Economic Growth and the Environment:
The Welfare Effect of R&D Taxation*

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ABSTRACT

This paper examines the welfare effect of R&D taxation in a model where the innovation of new products drives economic growth, which in turn pollutes the environment. In the presence of an environmental externality, the R&D taxation remedies overproduction and improves the environment. Taking transitional dynamics into account, we find that there exists a tax rate that maximizes the welfare of a representative consumer.

Keywords: Economic growth, Environment, Innovation, R&D taxation.

JEL Classication Numbers: E1, H2, O4, Q5.

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1 Introduction

Economists and policy makers have sought ways of simultaneously achieving both economic growth and environmental protection. The recent rapid economic development in the BRICS countries (Brazil, Russia, India, China and South Africa) makes us return to this central issue. Using a model in which product innovation is an engine of economic growth, this paper shows that a tax on R&D activity corrects overproduction caused by an environmental externality and leads to a welfare improvement.

Numerous studies explore how to protect the environment in an optimal growth model with exogenous technological progress.[1] Since the environment as a source of utility and/or an input to production generally creates an externality, a market outcome becomes inefficient. Governments need to intervene in the market to internalize the externality. For instance, John *et al*. (1995) and Ono (1996) propose income and consumption taxes as instruments for realizing the optimal resource allocation.

In a growth model in which product innovation endogenously determines the factor productivity, this paper considers a role of R&D taxation in the presence of the environmental externality.[2] While the R&D taxation discourages profit-motivated innovation of new products and lowers the factor productivity, it remedies overproduction arising from the environmental externality. The two conflicting effects imply the existence of the optimal tax rate that maximizes the welfare of a representative consumer. In the baseline simulation, the welfare improves (or deteriorates) at tax rates below (or above) 3.8% and takes a maximum at the 1.9% rate. The R&D tax thus acts as an alternative to the environmental taxes discussed in the literature.[3]

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[1] See for example Keeler *et al*. (1972), Tahvonen and Kuuluvainen (1991, 1993), Chichilnisky *et al*. (1995) and Ayong Le Kama (2001).

[2] There are several types of endogenous growth models. John and Pecchenino (1994), Smulders and Gradus (1996) and Elíasson and Trunovsky (2004) address environmental problems using a model with an externality associated with knowledge spillovers in the final output sector. See Smulders (1995) for the case of human capital accumulation and Ligthart and van der Ploeg (1994) for the case of productive public goods. Note that none of them embeds the R&D activity of new products.

[3] Tahvonen and Kuuluvainen (1991, 1993), Bovenberg and Smulders (1995), Smulders and Gradus (1996) and Ono (2003) show a beneficial effect of imposing a tax on pollution emitted in the process of production.

The result differs from that of Grimaud (1999), which is based on a Schumpeterian growth framework with the dual externalities caused by both environmental pollution in the final output sector and knowledge spillovers in the R&D sector.[4] In his setting, it is optimal to subsidize the R&D activity because pollution permits are assumed to resolve the environmental problem perfectly. This paper complements Grimaud by introducing the R&D tax as an alternative to pollution permits. In our case, the R&D taxation, rather than the R&D subsidy, is beneficial to the welfare. Although we exclude the knowledge externality in the R&D sector, our results are qualitatively valuable as long as the inefficiency from the environmental externality is more serious.

The remaining of the paper is organized as follows. Section 2 constructs a general equilibrium model with the R&D activity of new products and the environmental externality. Section 3 analyzes the dynamics and compares the market equilibrium with the social optimum, thereby numerically deriving the welfare effect of R&D taxation. A sensitivity analysis of the simulation results shows that (i) the welfare-improving and welfare-maximizing tax rates are somewhat affected by the degree of the environmental externality and the nonseparability in preference over consumption and the environmental level and (ii) they depend heavily on the estimated value of environmental resources. We also pay attention to the case where the R&D sector is inactive. Section 4 concludes the paper.

2 The Model

An environmental externality is incorporated into an endogenous growth model developed by Grossman and Helpman (1991, chapter 3). There is a single final good produced by using

Ligthart and van der Ploeg (1994) deal with a tax on output in an endogenous growth model with productive government spending.

[4] The existing studies relating to an innovation-driven growth and an environmental protection, except for Grimaud (1999), do not focus on the welfare effect of R&D taxation. For example, Papyrakis and Gerlagh (2004) demonstrate that an increase in natural resources impedes income growth by reducing both work effort and a proportion of the labor force allocated to the innovation sector. Elbasha and Roe (1996) analyze an interaction among international trade, economic growth and the environment in a small open economy. Ono (2003) examines the growth effect of environmental taxation in a growth-cycle model in which the economy either fluctuates between exogenous and endogenous growth regimes or converges to one of them.

differentiated intermediate goods, each of which is monopolistically supplied. A variety of intermediate goods expands as a result of profit-motivated R&D activity. The variety expansion increases a level of output in the final good sector but simultaneously pollutes the environment. Individuals do not recognize the disutility from polluting the environment, so that over-consumption and under-environment occur in the market economy.

2.1 Production

The final good sector

A representative firm competitively produces a final good using the CES production technology:

$$Y_t = \left[\int_0^{N_t} x_t(j)^\theta \mathrm{d}j \right]^{\frac{1}{\theta}}, \quad 0 < \theta < 1,$$

where Y_t is output of the final good, $N_t(> 0)$ a variety of intermediate goods, and $x_t(j)$ an input of intermediate good $j(\in [0, N_t])$, respectively. The elasticity of substitution between intermediate inputs is represented by $1/(1-\theta)(> 1)$. Since the present model excludes capital investment, government purchases and international trade, Y_t equals aggregate consumption C_t. In a symmetric equilibrium where $x_t(j) = x_t$, the production function reduces to

$$C_t = N_t^{\frac{1}{\theta}} x_t. \tag{1}$$

It shows that an increase in N_t raises the factor productivity.

Letting the final good be the numeraire and $p_t(j)$ the price of intermediate good j, the optimal condition of profit maximization gives

$$x_t(j) = p_t(j)^{-\frac{1}{1-\theta}} C_t. \tag{2}$$

Intermediate goods sectors

Each intermediate good j is produced by a monopolistic firm, which pays profits to the R&D sector as patent fees. Labor is used to produce intermediate goods according to the linear-homogeneous technology in which the input-output coefficient is unity. Given the demand function (2), the monopolistic firm chooses $p_t(j)$ so as to maximize profit

$$\pi_t(j) = p_t(j)x_t(j) - w_t x_t(j), \tag{3}$$

where w_t is the wage rate. In a symmetric equilibrium, the optimal condition satisfies

$$p_t(j) = p_t \equiv \frac{w_t}{\theta}, \qquad x_t(j) = x_t \equiv \left(\frac{w_t}{\theta}\right)^{-\frac{1}{1-\theta}} C_t. \tag{4}$$

Applying the second equation in (4) to (1) leads to

$$w_t = \theta N_t^{\frac{1-\theta}{\theta}}. \tag{5}$$

Substituting (4) into (3) and using (5) to eliminate w_t from the result, we have

$$\pi_t(j) = \pi_t \equiv (1-\theta)\frac{C_t}{N_t}. \tag{6}$$

The R&D sector

With free entry, the marginal benefit from the R&D activity, v_t, equals the present discounted sum of future profits earned by the intermediate good sector:

$$v_t(j) = v_t \equiv \sum_{s=t}^{\infty} \pi_{s+1} \left(\prod_{t}^{z=s} \frac{1}{1+r_{z+1}} \right),$$

where r_t represents the interest rate and π_{s+1} is given by (6).[5] It implies

$$1 + r_{t+1} = \frac{v_{t+1} + \pi_{t+1}}{v_t}. \tag{7}$$

The R&D sector employs labor L_t to create new intermediate goods, $N_{t+1} - N_t$:

$$N_{t+1} - N_t = L_t \ (\geq 0). \tag{8}$$

The optimal condition of profit maximization is

$$(1-\tau^R)v_t \leq w_t, \quad \text{with equality whenever } N_{t+1} - N_t > 0, \tag{9}$$

where $\tau^R (\in [0,1))$ is a tax rate on the R&D activity. In the case where (9) holds with inequality, the R&D sector becomes inactive.

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[5] Infinite patent length is assumed in the present analysis. See e.g., Futagami and Iwaisako (2007) and Iwaisako and Futagami (2003) for the effect of patent length on economic growth.

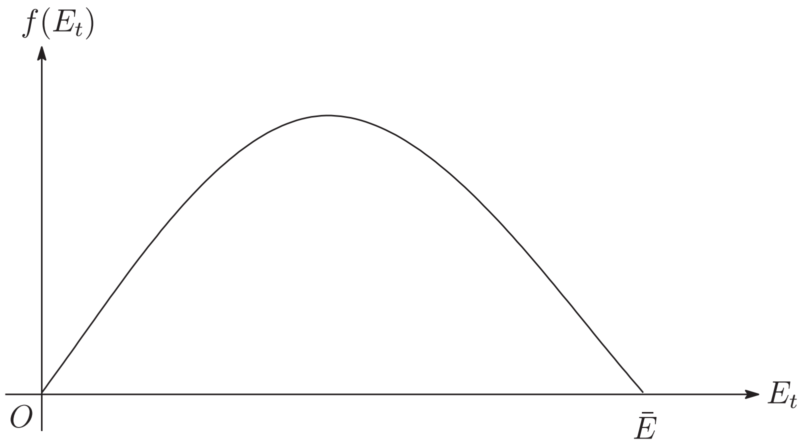

Figure 1. The reproduction function of the environment.

2.2 Environmental resources and the consumer behavior

Following Smulders (1995) and Ayong Le Kama (2001), we assume that the environment recovers through a natural regeneration process but is destroyed by the production activity in the final good sector, which equals the level of aggregate consumption—i.e.,

$$E_{t+1} - E_t = f(E_t) - \delta C_t, \quad \delta > 0,$$

where E_t is the stock of environmental resources at the beginning of period t. As illustrated in figure 1, we specify the reproduction function $f(\cdot)$ as

$$f(E_t) = -E_t(E_t - \bar{E}), \quad \bar{E} > 0.$$

From the above two equations, the environment evolves according to

$$E_{t+1} - E_t = E_t\left(\bar{E} - E_t\right) - \delta C_t. \tag{10}$$

Lifetime utility of a representative consumer, U_0, depends on not only consumption C_t but also the environmental level, E_t:

$$U_0 = \sum_{t=0}^{\infty} \beta^t \frac{\left({C_t}^{\kappa}{E_t}^{1-\kappa}\right)^{1-\gamma} - 1}{1-\gamma}, \qquad 0 < \beta < 1, \quad 0 < \kappa < 1, \quad \gamma > 0, \tag{11}$$

where β denotes the subjective discount factor.[6] The consumer ignores the evolutionary process of the environment, (10), and maximizes (11) subject to the financial budget constraint,

$$A_{t+1} = (1 + r_t)A_t + w_t\bar{L} - C_t + T_t,$$

where A_t is a financial asset, $\bar{L}$ a constant labor endowment, T_t a lump-sum transfer from the government, respectively. The optimal condition of utility maximization are the transversality condition and

$$\left(\frac{C_{t+1}}{C_t}\right)^{(1-\kappa)+\kappa\gamma} = (1 + r_{t+1})\beta\left(\frac{E_{t+1}}{E_t}\right)^{-(1-\kappa)(\gamma-1)}. \tag{12}$$

The government transfers the collected funds to the consumer in a lump-sum manner:

$$T_t = \tau^R v_t(N_{t+1} - N_t).$$

The equilibrium condition in the labor markets satisfies

$$\bar{L} = \int_0^{N_t} x_t(j)\mathrm{d}j + L_t. \tag{13}$$

3 Dynamics and the R&D Activity

3.1 The active R&D sector

As indicated in (9), there are two kinds of equilibrium dynamics depending on whether the R&D sector is active or inactive. Let us first analyze the former case. Applying (6) and (9) in which the equality holds to (7) and using (5) generates

$$1 + r_{t+1} = \left[1 + \frac{(1-\tau^R)(1-\theta)C_{t+1}}{\theta N_{t+1}^{\frac{1}{\theta}}}\right]\left(\frac{N_{t+1}}{N_t}\right)^{\frac{1-\theta}{\theta}},$$

[6] The model in which renewable environmental resources directly yield utility is extended in various directions. For instance, Li and Löfgren (2000) take account of heterogenous consumers differing with respect to the subjective discount rate. Ayong Le Kama and Schubert (2007) consider an endogenous discounting depending on the environmental quality and investigate the sustainability of economic growth. Wirl (2004) points out that multiple equilibria and stable limit cycles can arise in the framework of Ayong Le Kama (2001). John and Pecchenino (1994), John *et al*. (1995) and Ono (1996, 2003) employ an overlapping-generations model to explore intergenerational interactions in environmental preservation.

which reduces the dynamic equation of consumption (12) to

$$\left(\frac{C_{t+1}}{C_t}\right)^{(1-\kappa)+\kappa\gamma} = \left[1+\frac{(1-\tau^R)(1-\theta)C_{t+1}}{\theta N_{t+1}^{\frac{1}{\theta}}}\right]\left(\frac{N_{t+1}}{N_t}\right)^{\frac{1-\theta}{\theta}}\beta\left(\frac{E_{t+1}}{E_t}\right)^{-(1-\kappa)(\gamma-1)}. \tag{14}$$

The dynamic equation of the product variety comes from (8):

$$N_{t+1}-N_t=\bar{L}-C_t N_t^{-\frac{1-\theta}{\theta}}, \tag{15}$$

where the right-hand side, L_t, is by substituting the second equation in (4) into (13) and using (5).

An autonomous dynamic system in the market economy is represented by (10), (14) and (15) and has the steady-state values (C^*, N^*, E^*):

$$C^*=\left[\frac{(1-\tau^R)(1-\theta)\beta}{\theta(1-\beta)}\right]^{\frac{1-\theta}{\theta}}\bar{L}^{\frac{1}{\theta}}, \qquad N^*=\frac{(1-\tau^R)(1-\theta)\beta\bar{L}}{\theta(1-\beta)}, \tag{16}$$

$$E^*=\frac{\bar{E}+\sqrt{\bar{E}^2-4\delta\left[\frac{(1-\tau^R)(1-\theta)\beta}{\theta(1-\beta)}\right]^{\frac{1-\theta}{\theta}}\bar{L}^{\frac{1}{\theta}}}}{2}, \qquad f'(E^*)<0, \tag{17}$$

where we assume the existence of E^* that is dynamically stable.[7] It is apparent that there is a trade-off between economic growth and environmental protection.

Proposition 1. *In the market equilibrium, an increase in τ^R reduces C^* and N^* but raises E^*.*

Proof. Totally differentiating (16) and (17) yields

$$\frac{\mathrm{d}C^*}{\mathrm{d}\tau^R}=-\frac{(1-\theta)C^*}{(1-\tau^R)\theta}<0, \qquad \frac{\mathrm{d}N^*}{\mathrm{d}\tau^R}=-\frac{N^*}{1-\tau^R}<0,$$
$$\frac{\mathrm{d}E^*}{\mathrm{d}\tau^R}=\frac{\delta(1-\theta)C^*}{(1-\tau^R)\theta\sqrt{\bar{E}^2-4\delta C^*}}>0.$$

$Q.E.D.$

The social optimum is to maximize (11) subject to both (10) and (15)—i.e., the optimal

[7] Ogawa and Nakamura (2016) theoretically analyze how a subsidy on R&D activity affects the existence of E^* and the dynamic stability of the economy.

Table 1. Parameters in the baseline simulation.

θ^{-1}	β	δ	$\bar{E}$	$\bar{L}$	κ	γ
1.2	$(0.995)^4$	0.01	1	5.761	0.5	1

allocation $\{C_t^o, N_t^o, E_t^o\}_{t=0}^{\infty}$ satisfies the transversality condition and

$$\delta\mu_t + (N_t^o)^{-\frac{1-\theta}{\theta}}\xi_t = \kappa(C_t^o)^{-[(1-\kappa)+\kappa\gamma]}(E_t^o)^{-(1-\kappa)(\gamma-1)},$$

$$\mu_t = \beta\left[(1-\kappa)(C_{t+1}^o)^{-\kappa(\gamma-1)}(E_{t+1}^o)^{-[\kappa+(1-\kappa)\gamma]} + (1+\bar{E}-2E_{t+1}^o)\mu_{t+1}\right],$$

$$\xi_t = \left[1 + \frac{1-\theta}{\theta}C_{t+1}^o(N_{t+1}^o)^{-\frac{1}{\theta}}\right]\beta\xi_{t+1},$$

where μ_t and ξ_t are respectively the Lagrange multiplier of (10) and that of (15). In the present setting, the resulting optimal path converges to (16) and (17) in which $\tau^R = 0$. The transitional path of the market equilibrium, however, deviates from the social optimum due to the environmental externality. It will be formally shown in the following simulation.

3.2 Simulation

We shall numerically analyze the transitional dynamics using Dynare++4.3.3. The parameter values are reported in table 1. Setting θ^{-1} = 1.2 and β= $(0.995)^4$ follows Sugo and Ueda (2008).[8] $\bar{E}$ is normalized to be unity. δ and $\bar{L}$ are calculated from the trial estimates for Japan's integrated environmental and economic accounting, presented by the Economic Planning Agency, government of Japan, in July 1998 (see appendix A for details). The baseline simulation assumes κ= 0.5 and γ= 1. The terminal period of the simulation is assumed to be the 1,000 period (1,000 year).

[8] Sugo and Ueda (2008) estimate a dynamic stochastic general equilibrium model with new-Keynesian features using quarterly Japanese data. See Christiano *et al*. (2005) and Levin *et al*. (2006) for the U.S. economy.

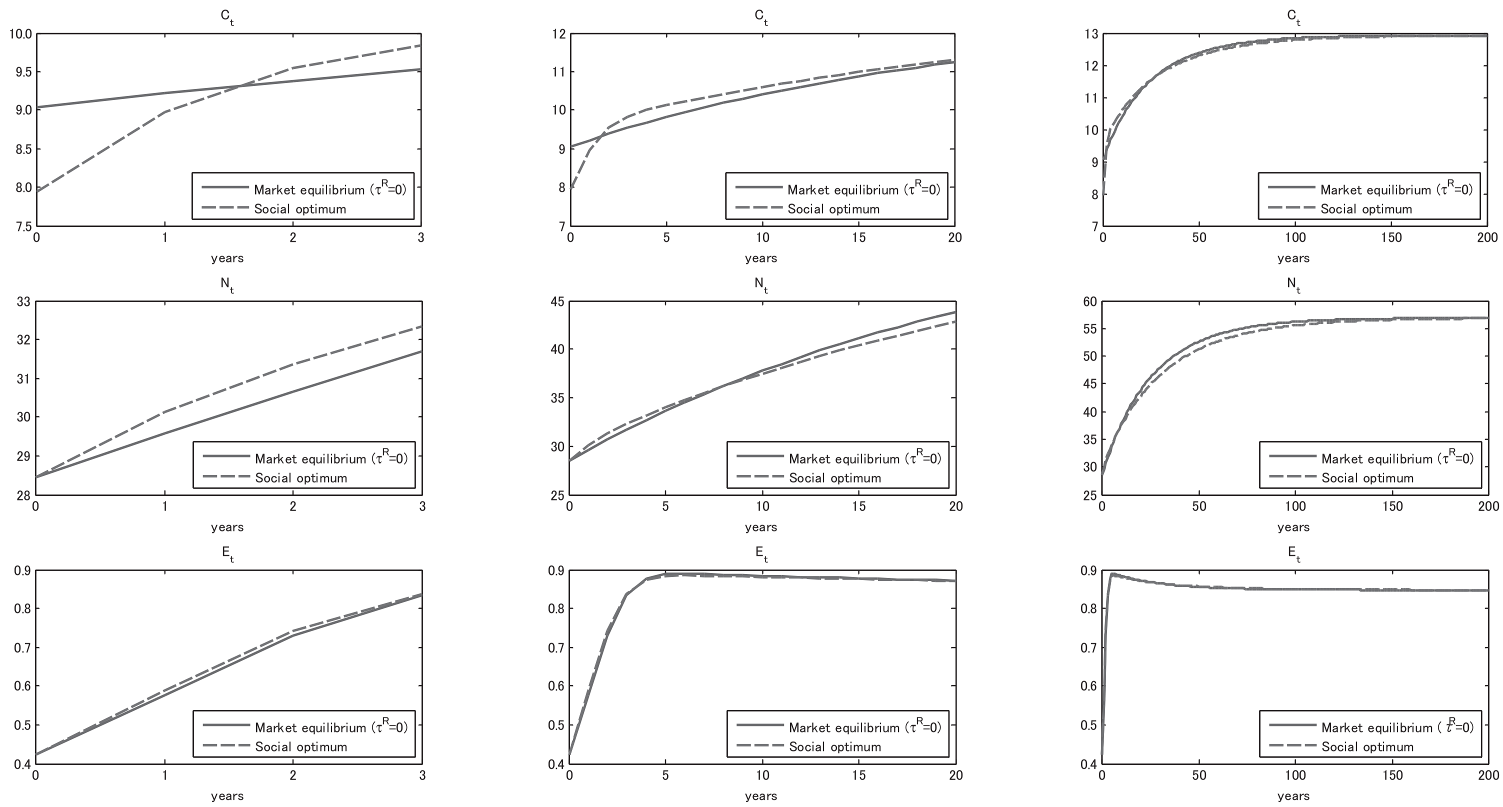

Figure 2. The market-equilibrium path and the optimal path.

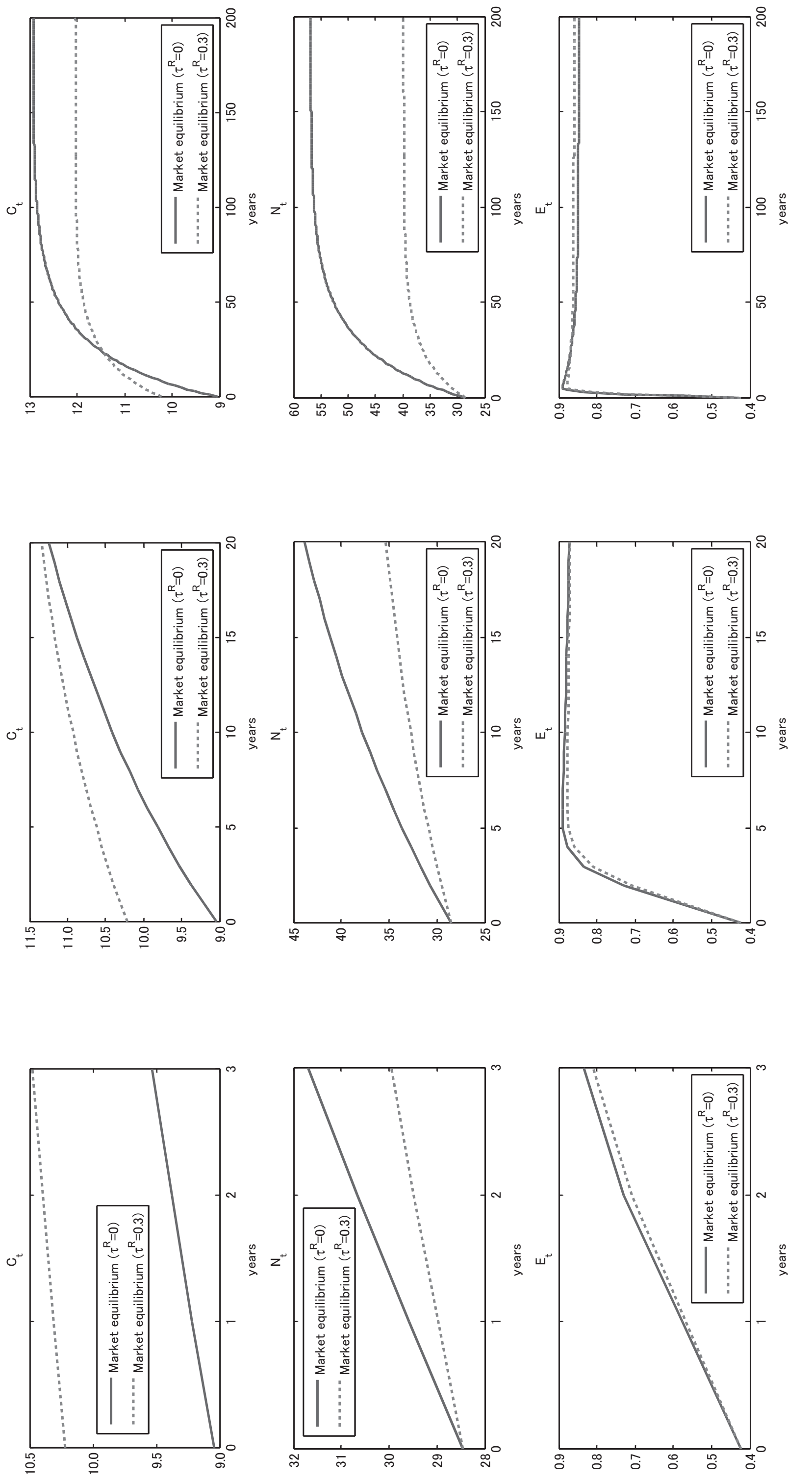

Figure 3. The market-equilibrium paths: $\tau^R = 0$ and $\tau^R = 0.3$.

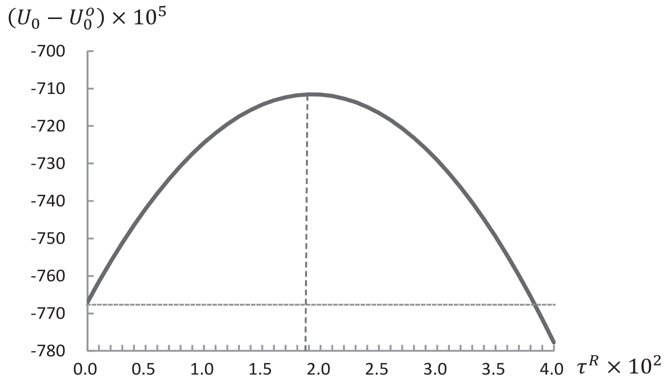

Figure 4. The welfare effect of τ^R.

The baseline simulation

Figure 2 depicts the dynamic path in which the initial stock variables $(N_0,\ E_0)$ are given by $N_0 = 0.5N^{o*}$ and $E_0 = 0.5E^{o*}$.[9] The solid line represents the market equilibrium in which $\tau^R =$ 0, whereas the broken line is the social optimum. The deviation between the two lines shows the inefficiency of the market outcome. In early periods, due to the environmental externality, consumption is excessive whereas both the R&D activity and the environmental level are smaller than the optimum (see figures on the left-hand side). The current under-investment in the R&D sector leads to a subsequent decline in consumption, which in turn raises the labor supply allocated to the R&D sector. Eventually, market-equilibrium and optimal paths converge to the same steady state if $\tau^R = 0$ (see figures on the right-hand side).

Figure 3 shows an effect of the R&D taxation on the transitional path and the steady state in the market equilibrium. The dotted line is the case of $\tau^R = 0.3$, whereas the solid line is that of $\tau^R = 0$. Throughout the whole period, the tax discourages the R&D activity. In the short-run, it increases the labor supply allocated to the final good sector and damages the environment. In the long-run, however, a decline of the factor productivity results in a decrease in consumption and an improvement in the environment (proposition 1). The total welfare effect depends on the tax rate, as seen in figure 4.[10] Within $0 < \tau^R \leq 0.038$, the lifetime utility rises

[9] The values of N^{o*} and E^{o*} are given by the second equation in (16) and (17) in which $\tau^R = 0$.

[10] In figure 4, U_0 denotes the lifetime utility achieved in the market equilibrium and U_0^o is that in the social optimum. The vertical line measures the difference between these two.

Table 2. A sensitivity analysis.

$\bar{L}$	κ	γ	Improving within	Maximum at
5.761	0.5	1	$0 < \tau^R \leq 0.038$	$\tau^R = 0.019$
5.761	0.8	1	$0 < \tau^R \leq 0.008$	$\tau^R = 0.004$
5.761	0.5	1.249	$0 < \tau^R \leq 0.031$	$\tau^R = 0.016$
0.179	0.5	1	$0 < \tau^R \leq 0.00026$	$\tau^R = 0.00013$

since the long-run beneficial effect dominates the short-run harmful effect. The R&D taxation is useful to reduce the inefficiency arising from the environmental externality. The lifetime utility takes a maximum at $\tau^R = 0.019$. As the tax rate is higher ($\tau^R > 0.038$), the welfare falls since the harmful effect dominates. We can summarize the results as follows:

Result 1. *In the presence of the environmental externality, the R&D taxation can improve the welfare of the representative consumer and a welfare-maximizing tax rate exists.*

A sensitivity analysis

Table 2 reports results of a sensitivity analysis. The larger κ indicates that the utility from the environment is less important and the inefficiency is minor. In the case of $\kappa = 0.8$, the welfare improves at tax rates below 0.008, which is lower than 0.038 in the case of $\kappa = 0.5$. The welfare-maximizing tax rate is also smaller.

Let us consider a role of nonseparable preference by setting γ equal to 1.249, estimated by Sugo and Ueda (2008). Under the felicity function given in (11), the marginal utility of consumption, λ_t, satisfies

$$\lambda_t = \kappa C_t^{-[(1-\kappa)+\kappa\gamma]} E_t^{-(1-\kappa)(\gamma-1)},$$

which is decreasing with respect to E_t if $\gamma > 1$. Along the growing path of the environment, consumption is more in early periods and becomes less toward the steady state. It mitigates the inefficiency as long as the long-run effect dominates the short-run effect. Relative to the case of $\gamma = 1$, the range within which the taxation is beneficial narrows ($0 < \tau^R \leq 0.031$) and the welfare-maximizing tax rate is lower ($\tau^R = 0.016$).

Finally, we confirm that the results are sensitive to the magnitude of $\bar{L}$. In the baseline

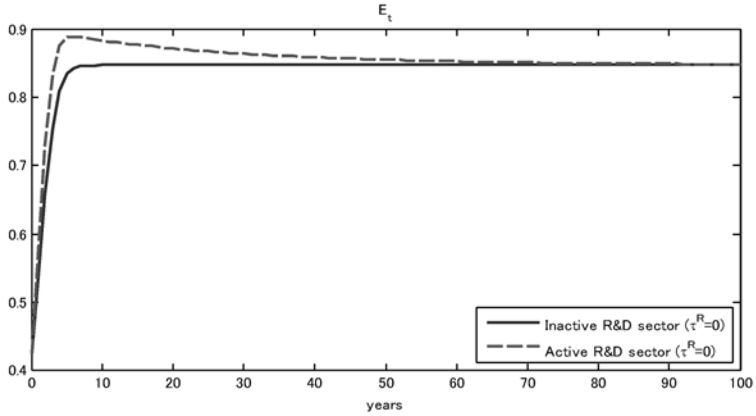

Figure 5. The market-equilibrium path of E_t: $N_0 = N^{o*}$ and $N_0 = 0.5N^{o*}$.

simulation we interpret E_t as the "Environmental Protection Assets," of which amount is consistent with $\bar{L}$ = 5.761 (see appendix A for the derivation of $\bar{L}$). If the "Non-Produced Assets" is used as a proxy for E_t, we have $\bar{L}$ = 0.179 and smaller C^*. As a result, there is almost no need for imposing a tax. To calculate accurate tax rates that improve or maximize the welfare, therefore, we should get the rigorous value of environmental resources although it is a difficult task.

3.3 The inactive R&D sector

If the initial stock satisfies $N_0 \geq N^*$, the R&D activity is no longer profitable. Equiation (9) has the inequality, so that the R&D sector is inactive (i.e., L_t = 0) and N_t stays at N_0. Since $x_t = \bar{L}/N_0$ holds from (13), (1) implies that consumption keeps constant at

$$C_t = N_0^{\frac{1-\theta}{\theta}} \bar{L}.$$

The environment evolves according to

$$E_{t+1} - E_t = E_t(\bar{E} - E_t) - \delta N_0^{\frac{1-\theta}{\theta}} \bar{L},$$

which is from (10). The R&D tax obviously has no effect on the equilibrium dynamics.

Suppose two types of countries: the one has a variety of intermediate goods sufficient to make the R&D sector inactive and the other has the active R&D sector satisfying $N_0 = 0.5N^{o*}$.

One may refer to the former as a developed country and the latter as a developing country. Figure 5 compares the E_t dynamics in the two countries, both of which face a natural or human-caused disaster damaging the environment so that $E_0 = 0.5E^{o*}$. After the disaster, the environment stock recovers more slowly in the country with the inactive R&D sector because consumption is larger. Furthermore, the government in such a country cannot intervene the market in a Pareto-improving way because the R&D taxation is useless.

Result 2. *In the economy that has a variety of intermediate goods sufficient to make the R&D sector inactive, the environment recovers slowly after disasters and is unaffected by the R&D taxation.*

4 Conclusion

In this paper we show that imposing a tax on the R&D activity can be beneficial in an innovation-driven growth model with the utility-enhancing environmental stock. The R&D taxation mitigates overconsumption, thereby partly solving the distortion generated by the environmental externality. We find a positive tax rate that maximizes the welfare if the R&D sector is active. It is also shown that the taxation has no effect if the R&D sector is inactive.

There are several directions for future research. To calculate a more accurate tax rate that improves the welfare, we have to introduce capital accumulation, endogenous labor supply and price rigidities into the model. It is also a crucial task to estimate the value of environmental resources and the imputed environmental costs. The second direction is to take account of the R&D activity that promotes pollution abatement technology (see for example Bovenberg and Smulders 1995, 1996 and Hart 2004). Finally, the presence of a knowledge externality in the R&D sector tends to make research effort less than the social optimum, thereby changing quantitative implications of the R&D taxation (such as Grossman and Helpman 1991 and Grimaud 1999).

Table 3. Data.

Description	Value (billion yen)	Variable
Net Domestic Product	429,860.4	$Y^* = C^*$
Imputed Environmental Costs	4,186.4	δY^*
Environmental Protection Assets	33,253.7	E^*
Non-Produced Assets	2,148,317.9	

Appendix A. Data and Parameter Values

This appendix explains how to derive the values of δ and $\bar{L}$. The data used in the simulation is available from the website of the Cabinet Office, government of Japan.[11] They are the results of trial estimates of the "Satellite System for Integrated Environmental and Economic Accounting" in 1990 at constant prices (see table 3 for the data).

We can employ two alternatives as a proxy of E_t. The one is the "Environmental Protection Assets," a part of which is used by industries in the production processes. The other is the "Non-Produced Assets" that is composed mainly of Land and Subsoil Resources. Since it is more difficult to estimate the latter value accurately, we use the former value in the baseline simulation. Actually the data set does not give the stock value of Air, Water and Soil that are categorized into the "Non-Produced Assets."

δ is calculated by dividing "Imputed Environmental Costs" by "Net Domestic Product".

$$\delta = \frac{\text{Imputed Environmental Costs}}{\text{Net Domestic Product}} \simeq 0.01.$$

We next derive the value of $\bar{L}$. Evaluating (10) in the steady state and using the data in table 3 generates

$$\bar{E} = E^* + \frac{\delta C^*}{E^*} \simeq \begin{cases} 33,253.8 & \text{if} \quad E^* = \text{Environmental Protection Assets}, \\ 2,148,317.9 & \text{if} \quad E^* = \text{Non-Produced Assets}. \end{cases}$$

[11] http://www.esri.cao.go.jp/en/sna/satellite/1998/19980714g-eco-e.html (2017, October 6)

We normalize this value to be unity in both cases and then obtain the value of $\bar{L}$ from the first equation in (16) in which $\tau^R = 0$:[12]

$$\bar{L} = (\text{Net Domestic Product})^{\theta} \left[\frac{(1-\theta)\beta}{\theta(1-\beta)}\right]^{\theta-1}$$
$$\simeq \begin{cases} 5.761 & \text{if} \quad E^* = \text{Environmental Protection Assets}, \\ 0.179 & \text{if} \quad E^* = \text{Non-Produced Assets}, \end{cases}$$

where the values of θ and β are given in table 1 and the "Net Domestic Product" is the value normalized by $\bar{E}$—i.e.,

$$\text{Net Domestic Product} = \begin{cases} \frac{429{,}860.4}{33{,}253.8} & \text{if} \quad E^* = \text{Environmental Protection Assets}, \\ \frac{429{,}860.4}{2{,}148{,}317.9} & \text{if} \quad E^* = \text{Non-Produced Assets}. \end{cases}$$

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