpha(1-\alpha)Y_t$. Since the R&D arbitrage condition is given as $w_t = \lambda V_t$, as suggested in Aghion and Howitt (2009), the impact of including abatement on the arbitrage condition is cancelled out. Endogenizing the technological change in abatement technology (Gerlagh et al. 2009) or considering heterogeneity in the pollution intensities of capital inputs (Ricci 2007) are important issues; however, such issues need to be separately investigated because these go beyond the scope of this analysis.

the first-order conditions are given as follows:

$$p_t = (1-h_t)\alpha(A_tL_t)^{1-\alpha}x_t^{\alpha-1}, \tag{2}$$
$$w_t = (1-h_t)(1-\alpha)A_t^{1-\alpha}L_t^{-\alpha}x_t^{\alpha} = (1-h_t)(1-\alpha)Y_t/L_t. \tag{3}$$

2.2 Intermediate Sector

The intermediate sector is monopolistic. A monopolist, faced with factor demand (2), provides an intermediate good to the final producer using the final good as an input. The formulation follows Romer (1990) as well as Aghion and Howitt (2009). As Romer (1990) mentions, an intermediate-goods sector uses designs from the research sector, together with resources indicated as investment or foregone output, to produce various intermediate goods. In Aghion and Howitt (2009), all intermediate goods are assumed to be supplied using the final goods as input, one for one. By employing the same assumption as these models, this model assumes that providing an intermediate good requires foregone output, which should be subtracted from the level of consumption. The government is assumed to impose a profits tax on the monopolist, i.e., $\tau_t \in (0,1)$. The after-tax profits of the monopolist are represented by the following equation:

$$\pi_t = (1-\tau_t)[\alpha(1-h_t)(A_tL_t)^{1-\alpha}x_t^{\alpha} - x_t]. \tag{4}$$

The first-order condition gives the supply of an intermediate input as

$$x_t = \left[(1-h_t)\alpha^2\right]^{\frac{1}{1-\alpha}} A_tL_t. \tag{5}$$

By substituting (5) into (1), the final output is rewritten as

$$Y_t = \left[(1-h_t)\alpha^2\right]^{\frac{\alpha}{1-\alpha}} A_tL_t. \tag{6}$$

Substituting (5) into (4) gives the after-tax profits of the monopolist as follows:

$$\pi_t = (1-\tau_t)(1-h_t)^{\frac{1}{1-\alpha}}\alpha^{\frac{1+\alpha}{1-\alpha}}A_tL_t = (1-\tau_t)(1-h_t)\alpha(1-\alpha)Y_t. \tag{7}$$

2.3 Research Sector

In this sector, research firms conduct R&D activities freely. All technological findings in this sector flow into a common pool of knowledge, and only a single research firm can obtain a patent for a particular technology. Applying the method of Aghion and Howitt (1992), innovation is assumed to follow a

Poisson process. The index of the productivity parameter A_t grows gradually at a rate proportional to the aggregate flow of innovations:

$$g_A \equiv \dot{A}_t / A_t = \lambda n_t \ln \gamma,$$

where λ is the productivity of the R&D sector, $\gamma(> 1)$ is the size of a new innovation, and n_t is the number of researchers in the R&D sector. The free-entry condition of the R&D sector is given as

$$w_t = \lambda V_t, \tag{8}$$

where the discounted expected value of innovation is given as $V_t = \int_t^{\infty} e^{-\int_t^v r_u du} e^{-\int_t^v \lambda n_u du} \pi_v dv$. Further, the labor demand function is given as

$$L_t^d = L_t + n_t,$$

where n_t is the amount of time allocated to research.

2.4 Consumer

The consumption and labor supply are determined by a representative consumer maximizing the positive utility derived from its consumption (c_t) and leisure (l_t), and negative utility from pollution (P_t). The government levies an income tax proportionate to the wage rate, i.e., $\phi_t w_t$, where $\phi_t \in (0, 1)$. The representative consumer maximizes the present value stream of the following utilities:

$$\max \int_0^{\infty} e_t^{-\rho t} (\ln c_t + \beta \ln l_t - \eta \ln P_t) \, dt,$$

subject to its budget constraint:

$$\int_0^{\infty} [(1 - \phi_t) w_v (\epsilon - l_v) + T_v / N - c_v] \, e^{-\int_0^v r_u du} dv = 0, \tag{9}$$

where $\beta \in (0, 1)$ and $\eta \in (0, 1)$ are the parameters determining the consumer's preference toward leisure and a clean environment, respectively; ϵ is the consumer's time endowment; T_t is the transfer from the government; N is the size of population; and $\rho \in (0, 1]$. As usual, the optimal condition in a decentralized economy is given by $g_c \equiv \dot{c}_t / c_t = r_t - \rho$ and the transversality condition.

2.5 Government

The government levies an income tax on the consumer, a profits tax on the intermediate supplier, and an environmental tax on the final producer. In turn, the government gives a transfer to a representative consumer. The budget constraint of the government is expressed as

$$\int_0^\infty T_v e^{-\int_0^v r_u du} dv = \int_0^\infty \phi_v w_v L_v^s e^{-\int_0^v r_u du} dv + \int_0^\infty h_v Y_v e^{-\int_0^v r_u du} dv \\ + \int_0^\infty \tau_v (1-h_v)\alpha(1-\alpha) Y_v e^{-\int_0^v r_u du} dv, \quad (10)$$

where T_t is the transfer from the government and L_t^s is the labor supply.

3 Balanced Growth Path

In this section, the balanced growth path is determined where the rate of interest and the level of research are constant: $r_t \equiv r$ and $n_t \equiv n$. Since this analysis assumes no population growth, both consumption and output growth rates are proportional to the growth rate of the productivity parameter, $g_c = g_Y(\dot{Y}_t/Y_t) = g_A$. Consequently, the wage rate is growing at the same rate, $g_w \equiv g_A$. Following Aghion and Howitt (1992), the expected (average) growth rate of output is $g_Y = g_A = \lambda n \ln \gamma$; therefore, the optimal condition is given by

$$r - \rho = \lambda n \ln \gamma. \quad (11)$$

3.1 Market Equilibrium and the Government

Now, the market equilibrium is examined. The consumer's budget constraint (9) must be balanced along the balanced growth path. Thus, the consumer maximizes the utility function $u = \ln c + \beta \ln l - \eta \ln P$ with respect to $c = (1-\phi)w(\epsilon - l) + T/N$. Labor supply and the aggregate consumption (C) in the decentralized economy are determined as follows:

$$L^s = \frac{1}{1+\beta}\left[\epsilon N - \frac{\beta T}{(1-\phi)w}\right], \quad (12)$$

$$C = \frac{1}{1+\beta}\left[(1-\phi)w\epsilon N + T\right]. \quad (13)$$

The governmental budget constraint (10) must be balanced along this path. Substituting the wage rate (3) and monopolistic profits (7) into the above constraint along with the level of final output (1) provides the following constraint:

$$T = \theta Y, \quad (14)$$

where θ is the ratio of government transfer to output, i.e.,

$$\theta = \left\{ \phi(1-h)(1-\alpha)\frac{L^s}{L} + [h + \tau(1-h)\alpha(1-\alpha)] \right\},$$

which gives the labor supply:

$$L^s = \frac{\theta - [h + \tau(1-h)\alpha(1-\alpha)]}{\phi(1-h)(1-\alpha)} L. \tag{15}$$

The final market equilibrium provides $C \equiv Y - x$, since the final output is used for producing an intermediate good. Substituting (5) and (6) gives

$$C \equiv Y - x = \left[1 - (1-h)\alpha^2\right] Y. \tag{16}$$

Now, the population (N) is normalized as unity. By substituting (13), (3), and (14) into (16), the final market equilibrium condition can be rewritten as

$$\frac{1}{1+\beta}\left[(1-\phi)(1-h_t)(1-\alpha)\epsilon/L_t + \theta\right] = 1 - (1-h)\alpha^2.$$

Hence, final labor demand is obtained as

$$L = \frac{(1-\phi)(1-h_t)(1-\alpha)\epsilon}{(1+\beta)\left[1-(1-h)\alpha^2\right] - \theta}. \tag{17}$$

If the above is substituted into (15), labor supply is obtained as

$$L^s = \frac{\theta - [h + \tau(1-h)\alpha(1-\alpha)]}{(1+\beta)\left[1-(1-h)\alpha^2\right] - \theta} \frac{1-\phi}{\phi} \epsilon. \tag{18}$$

Using the wage rate (3), government budget constraint (14), and final labor demand (17), labor supply (12) can be rewritten as

$$L^s = \frac{\left[1-(1-h)\alpha^2\right] - \theta}{(1+\beta)\left[1-(1-h)\alpha^2\right] - \theta} \epsilon. \tag{19}$$

Since (18) should be equal to (19), the ratio of government transfer to output θ is rewritten as

$$\theta = \phi\left[1-(1-h)\alpha^2\right] + (1-\phi)\left[h + \tau(1-h)\alpha(1-\alpha)\right].$$

In the following sections, the policy rule for the reform is defined by maintaining the proportion θ as constant, i.e., an environmental tax reform must enable the maintenance of the ratio of government transfer to output at a constant level. Numerous existing articles, particularly those dealing with a static framework, discuss double dividends under a revenue-neutral constraint, thereby ensuring that governmental revenues (or a transfer payment T in this article) are constant. However, in this paper, the constant θ rule is employed as in Devereux and Love (1995) and Turnovsky (2000). This method is often employed in growth models considering the fact that the ratio of government spending to GDP has been stable for the last decade (Ono 2008). The economy continuously grows along the balanced growth path; hence, if θ remains constant, the contribution of the government toward the economy is continued over time.

The labor market clearing condition is described using (19) as

$$\frac{[1-(1-h)\alpha^2]-\theta}{(1+\beta)\,[1-(1-h)\alpha^2]-\theta}\epsilon \equiv L^s\left[h, \theta(\phi, h, \tau)\right] \equiv L+n. \tag{20}$$

From the free-entry condition of the R&D sector (8), (3), and (7), the research arbitrage condition on the balanced growth path is given as

$$1=\frac{\lambda(1-\tau)\alpha(L^s-n)}{r+\lambda n}. \tag{21}$$

If optimal condition (11) is substituted into the above, the level of research along the balanced growth path is determined as follows:

$$n=\frac{\lambda(1-\tau)\alpha L^s-\rho}{\lambda\left[(1-\tau)\alpha+(1+\ln\gamma)\right]}. \tag{22}$$

The level of final labor input on the balanced growth path is given as

$$L=L^s-n=\frac{\lambda(1+\ln\gamma)L^s+\rho}{\lambda\left[(1-\tau)\alpha+(1+\ln\gamma)\right]}.$$

Due to the focus on the balanced growth path, every variable grows constantly; this implies that $\lambda(1-\tau)\alpha L^s-\rho>0$. This condition ensures the existence of a unique stationary equilibrium.

4 Environmental Tax Reform

This section investigates the impacts of environmental tax reforms on economic growth and pollution. Through the introduction of an environmental tax, two types of tax reforms are examined: income tax and profits tax reductions. Initially, an economy without environmental taxation is assumed to be on the balanced growth path. Then, the effect of an income tax cut with environmental taxation on growth is examined, while maintaining the profits tax at a constant level, $d\tau=0$. Next, the impact of a profits tax reduction on growth is analyzed with constant income tax, $d\phi=0$.

4.1 Policy Rule for Reforms

The reforms examined here must follow the policy rule previously mentioned: the proportion of government transfer to output must be maintained at a constant level ($d\theta = 0$). The following marginal relationships between ϕ and h and between τ and h are derived in Appendix 1:

$$\frac{d\phi}{dh} = -\frac{\partial\theta/\partial h}{\partial\theta/\partial\phi} = -\frac{\phi\alpha^2 + (1-\phi)\left[1-\tau\alpha(1-\alpha)\right]}{(1-h)(1-\alpha)\left[1+\alpha(1-\tau)\right]} < 0, \tag{23}$$

$$\frac{d\tau}{dh} = -\frac{\partial\theta/\partial h}{\partial\theta/\partial\tau} = -\frac{\phi\alpha^2 + (1-\phi)\left[1-\tau\alpha(1-\alpha)\right]}{(1-\phi)(1-h)\alpha(1-\alpha)} < 0. \tag{24}$$

The above equations indicate the extent to which income or profits tax rates can be reduced by introducing one unit of environmental tax.

4.2 Impacts on Growth

The following proposition is obtained with regard to the impact of an income tax cut on growth.

Proposition 1 *The introduction of an environmental tax h for reducing income tax ϕ, while maintaining both profits tax τ and the ratio of government transfer to output θ at a constant level, increases the growth rate of output, i.e.,*

$$\left.\frac{dn}{dh}\right|_{d\tau=0,h=0}^{d\theta=0} > 0.$$

Proof. As derived in Appendix 1, totally differentiating the level of research on the balanced growth path (22) around the initial tax rate, $h = 0$, yields

$$\left.\frac{dn}{dh}\right|_{d\tau=0,h=0}^{d\theta=0} = \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial h} > 0.$$

■

Next, with regard to the impact of a profits tax reduction on growth, the following proposition is obtained.

Proposition 2 *The introduction of an environmental tax h for reducing profits tax τ, while maintaining both income tax ϕ and the ratio of government transfer to output θ at a constant level, increases the growth rate of output:*

$$\left.\frac{dn}{dh}\right|_{d\phi=0,h=0}^{d\theta=0} > 0.$$

Proof. As is shown in Appendix 1, totally differentiating (22) around the initial tax rate, $h = 0$, yields

$$\left.\frac{dn}{dh}\right|_{d\phi=0,h=0}^{d\theta=0} = \frac{\partial n}{\partial \tau}\frac{d\tau}{dh} + \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial h} > 0.$$

■

The following is a diagrammatic representation of the equilibrium and the impacts of reforms. Figure 1 demonstrates the manner in which environmental taxation and tax reforms affect growth. Prior to reforms without environmental taxation, an economy is supposed to be on the balanced growth path. The R&D arbitrage condition (21), which is upward sloping, is denoted as (A), and the labor market-clearing condition (20), which is downward sloping, is designated as (L).

{Figure 1 should be placed around here.}

With regard to the impact of an income tax cut, environmental taxation slightly increases labor supply and moderates the resource constraint on R&D activities. Since a tax on pollution decreases output, households decrease leisure for supplying more labor and try to increase the ratio of consumption to output. This effect marginally shifts the (L) upwards to (L^{ϕ}). The income tax cuts also encourage consumers to supply more labor through the reduction in tax reimbursement. However, the simultaneous increase in the environmental tax for keeping θ at a constant level offsets this impact. Hence, an income tax cut only has a small impact on the R&D resource constraint. On the contrary, a profits tax reduction increases the present value of innovation. It directly enhances R&D activities, which turns (A) counterclockwise to (A^{τ}).

The following proposition is obtained with regard to which type of tax reform would be more growth-enhancing.

Proposition 3 *A profits tax reduction is more growth-enhancing than an income tax cut, i.e.,*

$$\left.\frac{dn}{dh}\right|_{d\phi=0,h=0}^{d\theta=0} > \left.\frac{dn}{dh}\right|_{d\tau=0,h=0}^{d\theta=0}.$$

Proof. The derivation is provided in Appendix 1. ■

4.3 Impacts on Pollution

Next, the impacts of environmental tax reforms on pollution are examined. As Appendix 2 demonstrates, with regard to the income tax cuts, totally differentiating P_t at the initial tax rate, i.e., $h = 0$, provides

$$\left.\frac{dP}{dh}\right|_{d\tau=0,h=0}^{d\theta=0} = \left(\frac{\partial Y}{\partial h} + \frac{\partial Y}{\partial L}\frac{\partial L}{\partial L^s}\frac{\partial L^s}{\partial h}\right).$$

Although the first term on the right hand side is negative, the second term is positive. This indicates that whether the impact of income tax cuts on pollution is positive or negative depends on parameters. The effect of profits tax cuts on pollution is given as,

$$\frac{dP}{dh}\Big|_{d\phi=0,h=0}^{d\theta=0} = \left(\frac{\partial Y}{\partial L}\frac{\partial L}{\partial \tau}\frac{d\tau}{dh} + \frac{\partial Y}{\partial h} + \frac{\partial Y}{\partial L}\frac{\partial L}{\partial L^s}\frac{\partial L^s}{\partial h}\right).$$

Pollution is smaller with profits tax cuts than with income tax cuts since the first term on the right hand side in the above equation is negative; hence,

$$\frac{dP}{dh}\Big|_{d\phi=0,h=0}^{d\theta=0} < \frac{dP}{dh}\Big|_{d\tau=0,h=0}^{d\theta=0}. \tag{25}$$

Discovering the impact of environmental tax reform on pollution is difficult to determine analytically. Hence, numerical examples are necessary to address this issue.

4.4 Numerical Examples

For examining the extent to which environmental tax reforms affect the growth rate of output and the level of pollution, numerical examples are used. Three cases are investigated: (i) income tax and profits tax without environmental tax, i.e., $h = 0$, $\phi = 0.2$, and $\tau = 0.3$; (ii) income tax cut with environmental tax while profits tax remains constant, i.e., $h = 0.01$, $\phi = 0.18$ (calculated using (23)), and $\tau = 0.3$; and (iii) profits tax reduction with environmental tax while income tax remains constant, i.e., $h = 0.01$, $\phi = 0.2$, and $\tau = 0.26$ (calculated using (24)). The other common parameters are as follows: the intermediate input share is given by $\alpha = 0.4$, following Barro and Sala-i-Martin (2003), and the productivity of the R&D sector is $\lambda = 0.8$, as suggested in Howitt (2000). After considering the nature of the balanced growth path, parameters such as the discount factor and the size of new innovation are set for both growth and interest rates to be positive, i.e., $\rho = 0.05$ and $\gamma = 2.72$, respectively. Other parameters are set as follows: $\beta = 0.2$ and $\epsilon = 1$. The calibrated growth rates ($g_Y = \lambda n \ln \gamma$, where n is the balanced growth research determined as (22)) are, 0.0552, 0.0552, and 0.0592 in cases (i), (ii), and (iii), respectively. If the level of pollution without environmental taxation is normalized as unity, the calibrated levels of pollution in cases (ii) and (iii) are 0.9961 and 0.9864, respectively. This result implies that profits tax reduction (case (iii)) would be more growth-enhancing and less polluting than an income tax cut (case (ii)).

{Figure 2 should be placed around here.}

Please note that the impact of reform on pollution is sensitive to the level of income tax, although it is not responsive to other parameters. Figure 2 demonstrates the relationship between the impact of reforms on pollution (dP on the vertical axis) and the level of income tax (ϕ on the horizontal axis). It shows that the impact is mostly negative; however, if the income tax is excessively high, i.e., $\phi > 0.85$, there is the possibility that the effect will become positive. When the level of income tax is considerable, it becomes more distortionary. In such cases, while the implementation of environmental tax reduces output and pollution, the subsequent reduction in income tax induces a sharp increase in labor supply, which boosts output as well as pollution. As a result, the reform could increase pollution, despite the intention of the policy. However, it seems that this excessively high level of income tax is unlikely in practice.

4.5 Impacts on Welfare

In this subsection, the impact of environmental tax reform on welfare is examined. The equilibrium along the balanced growth path is focused without its transition. The welfare along the balance growth path is given by the following equation:

$$\begin{aligned}
W^* &= \int_0^\infty (\ln c_t N + \beta l_t N - \eta \ln P_t) e^{-\rho t}\, dt \\
&= \ln c_0 \int_0^\infty e^{-(\rho-g)t}\, dt + \beta \frac{\ln l^*}{\rho} - \eta \ln Y_0 \int_0^\infty e^{-(\rho-g)t}\, dt \\
&= (\ln c_0 - \eta \ln Y_0) \int_0^\infty e^{-(\rho-g)t}\, dt + \beta \frac{\ln l^*}{\rho} \\
&= \frac{1}{\rho - g} (\ln c_0 - \eta \ln Y_0) + \beta \frac{\ln l^*}{\rho},
\end{aligned}$$

where $N = 1$. Then, as is derived in Appendix 3, the type of reform that would be more welfare-improving depends on parameter η because

$$\begin{aligned}
&\frac{dW^*}{dh}\Big|_{d\phi=0,h=0}^{d\theta=0} - \frac{dW^*}{dh}\Big|_{d\tau=0,h=0}^{d\theta=0} \\
&= \frac{1}{\rho-g} \frac{\partial L}{\partial \tau} \frac{d\tau}{dh} \frac{1}{Y_0} \frac{\partial Y_0}{dL} (1-\eta) \left\{ \begin{array}{ll} < 0 & \text{if} \quad \eta < 1 \\ \geq 0 & \text{if} \quad \eta \geq 1 \end{array} \right. .
\end{aligned}$$

The above inequalities indicate that a profits tax reduction is more welfare-improving than an income tax cut if the consumer's preference towards the environment is large, and vice versa. As compared to an income tax cut, although the economy pollutes less under a profits tax reduction, the level of consumption is also smaller. As a consequence, the impact depends on the preference toward the environment.

4.6 Discussion

The analysis indicates that a reduction in distortionary tax rates in combination with environmental tax revenues positively affects growth. Moreover, a profits tax reduction for an intermediate monopolist is more growth-enhancing than an income tax cut because a profits tax reduction encourages R&D activities.

As mentioned earlier, various existing articles, such as Greiner (2005) and Fullerton and Kim (2008), analyzed the impact of environmental taxation and subsequent reduction in distortionary tax rates on growth. However, these works have not investigated the impact of profits tax cuts. Bovenberg and de Mooij (1997) have analyzed this impact but have obtained different results. In their analysis, a shift in tax burden from capital to profits enhances growth since the main engine of growth is capital accumulation. In such an economy, profits tax is not distortionary because it has no impact on the decision-making of producers. Therefore, shifting the tax burden from a distortionary capital tax toward a profits tax enhances growth. On the contrary, a profits tax reduction may influence growth differently where technological change is resulted from actions of economic agents with incentives. In such an economy, firms earn positive profits as rewards for creating new products; therefore, although the profits tax for an intermediate monopolist has no impact on his output decision, it acts as a distortionary tax on the R&D behavior of research firms by changing the expected present value of innovation. Hence, a profits tax reduction is more growth-enhancing than an income tax cut.

5 Conclusion

This paper has investigated how growth is affected by recycling revenues generated by environmental taxes through different types of tax cuts. The growth model with creative destruction (Aghion and Howitt 1992, 2009) is modified by including the production of final output as a source of pollution. The decentralized economy has a competitive final sector, and an intermediate good is provided by a monopolistic supplier. The analysis demonstrates that a reduction in distortionary tax rates, which are associated with environmental tax revenues, positively affects growth and reduces pollution. Moreover, the paper shows that a profits tax reduction for an intermediate monopolist is more growth-enhancing than an income tax cut. In the analysis of Bovenberg and de Mooij (1997), profits tax reduction while implementing environmental taxation is equivalent to a shift in the tax burden from profits to capital. Hence, it has a negative effect on capital accumulation and output growth. However, this model reveals that profits tax cuts also have a positive impact because they alleviate the negative effect on R&D activities by increasing the expected present value of innovation. Obviously, the above argument has several limitations. For example, capital is not explicitly included as a factor input. Furthermore, what would happen if governmental expenditure was polluting? These factors require further examination.

Appendix 1: Impacts of Reforms on Growth and Pollution

The multiple impacts of environmental tax reforms on growth are examined here. For this purpose, partial derivatives are determined as follows:

$$\begin{aligned}
\frac{\partial \theta}{\partial \phi} &= (1-h)(1-\alpha)\left[1+\alpha(1-\tau)\right] > 0, \\
\frac{\partial \theta}{\partial h} &= \phi\alpha^2 + (1-\phi)\left[1-\tau\alpha(1-\alpha)\right] > 0, \\
\frac{\partial \theta}{\partial \tau} &= (1-\phi)(1-h)\alpha(1-\alpha) > 0, \\
\frac{\partial L^s}{\partial \theta} &= -\frac{\beta\left[1-(1-h)\alpha^2\right]}{\left\{(1+\beta)\left[1-(1-h)\alpha^2\right]-\theta\right\}^2}\epsilon < 0, \\
\frac{\partial L^s}{\partial h} &= \frac{\beta\alpha^2\theta}{\left\{(1+\beta)\left[1-(1-h)\alpha^2\right]-\theta\right\}^2}\epsilon > 0, \\
\frac{\partial n}{\partial \tau} &= -\frac{\alpha[\lambda(1+\ln\gamma)L^s+\rho]}{\lambda\left[(1-\tau)\alpha+(1+\ln\gamma)\right]^2} < 0, \\
\frac{\partial n}{\partial L^s} &= \frac{(1-\tau)\alpha}{(1-\tau)\alpha+(1+\ln\gamma)} > 0, \\
\frac{\partial n}{\partial \theta} &= \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial \theta} \\
&= -\frac{(1-\tau)\alpha}{(1-\tau)\alpha+(1+\ln\gamma)}\frac{\beta\left[1-(1-h)\alpha^2\right]}{\left\{(1+\beta)\left[1-(1-h)\alpha^2\right]-\theta\right\}^2}\epsilon < 0,
\end{aligned}$$

$$\frac{\partial L}{\partial \tau} = \frac{\alpha[\lambda(1+\ln\gamma)L^s+\rho]}{\lambda[(1-\tau)\alpha+(1+\ln\gamma)]^2} = \frac{\alpha}{(1-\tau)\alpha+(1+\ln\gamma)}L > 0,$$
$$\frac{\partial L}{\partial L^s} = \frac{(1+h)\alpha(1-\alpha)[\lambda(1+\ln\gamma)L+\rho]}{\lambda[(1-\tau)(1+h)(1-\alpha)+(1+\ln\gamma)\alpha]^2} > 0,$$
$$\frac{\partial Y}{\partial h} = -\frac{\alpha}{1-\alpha}\frac{Y}{1-h} < 0,$$
$$\frac{\partial Y}{\partial L} = \frac{Y}{L} > 0,$$
$$\frac{\partial L}{\partial L^s} = \frac{1+\ln\gamma}{(1-\tau)\alpha+(1+\ln\gamma)} > 0,$$
$$\frac{\partial C}{\partial h} = \left\{\alpha - \frac{1}{1-\alpha}\frac{1}{1-h}\left[1-(1-h)\alpha^2\right]\right\}\alpha Y,$$
$$\frac{\partial C}{\partial L} = \left[1-(1-h)\alpha^2\right]\frac{\partial Y}{\partial L} > 0.$$

1. The marginal relationships between ϕ and h and between τ and ϕ are derived in the following manner:

$$\frac{d\phi}{dh} = -\frac{\partial\theta/\partial h}{\partial\theta/\partial\phi} = -\frac{\phi\alpha^2+(1-\phi)\left[1-\tau\alpha(1-\alpha)\right]}{(1-h)(1-\alpha)\left[1+\alpha(1-\tau)\right]} < 0,$$
$$\frac{d\tau}{dh} = -\frac{\partial\theta/\partial h}{\partial\theta/\partial\tau} = -\frac{\phi\alpha^2+(1-\phi)\left[1-\tau\alpha(1-\alpha)\right]}{(1-\phi)(1-h)\alpha(1-\alpha)} < 0.$$

2. It is examined whether an income tax cut leads to an increase in growth. Totally differentiating (22) at the initial tax rate, i.e., $h=0$, provides the following equation:

$$\left.\frac{dn}{dh}\right|_{d\tau=0,h=0}^{d\theta=0} = \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial h} + \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial\theta}\left(\frac{\partial\theta}{\partial\phi}\frac{d\phi}{dh}+\frac{\partial\theta}{\partial h}\right) = \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial h} > 0,$$

because $\frac{\partial\theta}{\partial\phi}\frac{d\phi}{dh}+\frac{\partial\theta}{\partial h}=0$ for $d\theta$ to be zero.

3. Similarly, the impacts of a profits tax reduction are evaluated as follows. Totally differentiating (22) at $h=0$ provides

$$\left.\frac{dn}{dh}\right|_{d\phi=0,h=0}^{d\theta=0} = \frac{\partial n}{\partial\tau}\frac{d\tau}{dh} + \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial h} + \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial\theta}\left(\frac{\partial\theta}{\partial\tau}\frac{d\tau}{dh}+\frac{\partial\theta}{\partial h}\right) = \frac{\partial n}{\partial\tau}\frac{d\tau}{dh} + \frac{\partial n}{\partial L^s}\frac{\partial L^s}{\partial h} > 0,$$

because $\frac{\partial\theta}{\partial\tau}\frac{d\tau}{dh}+\frac{\partial\theta}{\partial h}=0$ for $d\theta$ to be zero. Therefore, the introduction of an environmental tax for reducing a profits tax, while maintaining both income tax and the ratio of government transfer to output at a constant level, increases the growth rate of output.

4. Finally, which type of reform would be more growth-enhancing is considered. A profits tax reduction is more growth-enhancing as compared to an income tax cut, while maintaining the ratio of government transfer to output θ at a constant level:

$$\left.\frac{dn}{dh}\right|_{d\phi=0,h=0}^{d\theta=0}-\left.\frac{dn}{dh}\right|_{d\tau=0,h=0}^{d\theta=0}=\frac{\partial n}{\partial\tau}\frac{d\tau}{dh}>0.$$

Appendix 2: Impacts of Reforms on Pollution

With regard to the impact of income tax cut on pollution, totally differentiating P_t at the initial tax rate, i.e., $h=0$, provides the following equation:

$$\begin{aligned}\left.\frac{dP}{dh}\right|_{d\tau=0,h=0}^{d\theta=0} &= \left.\frac{dY}{dh}\right|_{d\tau=0,h=0}^{d\theta=0}\\ &=\left\{\frac{\partial Y}{\partial h}+\frac{\partial Y}{\partial L}\frac{\partial L}{\partial L^s}\left[\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial\theta}\left(\frac{\partial\theta}{\partial\phi}\frac{d\phi}{dh}+\frac{\partial\theta}{\partial h}\right)\right]\right\}\\ &=\left(\frac{\partial Y}{\partial h}+\frac{\partial Y}{\partial L}\frac{\partial L}{\partial L^s}\frac{\partial L^s}{\partial h}\right)\\ &=Y\frac{\alpha}{1-\alpha}\left(-1+\Omega\right),\end{aligned}$$

where

$$\begin{aligned}\Omega=&\frac{\lambda(\ln\gamma+1)}{\lambda(\ln\gamma+1)(1-\phi)\left[1+\alpha(1-\tau)\right]\epsilon+\left[(1+\beta-\phi)(1+\alpha)-(1-\phi)\tau\alpha\right]\rho}\\ &\times\frac{\beta\alpha\left[\phi(1+\alpha)+(1-\phi)\tau\alpha\right]\epsilon}{(1+\beta-\phi)(1+\alpha)-(1-\phi)\tau\alpha}.\end{aligned}$$

The effect of profits tax cut on pollution is given as,

$$\begin{aligned}\left.\frac{dP}{dh}\right|_{d\phi=0,h=0}^{d\theta=0} &= \left.\frac{dY}{dh}\right|_{d\phi=0,h=0}^{d\theta=0}\\ &=\frac{\partial Y}{\partial h}+\frac{\partial Y}{\partial L}\left\{\frac{\partial L}{\partial\tau}\frac{d\tau}{dh}+\frac{\partial L}{\partial L^s}\left[\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial\theta}\left(\frac{\partial\theta}{\partial\tau}\frac{d\tau}{dh}+\frac{\partial\theta}{\partial h}\right)\right]\right\}\\ &=\left(\frac{\partial Y}{\partial L}\frac{\partial L}{\partial\tau}\frac{d\tau}{dh}+\frac{\partial Y}{\partial h}+\frac{\partial Y}{\partial L}\frac{\partial L}{\partial L^s}\frac{\partial L^s}{\partial h}\right)<\left.\frac{dP}{dh}\right|_{d\tau=0,h=0}^{d\theta=0}.\end{aligned}$$

Pollution with profits tax cut is smaller than with income tax cut; however, whether its impact is positive or negative depends on parameters.

Appendix 3: Impacts of Reforms on Welfare

The impact of income tax cut on welfare is determined as follows:

$$\begin{aligned}
\frac{dW^*}{dh}\Big|_{d\tau=0,h=0}^{d\theta=0} &= \frac{1}{\rho-g}\frac{1}{c_0}\left\{\frac{\partial c_0}{\partial h}+\frac{\partial c_0}{\partial L}\frac{\partial L}{\partial L^s}\left[\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial \theta}\left(\frac{\partial \theta}{\partial \phi}\frac{d\phi}{dh}+\frac{\partial \theta}{\partial h}\right)\right]\right\} \\
&\quad -\frac{\eta}{\rho-g}\frac{1}{Y_0}\left\{\frac{\partial Y_0}{\partial h}+\frac{\partial Y_0}{\partial L}\frac{\partial L}{\partial L^s}\left[\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial \theta}\left(\frac{\partial \theta}{\partial \phi}\frac{d\phi}{dh}+\frac{\partial \theta}{\partial h}\right)\right]\right\} \\
&\quad -\frac{\beta}{\rho}\frac{1}{l^*}\left[\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial \theta}\left(\frac{\partial \theta}{\partial \phi}\frac{d\phi}{dh}+\frac{\partial \theta}{\partial h}\right)\right] \\
&= \frac{1}{\rho-g}\frac{1}{c_0}\left(\frac{\partial c_0}{\partial h}+\frac{\partial c_0}{\partial L}\frac{\partial L}{\partial L^s}\frac{\partial L^s}{\partial h}\right) \\
&\quad -\frac{\eta}{\rho-g}\frac{1}{Y_0}\left(\frac{\partial Y_0}{\partial h}+\frac{\partial Y_0}{\partial L}\frac{\partial L}{\partial L^s}\frac{\partial L^s}{\partial h}\right)-\frac{\beta}{\rho}\frac{1}{l^*}\frac{\partial L^s}{\partial h}.
\end{aligned}$$

Next, the impact of profits tax reduction on welfare is determined as

$$\begin{aligned}
&\frac{dW^*}{dh}\Big|_{d\phi=0,h=0}^{d\theta=0} \\
&= \frac{1}{\rho-g}\frac{1}{c_0}\left\{\frac{\partial c_0}{\partial h}+\frac{\partial c_0}{\partial L}\left[\frac{\partial L}{\partial \tau}\frac{d\tau}{dh}+\frac{\partial L}{\partial L^s}\left(\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial \theta}\left(\frac{\partial \theta}{\partial \phi}\frac{d\phi}{dh}+\frac{\partial \theta}{\partial h}\right)\right)\right]\right\} \\
&- \frac{\eta}{\rho-g}\frac{1}{Y_0}\left\{\frac{\partial Y_0}{dh}+\frac{\partial Y_0}{dL}\left[\frac{\partial L}{\partial \tau}\frac{d\tau}{dh}+\frac{\partial L}{dL^s}\left(\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial \theta}\left(\frac{\partial \theta}{\partial \phi}\frac{d\phi}{dh}+\frac{\partial \theta}{\partial h}\right)\right)\right]\right\} \\
&- \frac{\beta}{\rho}\frac{1}{l^*}\left[\frac{\partial L^s}{\partial h}+\frac{\partial L^s}{\partial \theta}\left(\frac{\partial \theta}{\partial \phi}\frac{d\phi}{dh}+\frac{\partial \theta}{\partial h}\right)\right] \\
&= \frac{1}{\rho-g}\frac{1}{c_0}\left[\frac{\partial c_0}{\partial h}+\frac{\partial c_0}{\partial L}\left(\frac{\partial L}{\partial \tau}\frac{d\tau}{dh}+\frac{\partial L}{\partial L^s}\frac{\partial L^s}{\partial h}\right)\right] \\
&- \frac{\eta}{\rho-g}\frac{1}{Y_0}\left[\frac{\partial Y_0}{dh}+\frac{\partial Y_0}{dL}\left(\frac{\partial L}{\partial \tau}\frac{d\tau}{dh}+\frac{\partial L}{dL^s}\frac{\partial L^s}{\partial h}\right)\right]-\frac{\beta}{\rho}\frac{1}{l^*}\frac{\partial L^s}{\partial h}.
\end{aligned}$$

Hence, which type of reform would be more welfare-improving is evaluated in the following manner:

$$\begin{aligned}
&\frac{dW^*}{dh}\Big|_{d\phi=0,h=0}^{d\theta=0}-\frac{dW^*}{dh}\Big|_{d\tau=0,h=0}^{d\theta=0} \\
&= \frac{1}{\rho-g}\frac{1}{c_0}\frac{\partial c_0}{\partial L}\frac{\partial L}{\partial \tau}\frac{d\tau}{dh}-\frac{\eta}{\rho-g}\frac{1}{Y_0}\frac{\partial Y_0}{dL}\frac{\partial L}{\partial \tau}\frac{d\tau}{dh} \\
&= \frac{1}{\rho-g}\frac{\partial L}{\partial \tau}\frac{d\tau}{dh}\left(\frac{1}{c_0}\frac{\partial c_0}{\partial L}-\frac{1}{Y_0}\frac{\partial Y_0}{dL}\right) \\
&= \frac{1}{\rho-g}\frac{\partial L}{\partial \tau}\frac{d\tau}{dh}\frac{1}{Y_0}\frac{\partial Y_0}{dL}(1-\eta),
\end{aligned}$$

because $c_0 = [1-\alpha^2(1-h)]Y_0$ and $\frac{\partial c_0}{\partial L} = [1-\alpha^2(1-h)]\frac{\partial Y_0}{\partial L}$.

Therefore, the following inequality is obtained:

$$\frac{dW^*}{dh}\Big|_{d\phi=0,h=0}^{d\theta=0} - \frac{dW^*}{dh}\Big|_{d\tau=0,h=0}^{d\theta=0} \begin{cases} <0 & \text{if} \quad \eta < 1 \\ \geq 0 & \text{if} \quad \eta \geq 1 \end{cases} .$$

References

[1] Aghion, P. and P. Howitt A Model of Growth through Creative Destruction. *Econometrica*, 60(2):323–351, 1992.

[2] Aghion, P. and P. Howitt *The Economics of Growth*. MIT Press, 2009.

[3] Barro, R.J. and X. Sala-i-Martin *Economic Growth*. MIT Press, 2003.

[4] Bovenberg, A.L. and R. de Mooij Environmental Levies and Distortionary Taxation. *American Economic Review*, 94(4):1085–1089, 1994.

[5] Bovenberg, A.L. and R. de Mooij Environmental Tax Reform and Endogenous Growth. *Journal of Public Economics*, 63:207–237, 1997.

[6] Bovenberg, A.L. and S.A. Smulders Environmental Quality and Pollution-Argumenting Technological Change in a Two-Sector Endogenous Growth Model. *Journal of Public Economics*, 57:369–391, 1995.

[7] Bovenberg, A.L. and S.A. Smulders Transitional Impacts of Environmental Policy in an Endogenous Growth Model. *International Economic Review*, pages 861–893, 1996.

[8] Bovenberg, A.L. and F. Van der Ploeg Consequences of environmental tax reform for unemployment and welfare. *Environmental and Resource Economics*, 12(2):137–150, 1998.

[9] Christainsen, G.B. and R.H. Haveman Public Regulations and the Slowdown in Productivity Growth. *American Economic Review*, 71(2):320–325, 1981.

[10] Devereux, M.B. and D.R.F. Love The Dynamic Effects of Government Spending Policies in a Two-Sector Endogenous Growth Model. *Journal of Money, Credit and Banking*, 27(1):232–256, 1995.

[11] Elbasha, E.H. and T.L. Roe On Endogenous Growth: The Implications of Environmental Externalities. *Journal of Environmental Economics and Management*, 31:240–268, 1996.

[12] Fullerton, D. and S.R. Kim Environmental Investment and Policy with Distortionary Taxes, and Endogenous Growth. *Journal of Environmental Economics and Management*, 56(2):141–154, 2008.

[13] Koskela, E. and R. Schöb Alleviating Unemployment: The Case for Green Tax Reforms. European Economic Review, 43(9):1723–1746, 1999.

[14] Futagami, K., Y. Morita and A. Shibata Dynamic Analysis of an Endogenous Growth Model with Public Capital. *Scandinavian Journal of Economics*, 95(4):607–625, 1993.

[15] Gerlagh, R. and B. C. C. van der Zwaan The Effects of Ageing and an Environmental Trust Fund in an Overlapping Generations Model on Carbon Emission Reductions. *Ecological Economics*, 36(2):311–326, 2001.

[16] Gerlagh, R., S. Kverndokk and K. Rosendahl Optimal Timing of Climate Change Policy; Interaction between Carbon Taxes and Innovation Externalities. *Environmental and Resource Economics*, 43(3):369–390, 2009.

[17] Gollop, F.M. and M.J. Roberts Environmental Regulations and Productivity Growth: The Case of Fossil-Fueled Electric Power Generation. *Journal of Political Economy*, 91(4):654–674, 1983.

[18] Greiner, A. Fiscal Policy in an Endogenous Growth Model with Public Capital and Pollution. *Japanese Economic Review*, 56(1):67–84, 2005.

[19] Grimaud, A. Pollution Permits and Sustainable Growth in a Schumpeterian Model. *Journal of Environmental Economics and Management*, 38:249–266, 1999.

[20] Grimaud, A. Environmental Policies, Pollution and Growth in a Model with Vertical Innovations. In Ouestlati, W. and G. Rotillon, editor, *Macroeconomic Perspectives on Environmental Concerns*. Edward Elgar, 2000.

[21] Grossman, G.M. and E. Helpman Quality Ladders in the Theory of Growth. *The Review of Economic Studies*, 58(1):43–61, 1991.

[22] Hart, R. Growth, Environment and Innovation, A Model with Production Vintages and Environmentally Oriented Research. *Journal of Environmental Economics and Management*, 48:1078–1098, 2004.

[23] Hettich, F. Growth Effects of a Revenue-neutral Environmental Tax Reform. *Journal of Economics*, 67(3):287–316, 1998.

[24] Howitt, P. Endogenous Growth and Cross-Country Income Differences. *The American Economic Review*, 90(4):829–846, 2000.

[25] Michel, P. and G. Rotillon Disutility of Pollution and Endogenous Growth. *Environmental and Resource Economics*, 6(3):279–300, 1995.

[26] Nakada, M. Does Environmental Policy Necessarily Discourage Growth? *Journal of Economics*, 81(3):249–275, 2004.

[27] Oates, W.E. Green Taxes: Can We Protect the Environment and Improve the Tax Systemat the Same Time? *Southern Economic Journal*, 61(4):915–922, 1995.

[28] Ono, T. Growth and Welfare Effect of an Environmental Tax-based Public Pension Reform. *Japanese Economic Review*, 58(3):362–381, 2007.

[29] Ono, T. Environmental Tax Reform in an Overlapping-Generations Economy with Involuntary Unemployment. *Environmental Economics and Policy Studies*, 9:213–238, 2008.

[30] Parry, I.W.H. Pollution Taxes and Revenue Recycling. *Journal of Environmental Economics and Management*, 29(3):S64–S77, 1995.

[31] Porter, M.E. and C. van der Linde Toward a New Competition of the Environmental Competitiveness Relationship. *Journal of Economic Perspectives*, 9(4):97–118, 1995.

[32] Ricci, F. Environmental Policy and Growth When Inputs are Differentiated in Pollution Intensity. *Environmental and Resource Economics*, 38(3):285–310, 2007.

[33] Romer, P.M. Endogenous Technological Change. *Journal of Political Economy*, 98(5):s71–s102, 1990.

[34] Turnovsky, S.J. Fiscal Policy, Elastic Labor Supply, and Endogenous Growth. *Journal of Monetary Economics*, 45(1):185–210, 2000.

[35] Verdier, T. Environmental Pollution and Endogenous Growth. In C. Carraro and J.A. Filar, editors, *Control and Game-Theoretic Models of the Environment*, pages 175–200. Birkhauser, 1995.

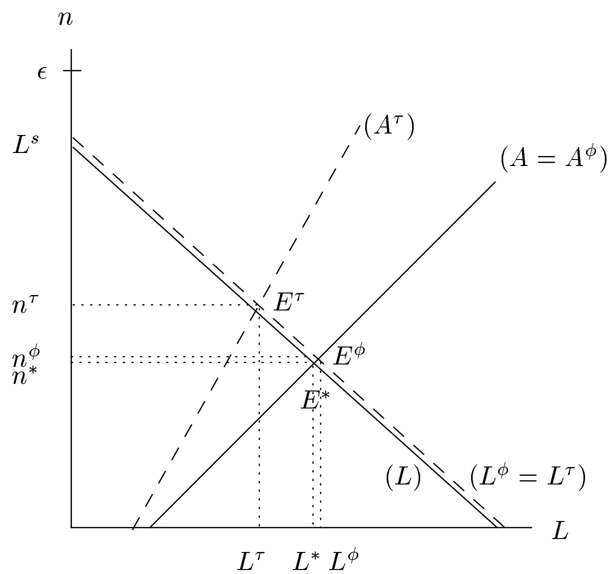

Figure 1: Impacts of Environmental Tax Reforms

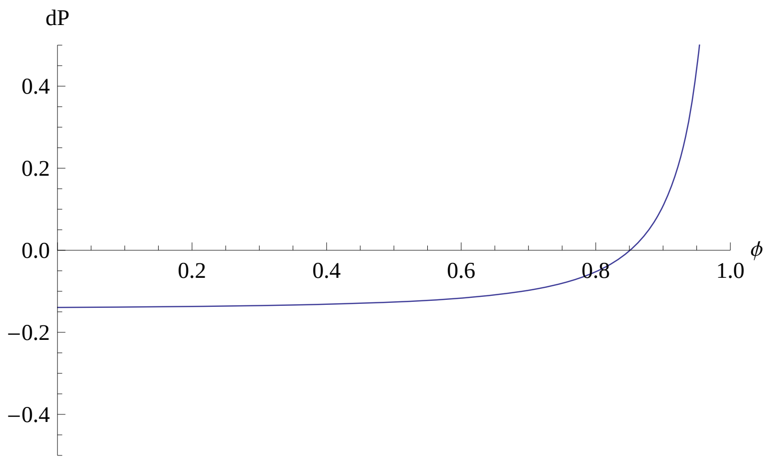

Figure 2: Impacts on Pollution Responding to an Income Tax