The Scandinavian
Journal of Economics

Scand. J. of Economics 120(1), 211–241, 2018
DOI: 10.1111/sjoe.12213

The Feasibility of the Double-Dividend Hypothesis in a Democratic Economy*

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Abstract

The two dividends in the double-dividend hypothesis are assumed to be independent. This assumption can be misleading when it comes to formulating policy. I construct a model where the pollution tax rate is voted for by heterogeneous people. In addition to the revenue-recycling effect, the equilibrium pollution tax rate depends on two opposite forces: the tax-cutting effect and the profit effect. The two forces show that an instrument that exploits a greater revenue-recycling effect can cause a more severe environmental deterioration, thereby resulting in the infeasibility of the hypothesis. The introduction of the interdependence between the two dividends can also mean that non-revenue-raising instruments are more efficient than revenue-raising instruments.

Keywords: Environmental policy; green tax reform; income inequality; political economy

JEL classification: *D*72; *Q*52; *Q*58

I. Introduction

Environmental policy instruments that can raise tax revenues have been receiving much support. The reasoning for this is not hard to understand. Revenues from revenue-raising (RR) instruments can be used to cut existing distortionary taxes, such as labor taxes, and thus the overall excess burden of the tax system is reduced. This is known as the revenue-recycling effect.[1] In other words, RR instruments can generate two benefits: environmental protection, and the welfare enhancement that arises from cutting distortionary taxes. This is the main assertion of the double-dividend hypothesis.

*The author is grateful to two anonymous referees for their valuable comments and suggestions. The remaining errors are the author's sole responsibility. Financial support from the Ministry of Science and Technology (Grant 104-2410-H-004-006-MY2) is also gratefully acknowledged.

[1] As indicated by Goulder *et al*. (1997), the distinction between the revenue-recycling effect and revenue raising is essential. Revenue-recycling refers to the use of environmental tax revenues to reduce other distortionary taxes, rather than distributing the tax revenues in a lump-sum manner. In this paper, RR instruments are instruments that can generate a revenue-recycling effect.

When demonstrating the double-dividend hypothesis, most of the literature implicitly assumes that the stringency of environmental regulation is independent of the way that pollution tax revenues are used. In practice, however, the two dividends are closely related (Sterner, 2003). Then there arises the following question. What is the relationship between the two dividends? In this paper, I aim to address this question. In other words, I do not treat the two dividends in the hypothesis as fixed; instead, I establish an interdependence between them.

The answer to the above question is important in two respects. First, there is the infeasibility of the double-dividend hypothesis. If the two dividends are in conflict with each other, then the hypothesis literally fails. Although a number of papers have pointed out the infeasibility of the hypothesis, their infeasibility refers to the augmented distortion of existing taxes caused by the pollution tax rate, rather than the trade-off between the two dividends.

Second, there is the relative efficiency of policy instruments. As pointed out, given the stringency of environmental protection, the double-dividend hypothesis claims that RR instruments are more efficient than non-revenue-raising (NRR) instruments. Once the interdependence between the dividends is introduced, I show that the opposite result can occur. This indicates that, regardless of whether the interdependence between the two dividends is introduced or not, different policy implications can arise.

To demonstrate these points, I consider a democratic economy, where people vote for the pollution tax rate. I set up a voting model because determining environmental policies through referenda is common around the world, and thus it appears necessary to investigate policy formation from the perspective of political economy. The model contains individuals who are endowed with different levels of labor productivity. The decisive voter is the one with the median productivity. By contrast, the optimal pollution tax rate that maximizes social welfare reflects the ideal tax rate of the individual with average productivity. Because the median productivity is assumed to be below the average productivity, the difference in the endowment between the median voter and the average individual generates two effects, leading the equilibrium pollution tax rate to be higher or lower than the optimal level.[2]

This model contains a clean-goods sector and a polluting-goods sector. Individuals provide labor to the two sectors as the input. The labor income

[2] As pointed out by Bovenberg (1999), distributional considerations can prevent the government from adopting the efficient policy. He further argues that "distributional issues are at the heart of the double-dividend issue" (Bovenberg, 1999, p. 433). This paper's approach corresponds to his claim.

is subject to a labor tax. To protect the environmental quality, a pollution tax is imposed on the emissions generated by the polluting-goods sector.

A parameter $\lambda \in [0, 1]$ is used to denote the proportion of the pollution tax revenues that are used to cut the labor tax; the remaining $1 - \lambda$ of the tax revenues is retained by the polluting industry. As will become clear later, λ can characterize different types of instruments. When $\lambda = 0$, the environmental instrument is an NRR instrument, and when $\lambda > 0$, it is an RR instrument; if $\lambda = 1$, then it is then a pure RR instrument. One feature of this setting is that it allows for continuous types of policy instruments.

The timing of the events is as follows. First, given the policy instrument λ, people vote for the pollution tax rate. Both the parameter λ and the pollution tax rate jointly determine the effective labor tax rate. Then, given the pollution tax rate and the labor tax rate, individuals decide their consumption and labor supply, and the firms make decisions.

I first derive the optimal pollution tax rate, which maximizes the aggregate welfare of all people, as a benchmark. As indicated, the optimal tax rate is equal to the ideal tax rate of the individual with average productivity. Moreover, the optimal pollution tax reflects the individual's environmental concerns and the revenue-recycling effect.

When we turn to the equilibrium pollution tax rate, two additional politically related factors emerge. First, using the pollution tax revenues to cut the labor taxes lowers the median voter's income position relative to the average individual. The benefit of cutting the labor tax increases with the individuals' productivity (i.e., the labor tax relief is regressive). Thus, the benefit of the labor tax relief received by the median voter is less than that received by the average individual. This is referred to as the tax-cutting effect. This effect induces the median voter to choose a pollution tax rate that is lower than the optimal tax rate.

The second effect is related to the polluting firm's profit. An increase in the pollution tax rate reduces the income extracted by the polluting firm, which is beneficial to the median voter. A higher pollution tax rate also lowers people's profit income, which is harmful to the median voter. Because the median voter's share of the profit is less than the average level, the benefit from the reduced income extraction is greater than the loss from the decline in the profit income. Moreover, for the average individual, the two effects are exactly offset. Thus, the median voter prefers a pollution tax rate that is higher than the optimal tax rate. This effect has been referred to as the profit effect. If the profit effect outweighs the tax-cutting effect, then the equilibrium pollution tax rate is higher than the optimal tax; otherwise, the opposite occurs.

A main goal of this paper is to investigate the equilibrium pollution tax rate under the different types of instruments (i.e., the different values of

λ). I find that the effect of λ on the pollution tax rate is ambiguous. This is because an increase in λ enlarges the revenue-recycling effect and the profit effect, both of which lead to a higher pollution tax rate. However, a larger value of λ also strengthens the tax-cutting effect, resulting in a lower tax rate. The net impact of λ depends on which force prevails. When the change in the tax-cutting effect is dominant, then the pollution tax rate decreases with λ, meaning that the two dividends are in conflict with each other.

Another concern of this paper is the relative efficiency of the environmental policy instruments. To this end, I decompose the total effect of λ on social welfare into a direct effect and an indirect effect. The direct effect measures the welfare effect of λ, holding the pollution tax rate as given. The direct effect is positive, because an increase in λ lowers the labor tax rate, and thus enlarges the labor supply. The indirect effect reflects the welfare impact of λ through changing the pollution tax rate. The indirect effect can be positive or negative. A negative indirect effect is the necessary condition for the NRR instruments to be more efficient than the RR instruments. The indirect effect is equal to zero, when the pollution tax rate is determined by a benevolent dictator.[3] This explains the conventional result, which states that a policy with a lower λ cannot be more efficient than that with a higher λ.

In this paper, the indirect effect exists. Because the voting mechanism and the unequal distribution of the endowment lead the pollution tax rate to deviate from the optimal level, a change in the pollution tax rate due to an increase in λ has an impact on social welfare, so that the indirect effect exists. Section V illustrates two scenarios in which a policy with a lower λ can be more efficient than that with a higher λ.

In addition, I provide the condition ensuring that the NRR instruments generate a higher level of social welfare than the RR instruments. This result occurs only when the pollution tax rate increases with λ. The reason for this result is that the NRR instruments have neither the revenue-recycling effect nor the tax-cutting effect; they generate only the profit effect, causing the equilibrium pollution tax rate to be higher than the optimal level. With a positive relationship between the pollution tax rate and λ, an increase in λ pushes the already excessively high tax rate even higher, bringing about a negative indirect welfare effect of λ. If the negative indirect effect is sufficiently large, then the relative efficiency of the NRR instruments is achieved.

In the next section, I discuss the related body of literature. Section III introduces the model underlying the analysis. In Section IV, I investigate

[3] In this case, the choice of the pollution tax rate has been optimized, so that an infinitesimal change in the pollution tax rate due to a change in λ has no welfare impact.

the properties of the equilibrium pollution tax rate. The relationship between the two dividends is examined in Section V. In Section VI, I discuss some extensions of the basic model. I give concluding remarks in Section VII.

II. Related Body of Literature

This paper is related to several strands of the literature. One strand concerns the double-dividend hypothesis and the choice of environmental instrument. The number of related studies is huge, including, for example, Lee and Misiolek (1986), Bovenberg and van der Ploeg (1994), Bovenberg and de Mooij (1994), Fullerton (1997), Goulder *et al*. (1997), Fullerton and Metcalf (2001), Bento and Jacobsen (2007), and others.[4] This current paper differs from this strand of the literature in several respects. First, in these papers, the policy is chosen by a benevolent dictator, who intends to maximize social welfare; in this model, the policy is determined by a self-interested agent, whose income is below average. Second, this present paper identifies a mechanism that could not be captured in this strand of the literature. As indicated, the voting mechanism and the unequal distribution of the endowments generate the tax-cutting effect and the profit effect, which do not exist in the literature.[5] Third, these papers conclude that the NRR instruments cannot be more efficient than the RR instruments. However, I show that this result does not necessarily hold.

Many of the papers mentioned above have pointed out the infeasibility of the double-dividend hypothesis. They focus on the situation where the pollution tax aggravates the distortion caused by the existing distortionary taxes, which is known as the tax-interaction effect.[6] They argue that the revenue-recycling benefit is not enough to offset both the primary costs of imposing the pollution tax and the tax-interaction effect, and thus the double-dividend hypothesis fails.

By contrast, this model does not have a tax-interaction effect. Instead, the infeasibility of the hypothesis in this paper arises from the unequal distribution of the labor endowment and the policy-making mechanism, which reflects the median voter's preferences. This paper is complementary

[4] Also see the surveys of related papers provided by Goulder (1995) and Bovenberg (1999).

[5] As will become clear later, when the policy-maker seeks to maximize social welfare, the two effects disappear.

[6] In order to highlight the trade-off between the revenue-recycling effect and environmental protection, I assume away the tax-interaction effect by considering a small open economy, such that the price level is given. Because the tax-interaction effect occurs in all types of policy instruments, the introduction of the tax-interaction effect does not qualitatively change the results, while it makes the analysis much more complicated. In addition, the tax-interaction effect also occurs in the presence of existing market imperfections. I assume away this problem by considering competitive markets.

to these studies, and I particularly highlight the interdependence between the two dividends.[7]

Another strand of the literature is concerned with the political economy of the environmental policy instruments.[8] The related papers are numerous, including Buchanan and Tullock (1975), Dewees (1983), Hahn (1990), Aidt (2010), MacKenzie and Ohndorf (2012), and others. These studies focus on the influence of special interest groups, whereas this present paper considers the role played by voters.

There are a number of studies on the voting mechanism and environmental externality. Bergstrom (1979) investigates the conditions under which the public good determined by a majority vote will be efficient. However, I examine the properties of the policies (most of them are inefficient) determined by majority voting. Although the environmental policy has been viewed as a secondary policy issue, List and Sturm (2006) argue that electoral incentives are an important determinant of policy choices on secondary policy issues. They predict when the incumbent will manipulate the secondary policy to attract voters. Alesina and Passarelli (2014) investigate which policy instrument – and at what level – is determined by majority voting in order to reduce pollution. Unlike this model, the above three studies do not examine the use of the pollution tax revenues, nor do they compare the relative efficiency of different types of instruments.

McAusland (2003) addresses how the distribution of factor ownership affects individual and aggregate demand for the environmental policy, which is determined by majority voting. Her model has two types of input, one for the clean goods and the other for the dirty goods. She finds that an increase in a voter's share of an economy's capacity to produce dirty or clean goods can lead the voter to prefer a weaker environmental policy. Unlike her model, this present paper contains only one input. In addition, the use of the tax revenues is my main concern, while in McAusland (2003) the environmental policy does not generate any tax revenues.

Cremer *et al*. (2004) also consider a framework in which the pollution tax rate is determined by a majority voting process. In their model, all of the environmental tax proceeds are refunded through reductions in labor and capital income taxes. They focus on the optimal rule to allocate the refunded tax revenues between the reduction in the labor tax and the reduction in the capital tax. This present paper departs from theirs in at

[7] Bovenberg (1999) discusses the trade-off between equity and efficiency without explicit modeling. He puts the emphasis on the distribution of the environmental benefit, rather than on the political aspect of the revenue-recycling effect.

[8] Oates and Portney (2003) provide a survey of the related papers, although they focus on the influence of special interest groups and environmental federalism.

least two ways. First, the settings are quite different.[9] Second, they do not address the issue of the double-dividend hypothesis and the relative efficiency of different types of instruments.

Kempf and Rossignol (2007) investigate the relationship between inequality and environmental protection in a growth model from a political economy perspective. In their model, the resources devoted to stimulating economic growth or to protect the environment are determined by heterogeneous individuals, who have won different capital endowments. Because the relatively poor agents receive a relatively high marginal utility from consumption, they are more interested in stimulating economic growth at the expense of a clean environment. The poorer the median voter relative to the average agent, the more resources that will be used to sustain the economic growth, and the more degraded the environment will be. Unlike Kempf and Rossignol (2007), in this present paper a decline in the median voter's relative income can either improve or worsen the environmental quality, depending on the tax-cutting effect and the profit effect. Even though there emerges an adverse effect of income inequality on the environmental protection, the reasoning is different from that in Kempf and Rossignol (2007), because they do not have effects similar to the tax-cutting and the profit effects.

III. The Model

The basic model is inspired by Fullerton and Metcalf (2001).[10] A small open economy is populated by heterogeneous individuals who own a single resource and sell it in the market to earn income. To fix the idea, I refer to the resource as the time available for labor supply.

There are N individuals. Individual i's preferences are given by[11]

$$U^i = x^i + u(y^i) + v(h^i) - \phi(Z) + \mu(G). \tag{1}$$

The above equation says that individual i receives utility from a clean good (x^i), a polluting good (y^i), leisure (h^i), and a public good (G). Individual i also receives disutility from pollution (Z). Individuals' utility functions have the properties that $u' > 0$, $u'' < 0$, $v' > 0$, $v'' < 0$, $\mu' > 0$, $\mu'' < 0$, $\phi' > 0$, and $\phi'' > 0$.

[9] For example, Cremer *et al*. (2004) assume that both labor and capital income are exogenously determined, while the income is an endogenous variable in my model.

[10] Fullerton and Metcalf (2001) consider homogeneous individuals, and they do not take the voting mechanism into consideration.

[11] In the political economy literature, separable preferences are common settings; see, for example, Persson and Tabellini (1992, 2000), Cremer *et al*. (2004), and others. This specification helps us to derive analytical solutions more easily.

The production of both the clean good and the polluting good uses labor. The production of y generates pollution, while that of x does not. The two goods can be imported or exported without any tariffs or subsidies. The firms in each industry are assumed to be homogeneous, and the number of firms in each industry can be normalized to unity.

A unit of x is defined as the amount that can be produced using one unit of labor, so that the production function of x is given by

$$X = L_x, \tag{2}$$

where X is the domestic production of the clean good, and L_x denotes the labor used to produce this good. The clean good is the numeraire good, and its price is equal to unity. The linear production technology implies that the wage rate in industry x is equal to one. Moreover, as individuals can freely choose to supply labor in either industry x or industry y, or both, the wage rate in both industries is equal to unity.

The domestic production of good y is characterized by

$$Y = F(L_y), \tag{3}$$

where Y denotes the domestic production of good y, L_y represents the labor demanded in industry y, and the function F has the properties that $F' > 0$ and $F'' < 0$.

As indicated, the production of good y generates pollution, which is denoted by Z. The objective function of the representative polluting firm is given by

$$\Pi = pF(L_y) - L_y - tZ + R, \tag{4}$$

where p is the international price of y, and t is the pollution tax rate imposed per unit of pollution emitted. The variable R denotes the rebated pollution tax revenues. When determining the output, the firm treats t and R as given. The determination of t and R is discussed later.

The amount of pollution emissions increases with the domestic production of y. Because the output of y is a function of L_y, the emission amount can be expressed as a function of L_y (i.e., $Z = Z(L_y)$), with the properties that $Z' > 0$ and $Z'' > 0$. Inserting this function into equation (4), and then differentiating equation (4) with respect to L_y gives the following first-order condition of the polluting firm's profit-maximization:

$$\frac{\partial \Pi}{\partial L_y} = pF' - 1 - tZ' = 0. \tag{5}$$

A comparative statics exercise shows that L_y decreases with t.[12]

[12] The effect of t on L_y is $\partial L_y / \partial t = Z'/(pF'' - tZ'') < 0$.

Now I turn to the individual's consumption decision. Following Persson and Tabellini (2000), I assume that the productivity of individuals differs. Higher productivity is equivalent to an individual having more effective time available. Thus, individual i's time constraint is given by

$$h^i + l^i = 1 + e^i, \tag{6}$$

where l^i is i's labor supply, and e^i captures i's productivity. Individuals with greater productivity have a larger effective time endowment. The mean value and the median value of the distribution of e^i are denoted by $\bar{e}$ and e^m, respectively. I assume that e^m is less than $\bar{e}$.[13]

The labor income is subject to a labor tax at the rate of τ. Individual i's budget constraint is given by

$$x^i + py^i = (1 - \tau)l^i + \alpha^i \Pi. \tag{7}$$

In equation (7), we recall that the wage rate is equal to unity, and $\alpha^i \geqslant 0$ denotes the share of the polluting firm's profit accruing to individual i.[14]

Individual i maximizes the utility function (1), subject to the time constraint (6) and the budget constraint (7). Note that when making consumption decisions, individuals treat the pollution amount Z, the profit income $\alpha^i \Pi$, and the amount of the public good G as given.

The first-order conditions of individual i's utility-maximization are given by

$$u'(y^i) = p, \tag{8}$$

$$v'(1 + e^i - l^i) = 1 - \tau. \tag{9}$$

From equation (8), we solve individual i's demand for the polluting good as $y^i = u'^{-1}(p)$. Two implications arise from the demand function. First, the demand for y is a function of p only. Second, it implies that $y^i = y^j$ and $i \neq j$ (i.e., all people consume the same amount of y).[15] This result allows us to concentrate on the source side of the incidence of the environmental regulation.

According to equation (9), we obtain individual i's labor supply function as

$$l^i = l(\tau) + e^i - \bar{e}, \tag{10}$$

[13] The income distribution is generally skewed to the right, implying that the median income is less than the mean income. Thus, this setting is consistent with the stylized fact.

[14] The linear technology in industry x ensures that there is no excess profit that can be distributed to the shareholders of the clean firm. In Section VI, I briefly discuss the case where the polluting industry earns profits.

[15] This result implies that the tax burden relative to the income of the poor is higher than that of the rich, so that the pollution tax is regressive. This consequence is consistent with the empirical works (e.g., Klinge Jacobsen *et al.*, 2003; Wier *et al.*, 2005).

where $l(\tau) = 1 + \bar{e} - v'^{-1}(1 - \tau)$, recalling that $\bar{e}$ is the mean of the distribution of e^i. Equation (10) shows that each individual's labor supply increases with their productivity, and that l^i decreases with τ, because of $v'' < 0$.

IV. Equilibrium Pollution Tax Rate

The timing of events unfolds as follows. First, people vote for the pollution tax rate, which determines the stringency of environmental regulation. Then, given the pollution tax rate, consumers and firms make decisions.

All the related economic decisions in the second stage have been introduced in Section III. I now move on to the first stage to determine the pollution tax rate. I first discuss individual i's ideal pollution tax rate t^i, which is the tax rate maximizing i's utility function.

When determining t^i, individual i takes two constraints into consideration. The first is the overall resource constraint:[16]

$$\sum_{i=1}^{N} l^i = L_x + L_y. \tag{11}$$

The second constraint is the government budget constraint, which is given by

$$\tau \sum_{i=1}^{N} l^i + \lambda t Z = G, \tag{12}$$

where $\lambda \in [0, 1]$ denotes the proportion of pollution tax revenues used to finance the public good, and G is an exogenously determined constant. As will become clearer later, λ is an important parameter in the analysis.

Equation (12) states that the revenues from both the labor tax and the pollution tax are used to finance a constant level of public expenditure; in other words, this paper considers a revenue-neutral tax reform. By introducing λ, the polluting firm's tax rebate R can be expressed as $(1 - \lambda)tZ$ in the first stage. In addition, I assume that the maximum value of tZ is less than G, meaning that only the pollution tax revenues are not sufficient to finance the public good, and thus τ is always greater than zero.

The setting of λ and the pollution tax rate can be interpreted more broadly. It is well known that under certain conditions, a pure pollution tax ($\lambda = 1$) is equivalent to an auctioned tradable emission permit scheme. Another example is that a pollution tax that includes rebating all tax revenues ($\lambda = 0$) is equivalent to a scheme of grandfathered tradable

[16] In item 1 of the Appendix, I demonstrate that the overall resource constraint is equivalent to the balance-of-trade constraint.

emission permits.[17] The intermediate schemes can be captured by setting $\lambda \in (0,1)$. In 2013, the European Union (EU) emission trading system auctioned over 40 percent of the allowances (European Commission, 2016), and then λ was greater than 0.4. As a result, different values of λ represent different types of policy instruments (Pezzey, 1992).[18] The parameter λ is exogenously determined;[19] doing so helps us to highlight the effect of λ on the stringency of environmental regulation.

The parameter λ is related to the impact of t on the labor tax rate. Specifically, given a particular λ, the relationship between t and τ is characterized by

$$\frac{\partial \tau}{\partial t} = -\frac{\lambda(1-\eta)Z}{N(1-\varepsilon)l}, \tag{13}$$

where $\varepsilon = -(\partial l/\partial \tau)\cdot(\tau/l) > 0$ denotes the elasticity of the average value of labor supply (l) with respect to τ, and $\eta = -(\partial Z/\partial t)\cdot(t/Z) > 0$ represents the elasticity of the pollution emission with respect to t. Most of the empirical evidence shows that the labor supply is quite inelastic, so I assume that ε is less than unity. The empirical evidence also indicates that the elasticity of pollution emissions with respect to t is generally inelastic as well, and thus η is assumed to be less than unity (see Tietenberg, 1999).[20] Other things being the same, a larger λ brings about a greater decline in τ resulting from an increase in t. If $\lambda = 0$, then τ is independent of t.

To obtain the first-order condition of individual i's optimization, we can totally differentiate U^i with respect to t, and after some manipulations we derive[21]

[17] In 1992, the Swedish government levied a tax on NO_x, and returned all the proceeds to the polluting firms. In this case, λ was equal to zero. In the US, the SO_2 allowance trading system gave permits to polluters without charge, so that λ was also equal to zero.

[18] Many related political economy papers divide the policy instruments into two categories: quantity-control instruments and price-control instruments. In these papers, the adoption of quantity-control instruments generally implies that the scarcity rents accrue to polluters, while the adoption of price-control instruments implies that the rents belong to the general public. According to Goulder *et al*. (1997), what does matter is whether the instrument is RR or NRR, instead of whether the instrument is a quantity-control or price-control instrument. The setting follows the suggestion of Goulder *et al*. (1997).

[19] I endogenize λ in Section VI.

[20] I acknowledge that some studies estimate η as being greater than unity (e.g., Lee and Misiolek, 1986). However, in the case with $\eta > 1$, the pollution tax rate is positively related to the labor tax rate. This seems unlikely to happen, and thus I focus on the regular case where an increase in t reduces the labor tax rate.

[21] See item 2 in the Appendix for the derivation.

$$\frac{\partial U^i}{\partial t} = \tau \frac{\partial l}{\partial t} + \frac{1}{N}(t - N\phi')\frac{\partial Z}{\partial t} + (\bar{e} - e^i)\frac{\partial \tau}{\partial t} + \left(\alpha^i - \frac{1}{N}\right)\frac{\partial \Pi}{\partial t} = 0. \tag{14}$$

Individual i's ideal tax rate is characterized by the above equation. According to equation (14), t^i depends on several factors. I discuss each factor in turn.

Let us first examine the second term in the middle of equation (14). This term reflects the effect of t on the environmental deterioration. The welfare impact of an increase in t is equal to the difference between the rate of the pollution tax, which measures the decline in tax revenues due to a narrower pollution tax base, and a term representing the marginal social damage from pollution. In the case where all terms equal zero except for the second term in equation (14), t^i is simply equal to the Pigouvian tax (i.e., $t^i = N\phi'$). The presence of the other terms causes t^i to deviate away from the Pigouvian tax.

The first term, $\tau \cdot (\partial l / \partial t)$, measures the effect of t on the labor supply. Equation (9) and the comparative statics result ensure that a positive τ results in a suboptimally low level of labor supply. As indicated above, when $\lambda > 0$, an increase in t reduces τ, which in turn increases the labor supply and mitigates the distortion in the labor market. This effect is known as the revenue-recycling effect.

We note that this paper contains two types of revenue-recycling effect: one arises from a change in the pollution tax rate, while holding λ constant, and the other is related to a change in λ, given the pollution tax rate. Both can lower the labor tax rate, and both encourage the labor supply. To distinguish the two effects, I refer to the effect of a change in t as the revenue-recycling effect of t, and to the other as the revenue-recycling effect of λ.

As long as λ is positive, the revenue-recycling effect of t is positive, leading individual i to prefer a higher t. If $\lambda = 0$, implying $\partial\tau / \partial t = 0$, then the revenue-recycling effect of t vanishes.

The third factor, $(\bar{e} - e^i) \cdot (\partial\tau / \partial t)$, measures the welfare impact of the labor tax relief due to a change in t. This effect is referred to as the tax-cutting effect. When $\lambda = 0$, this effect no longer exists. When $\lambda > 0$, the benefit of the tax relief increases with individuals' productivity. With a positive λ, if individual i's productivity is smaller than $\bar{e}$, then i receives a negative tax-cutting effect. A negative tax-cutting effect causes t^i to be lower than the ideal t of the average individual. This is because an increase in t augments the tax burden of all people by the same amount on the expenditure side (recall that all individuals consume the same amount of y), while the benefit of the labor tax relief is relatively small for an individual whose productivity is below the mean level. As a result, the ideal t of individual i whose productivity is less than $\bar{e}$ is lower than that of the average individual. As shown below, the average individual's ideal t is equal to the pollution tax rate that maximizes social welfare. On the contrary, if e^i is greater than $\bar{e}$, then individual i receives a positive tax-cutting effect, and t^i is higher than the ideal t of the average individual.

The last factor, $[\alpha^i - (1/N)](\partial\Pi/\partial t)$, reflects the effect of t on the polluting firm's profit, which in turn affects individual i's welfare. This effect is referred to as the profit effect. The sign of $\partial\Pi/\partial t$ is given by

$$\frac{\partial\Pi}{\partial t} = -[1-(1-\lambda)(1-\eta)]Z. \tag{15}$$

With the assumptions that $\lambda \in [0,1]$ and $\eta < 1$, $\partial\Pi/\partial t$ is negative, meaning that an increase in t reduces the polluting firm's profit.

Individual i has dual roles associated with the polluting firm's profit, being both a consumer and a shareholder of the polluting firm. As a shareholder, a lower profit means a reduction in individual i's utility, while as a consumer, a lower profit implies that fewer resources are extracted by the polluting firm. When α^i is equal to the average level, $1/N$, the two forces are offset exactly. If α^i is less than $1/N$, then i receives a net benefit from a decline in the profit due to an increase in t (i.e., i has a positive profit effect, so that t^i is higher than the ideal t of the average individual). By contrast, if α^i is greater than $1/N$, then individual i receives a negative profit effect, and thus t^i is less than the ideal t of the average individual.

We note that both the tax-cutting effect and the profit effect arise from the voting mechanism and the unequal distribution of the endowments. If the policy-maker seeks to maximize the social welfare, or if all people have the same income, then the two effects vanish.

Before turning to the determination of the equilibrium pollution tax rate, I derive the pollution tax rate that maximizes the social welfare as a benchmark. The social welfare, denoted by W, is defined as the sum of the utilities of all individuals. The optimal tax rate, denoted by t^*, can be obtained by summing up equation (14) over all individuals, and we have

$$\frac{\partial W}{\partial t} = \frac{\partial(\sum_j U^j)}{\partial t} = \frac{Z}{N}\left[\frac{\lambda\varepsilon(1-\eta)}{1-\varepsilon} - (t - N\phi')\frac{\eta}{t}\right] = 0; \tag{16}$$

in deriving the above equation, I use equation (13).

From equation (16), the socially optimal pollution tax rate is solved as follows:

$$t^* = \frac{N\phi'}{1-[\lambda\varepsilon(1-\eta)/\eta(1-\varepsilon)]}. \tag{17}$$

The numerator of t^* measures the aggregate marginal environmental disutility, and the second term in the denominator reflects the revenue-recycling effect of t. Three remarks are made here: (i) t^* increases with λ due to the revenue-recycling effect of t; (ii) when $\lambda = 0$, t^* is equal to the Pigouvian tax; (iii) t^* is the average individual's ideal pollution tax rate.

I move on to the determination of the equilibrium pollution tax. It seems reasonable that a large share of the profit accrues to an individual with a larger productivity, and thus I assume that individual i's share of Π is an increasing function of e^i. To illustrate the results as clearly as possible, α^i is specified as

$$\alpha^i = \frac{e^i}{\sum_j e^j} = \frac{e^i}{N\bar{e}}. \tag{18}$$

With equation (18), the average individual's α is equal to $1/N$, and thus individual i's profit effect is equal to zero. If individual i's productivity is less (resp. greater) than $\bar{e}$, then their profit effect is positive (resp. negative).

The condition $\lambda > 0$ and other assumptions mentioned ensure that individual i's ideal pollution tax rate monotonically increases with their productivity. Formally, the individuals' preferences satisfy the single-crossing condition, ensuring the existence of a Condorcet winning tax rate.[22] The Condorcet winning tax rate, or the equilibrium tax rate, is the ideal tax rate of the individual with the median productivity.[23]

With the help of equation (13), the equilibrium tax rate is characterized by the median voter's first-order condition of the utility maximization:

$$\begin{aligned}\frac{\partial U^m}{\partial t} = \frac{Z}{N}\Bigg[&\frac{\lambda\varepsilon(1-\eta)}{1-\varepsilon} - (t - N\phi')\frac{\eta}{t} - (1-\sigma) \\ &\times \Bigg\{ \underbrace{\frac{\lambda(1-\eta)\bar{e}}{l(1-\varepsilon)}}_{A} \underbrace{-[1-(1-\lambda)(1-\eta)]}_{B} \Bigg\}\Bigg] = 0.\end{aligned} \tag{19}$$

The parameter σ, which is equal to $e^m/\bar{e}$, represents the ratio of the median productivity to the mean productivity. Because e^m is less than $\bar{e}$, σ is less than unity. This ratio characterizes the inequality of endowment distribution in this economy. The smaller σ is, the more unequal the endowment distribution.

[22] See Chapter 2 of Persson and Tabellini (2000) for details.

[23] This paper implicitly assumes the Condorcet method as the voting rule (i.e., it elects the pairwise champion). Most of the majority voting literature makes this assumption. The proof of the median voter theorem depends on the Condorcet method.

The product of $-(1-\sigma)$ and A in equation (19) represents the tax-cutting effect, and the product of $-(1-\sigma)$ and B reflects the profit effect. Because σ is less than unity, the median voter receives a negative tax-cutting effect, meaning that the median voter obtains less benefit from the labor tax relief than the average individual. The negative tax-cutting effect leads the median voter to choose a pollution tax rate below t^*.

The above result can be interpreted in an alternative way. Because the benefit of labor tax relief increases with people's productivity, it is regressive. The higher the pollution tax rate, the more regressive the labor tax relief, and the lower the median voter's relative income position. This causes the median voter to prefer a lower t to mitigate the problem of regressiveness.

The regressiveness arising from refunding pollution tax revenues has been receiving attention. The empirical evidence shows that the support for environmental taxation decreases as the concern for the regressive impact of the tax increases (Kallbekken and Sælen, 2011). Some actual carbon tax policies have been designed to involve lump-sum subsidies to avoid the regressiveness from cutting labor tax (Goulder, 2013).[24] Other scholars also recommend other measures to mitigate the regressiveness of the labor tax relief (e.g., Clinch *et al.*, 2006). According to the evidence mentioned, the regressiveness of refunding pollution tax revenues is an important issue in designing environmental policy.[25]

However, because the term B is less than zero, the median voter receives a positive profit effect. As the average individual's profit effect is equal to zero, a positive profit effect ensures that the median voter chooses a pollution tax rate that is higher than t^*. The reason for this is that an increase in t diminishes the polluting firm's profit, and thus reduces the income extracted by the polluting firm. Although a larger t also lowers the median voter's profit income, because he owns a relatively small share of the profit, the decline in the profit income is smaller than the reduced income extraction. Thus, the median voter prefers a higher pollution tax rate.

From equation (19), the equilibrium pollution tax rate can be solved as follows:

[24] For example, in 2008 the Canadian province of British Columbia implemented a carbon tax program, in which a large fraction of the tax revenues were directly rebated to households. Also see Harrison (2012).

[25] It is well known that voters are also concerned with other factors, including the environmental effects of the environmental policy. Here I focus on the distributional issue. This approach reflects the argument made by Hahn and Stavins (1992), who put forward the view that the making of the environmental policy involves trade-offs among multiple objectives, including efficiency, equity, political feasibility, and others.

$$t^{\circ} = (N\phi')\left[1 - \frac{\lambda\varepsilon(1-\eta)}{\eta(1-\varepsilon)} + \frac{1-\sigma}{\eta} \times \left\{\frac{\lambda(1-\eta)\bar{e}}{(1-\varepsilon)l} - [1-(1-\lambda)(1-\eta)]\right\}\right]^{-1}. \tag{20}$$

A comparison of equations (20) and (17) indicates that, in addition to reflecting the aggregate environmental disutility and the revenue-recycling effect of t, the equilibrium pollution tax has two more components: the tax-cutting effect and the profit effect. According to equation (20), when the two forces exactly offset each other, then the remaining environmental concern and the revenue-recycling effect lead t° to be the same as t^*. If the tax-cutting effect outweighs the profit effect, then t° is less than t^*. By contrast, with a dominant profit effect, the median voter prefers a higher t, so that t° is greater than t^*, and thus the environmental regulation is excessively stringent.

In what follows, I derive the conditions under which either the tax-cutting effect or the profit effect is dominant. From equation (20), if $\bar{e} \leqslant (1-\varepsilon)l$, then the profit effect outweighs the tax-cutting effect. If $\bar{e} > (1-\varepsilon)l$, then there exists a threshold value for λ, $\hat{\lambda}$, which is given by

$$\hat{\lambda} = \frac{\eta(1-\varepsilon)l}{(1-\eta)[\bar{e}-(1-\varepsilon)l]}. \tag{21}$$

If the actual λ is greater than $\hat{\lambda}$, then the tax-cutting effect is dominant. If the actual λ is less than $\hat{\lambda}$, then the profit effect is dominant.

The following proposition summarizes the relationship between the equilibrium pollution tax rate and the optimal tax rate:

Proposition 1. *(a) If $\bar{e} \leqslant (1-\varepsilon)l$, then the profit effect is dominant, and t° is greater than t^*. (b) When $\bar{e} > (1-\varepsilon)l$: (i) if the actual λ is greater than $\hat{\lambda}$, then the tax-cutting effect is dominant, and t° is smaller than t^*; (ii) if the actual λ is smaller than $\hat{\lambda}$, then the profit effect is dominant, and t° is greater than t^*; (iii) if the actual λ is equal to $\hat{\lambda}$, then t° is equal to t^*.*

Equation (20) indicates that t° depends on several factors, and I focus on two of these: one is how different types of instruments (λ) affect t°, and the other is the effect of the median voter's relative position on the income scale on t°. I deal with the second issue here, and leave the first issue to the next section.

The ratio σ can be seen as an inequality index in an economy; see Chapter 6 of Persson and Tabellini (2000), and Kempf and Rossignol (2007). The smaller the value of σ, the more unequal this economy is.

Equation (20) shows that the relationship between the inequality and t° is ambiguous, depending on the relative magnitude of the tax-cutting effect and the profit effect.

When the tax-cutting effect outweighs the profit effect, the higher the inequality (a smaller σ), the stronger the incentive a median voter has to choose a lower t, which mitigates the regressiveness of the labor tax relief. Thus, a larger inequality is harmful to the environment. However, if the profit effect prevails, an increase in the inequality leads the median voter to choose a higher t in order to reduce the polluting firm's profit. As a result, a higher degree of inequality is beneficial to the environment.

The following proposition summarizes the above results.

Proposition 2. *When the tax-cutting effect outweighs the profit effect, the higher the inequality (the smaller that σ is), the lower t° is. When the profit effect is dominant, the higher the inequality, the greater t° is.*

Proposition 2 also implies the relationship between t° and e^m. When other things are the same, because $\sigma = e^m/\bar{e}$, σ increases with e^m. Combining this result with Proposition 2 gives the following corollary.

Corollary 1. *If the tax-cutting effect outweighs the profit effect, then t° increases with e^m. If the profit effect dominates the tax-cutting effect, then t° decreases with e^m.*

Some empirical works, which are based on the data from referenda on environmental policy, indicate that voters with higher incomes are willing to pay more for a cleaner environment than lower-income voters; that is, the environmental quality is a normal good (Deacon and Shapiro, 1975; Kahn and Matsusaka, 1997; Elliott *et al*., 1995; Salka, 2003; Kotchen and Powers, 2006; Nelson *et al*., 2007). Such an observed voting pattern can be attributed to the regressiveness of the cost of the environmental regulation (Cropper and Oates, 1992). According to the empirical evidence, it seems that the tax-cutting effect is dominant.[26]

V. Interdependence between the Two Dividends

Pollution Tax Rate under Different Values of λ

In this section, I investigate the equilibrium pollution tax rate under different types of policy instruments (i.e., different values of λ). In most of the literature regarding the double-dividend hypothesis, the stringency

[26] These studies estimate the effects of socio-economic variables on the voting patterns, and they do not focus on the rule of allocating environmental tax revenues. However, as the tax-cutting effect generates the regressiveness problem, these empirical works are related to the results of this paper.

of environmental regulation is independent of the use of the pollution tax revenues. However, the above analysis has shown that once the pollution tax rate is endogenized, this tax rate depends on how the tax revenues are used (or the value of λ).

We can identify the change in λ from the data. One approach is to compare the regulations of different jurisdictions on the same pollutant. The tax on NO_x is an example. Both France and Sweden have imposed taxes on NO_x. The tax revenues are used to cut other taxes in France, so that $1-\lambda$ is equal to zero. The Swedish government returns all the tax revenues to the polluting firms, and thus $1-\lambda$ is equal to unity. The EU emission trading system also provides us with an opportunity to identify changes in λ from the data. Before 2013, most of the allowances were given away for free. Beginning in 2013, auctioning became the main method of allocating allowances. The EU legislation sets the goal of phasing out free allocation completely by 2027. These events imply that λ has been increasing over the years.

The effect of λ on t° can be obtained by differentiating equation (20) with respect to λ:

$$\begin{aligned}\frac{\partial t^\circ}{\partial \lambda} = & \left\{ N\phi' \frac{(1-\eta)}{(1-\varepsilon)\eta l}[\varepsilon l - (1-\sigma)\bar{e} + (1-\sigma)(1-\varepsilon)l] \right\} \\ & \times \left\{ \left[1 - \frac{\lambda\varepsilon(1-\eta)}{\eta(1-\varepsilon)} + \frac{1-\sigma}{\eta} \right.\right. \\ & \left.\left. \times \left\{ \frac{\lambda(1-\eta)\bar{e}}{(1-\varepsilon)l} - [1-(1-\lambda)(1-\eta)] \right\} \right]^2 \right\}^{-1}. \qquad (22)\end{aligned}$$

Equation (22) shows that the sign of $\partial t^\circ/\partial\lambda$ depends on the terms in the square brackets of the numerator. Among these terms, εl reflects the impact of λ on the revenue-recycling effect of t. With a larger λ, equation (13) shows that an increase in t causes a greater decline in τ, and thus strengthens the revenue-recycling effect of t. The stronger revenue-recycling effect of t brings about a higher t°.

The term $-(1-\sigma)\bar{e}$ measures the impact of λ on the tax-cutting effect. Given the fact that the labor tax decreases with λ,[27] a larger λ increases the regressiveness of the labor tax relief, and thus strengthens the tax-cutting effect, leading to a lower t°.

The last term $(1-\sigma)(1-\varepsilon)l$ represents the effect of λ on the profit effect. This term is positive because, given the same increase in t, a larger λ can prevent the polluting firm from extracting more resources. Thus,

[27] Given the pollution tax rate, the effect of λ on the labor tax rate is given by $\partial\tau/\partial\lambda = -[(tZ)/Nl(1-\varepsilon)] < 0$.

an increase in λ enlarges the profit effect, and the median voter prefers a higher pollution tax rate.

Because these forces do not work in the same direction, the net effect of an increase in λ on t° is ambiguous. For the ease of exposition, let us denote the value of $\varepsilon l - (1-\sigma)\bar{e} + (1-\sigma)(1-\varepsilon)l$ as γ. Depending on the value of γ, three possible cases emerge.

1. If γ is equal to zero, then t° is invariant with λ. Even though different values of λ give rise to the same level of environmental protection, they have different welfare consequences. To see this, we totaly differentiate the social welfare function $W = \sum_{i=1}^{N} U^i$ with respect to λ, which gives

$$\frac{dW}{d\lambda} = \frac{\partial W}{\partial \lambda} + \frac{\partial W}{\partial t}\frac{\partial t^{\circ}}{\partial \lambda}. \tag{23}$$

   The first term on the right-hand side of equation (23) is the direct effect of λ on social welfare, given the pollution tax rate. The second term is the indirect effect, in which λ affects social welfare through changing t°.

   The direct effect can be obtained by partially differentiating the social welfare function with respect to λ, which is given by

$$\frac{\partial W}{\partial \lambda} = \frac{\varepsilon t^{\circ} Z}{N(1-\varepsilon)} > 0. \tag{24}$$

   Equation (24) reveals that the direct effect is positive. This is because an increase in λ lowers the labor tax, and stimulates the labor supply.

   When γ is equal to zero, t° is invariant with λ, so that the indirect effect vanishes. The remaining direct effect ensures that social welfare increases with λ. This means that a policy with a higher λ (λ_h) is more efficient than one with a lower λ (λ_l).

2. If γ is less than zero, then t° decreases with λ. This result means that there exists a trade-off between protecting the environment and using the pollution tax revenues to reduce the distortionary labor tax. Therefore, the double-dividend hypothesis is infeasible.

   A welfare implication of this result is that λ_h is not necessarily more efficient than λ_l. When γ is less than zero, a change in λ has a larger impact on the tax-cutting effect than on the profit effect; this is because, among the three terms in γ, only the change in the tax-cutting effect is negative. The dominant tax-cutting effect leads t° to be less than t^*, and thus $\partial W(t^{\circ})/\partial t$ is positive. This result, along with a negative γ, leads to a negative indirect effect of λ on social welfare. The negative indirect effect can be explained as follows: a larger λ depresses the already suboptimally low pollution tax rate even more, and thus reduces social welfare. If the indirect effect is large enough, then λ_h is less efficient than λ_l.

3. If γ is greater than zero, then t° increases with λ. In this case, an increase in λ not only enlarges the labor supply, but it also raises t°. Because the use of pollution tax revenues to cut labor tax reinforces environmental protection, the double-dividend hypothesis is upheld.

   Given this result, it is tempting to conclude that λ_h must be more efficient than λ_l. However, this is not true. When γ is greater than zero, the impact of λ on the profit effect can outweigh the impact of λ on the tax-cutting effect, leading t° to be greater than t^* (or, equivalently, leading $\partial W(t^\circ)/\partial t$ to be negative). Combining this result with the positive relationship between λ and t°, we obtain a negative indirect effect of λ on social welfare. The negative indirect effect arises because an increase in λ pushes the already excessively high t° further away from the efficient level, and it reduces social welfare. Thus, λ_h is not necessarily more efficient than λ_l, even if there is no conflict between the two dividends.

We note that in the cases where $\gamma = 0$ and $\gamma < 0$, the NRR instruments cannot be more efficient than the RR instruments.[28] However, when $\gamma > 0$, the welfare superiority of the NRR instruments is possible, which requires $dW(\lambda = 0)/d\lambda$ to be less than zero. Item 3 of the Appendix shows that $dW(\lambda = 0)/d\lambda$ has the same sign as $\varepsilon\sigma l - \eta(1-\sigma)(1-\eta)\gamma$. The value of $\varepsilon\sigma l - \eta(1-\sigma)(1-\eta)\gamma$ is negative if and only if the NRR instruments are more efficient than the RR instruments.

To satisfy the condition that $\varepsilon\sigma l - \eta(1-\sigma)(1-\eta)\gamma$ is less than zero, two parameters are important. The first parameter is ε, the labor elasticity. The smaller ε is, the more likely that the condition is satisfied. The reason for this is straightforward. Let us consider an extreme case, in which ε is equal to zero. In this case, the RR instruments do not generate the revenue-recycling effect, and thus the direct welfare effect of λ vanishes. An increase in λ only has a negative indirect welfare effect, so that the RR instruments are less efficient than the NRR instruments.

The second parameter is σ, the inequality index. The smaller σ is, the more likely it is that the NRR instruments give rise to a higher level of

[28] Because the NRR instruments do not generate the tax-cutting effect, the profit effect prevails, and thus $\partial W(t^\circ)/\partial t$ is negative. When $\gamma < 0$, a negative $\partial W(t^\circ)/\partial t$ ensures a positive indirect effect of λ on social welfare, so that the NRR instruments must be less efficient than the RR instruments.

social welfare than the RR instruments. A smaller σ brings about a larger positive impact of λ on t° (see equation (A12) in item 3 of the Appendix). The reason for this is that when the distribution of the endowments is more unequal (a smaller σ), the problem of regressiveness caused by an increase in λ will be more severe, so that the median voter will raise t to a greater extent to mitigate the regressiveness. This larger positive impact of λ on t° strengthens the indirect welfare effect, making it more likely to outweigh the positive direct effect. Incidentally, when the distribution of the endowments is perfectly equal (i.e., $\sigma = 1$), $\varepsilon\sigma l - \eta(1-\sigma)(1-\eta)\gamma$ is positive. Thus, in a representative agent model, the NRR instruments are less efficient than the RR instruments.

The Critical Value of $\hat{\sigma}$

Equation (22) shows that $\partial t^{\circ}/\partial\lambda$ has the same sign as γ. By inserting the data for ε, l, σ, and $\bar{e}$ into γ, we can determine the relationship between t° and λ. However, the data for the distribution of labor endowments (or σ) seem to be unavailable.[29] Instead, in what follows, I derive the critical value for σ, denoted by $\hat{\sigma}$. Once the actual σ is available, comparing the actual σ with $\hat{\sigma}$ can determine whether the pollution tax rate increases or decreases with λ.

To derive $\hat{\sigma}$, I rewrite γ as $\sigma\varepsilon l - (1-\sigma)(\bar{e} - l)$. Then in order to obtain a tractable result, I specify $v(h^i) = \ln h^i$. This specification, along with equation (9), gives $\bar{e} - l = \tau/(1-\tau)$. Inserting the relationship $\bar{e} - l = \tau/(1-\tau)$ into $\gamma = \sigma\varepsilon l - (1-\sigma)(\bar{e} - l)$ gives

$$\operatorname{sign}\left[\frac{\partial t^{\circ}}{\partial\lambda}\right] = \operatorname{sign}\left[\sigma\varepsilon l - (1-\sigma)\left(\frac{\tau}{1-\tau}\right)\right]. \tag{25}$$

From equation (25), $\hat{\sigma}$ is solved as follows:

$$\hat{\sigma} = \frac{\tau}{(1-\tau)\varepsilon l + \tau}. \tag{26}$$

If the actual σ is greater than $\hat{\sigma}$, then t° increases with λ (i.e., the double-dividend hypothesis is feasible). If the actual σ is smaller than $\hat{\sigma}$, then t° decreases with λ, and thus the double-dividend is not sustained.

Equation (26) indicates that $\hat{\sigma}$ depends on the labor elasticity, the labor supply, and the labor tax rate. We also find that $\hat{\sigma}$ increases with τ, and decreases with ε and l. Inserting the data for ε, l, and τ into equation

[29] The Gini coefficient measures the income inequality in a society, while what we need here is a measure for endowment inequality. With the help of an income redistribution policy, a country with a relatively unequal endowment distribution can have a relatively equal income distribution.

Table 1. *Values of $\hat{\sigma}$ across countries*

Country	$\hat{\sigma}$	τ	ε	l
Australia	0.992	0.226	0.011	0.204
Canada	0.839	0.287	0.381	0.203
Germany	0.968	0.359	0.105	0.175
Netherlands	0.944	0.410	0.249	0.167
Sweden	0.955	0.485	0.24	0.184
United States	0.833	0.226	0.280	0.209

(26) gives a country's $\hat{\sigma}$. As an example, Table 1 shows the values of $\hat{\sigma}$ for Australia, Canada, Germany, the Netherlands, Sweden, and the United States.[30] Among these countries, the relatively high $\hat{\sigma}$ for the Netherlands and Sweden is attributed to their high effective tax rates on labor. The low elasticity of labor supply explains the large value of $\hat{\sigma}$ in Australia. When the pollution tax revenues are used to cut the labor tax rate, the countries with a larger $\hat{\sigma}$ should have a more equal distribution of labor endowments to avoid the reverse relationship between t° and λ.

Two policy implications arise. First, the more equal the distribution of the labor endowments in a society, the more likely it is that the double-dividend hypothesis will be upheld. Second, when a country has a relatively high $\hat{\sigma}$, it faces a relatively severe regressivity problem arising from using the pollution tax revenues to cut the labor tax. As suggested by some studies (Clinch *et al.*, 2006), in order to mitigate the regressivity problem, the country can adopt other ways of using the environmental tax revenues, such as distributing pollution tax revenues in a lump-sum manner. Although a lump-sum tax rebate does not generate the revenue-recycling effect, it does eliminate the tax-cutting effect. The remaining profit effect ensures that t° increases with λ.

VI. Discussion and Extensions

This model has made several assumptions. In this section, I discuss these assumptions, and I relax some of them.

Endogenous λ

The parameter λ has been assumed to be fixed, which enables us to investigate the effects of λ on the pollution tax rate and social welfare.

[30] See item 4 of the Appendix for the sources of the data and the derivation of $\hat{\sigma}$ for these countries.

In this subsection, I endogenize λ, such that λ is also determined through majority voting.

I assume that people vote for λ first, and for t next.[31,32] In item 5 of the Appendix, I derive the first-order condition for the equilibrium λ as follows:

$$\frac{\partial U^m}{\partial \lambda} = \frac{tZ}{Nl(1-\varepsilon)}\left[\varepsilon l - (\bar{e} - e^m) - \left(\alpha^m - \frac{1}{N}\right) Nl(1-\varepsilon)\right]. \qquad (27)$$

The first term in the brackets measures the revenue-recycling effect of λ. As indicated in footnote 27, an increase in λ lowers the labor tax rate, which in turn enlarges the labor supply. This term is positive, causing the median voter to choose a larger λ.

The second term reflects the decrease in the median voter's relative income due to an increase in λ. This effect is similar to the tax-cutting effect mentioned above, while it comes from a change in λ, holding t fixed. Because e^m is less than $\bar{e}$, the labor tax relief due to an increase in λ lowers the income of the median voter relative to that of the average individual, so that the median voter prefers a smaller λ.

The last term represents the effect of λ on the polluting firm's profit. Given $\alpha_m < 1/N$, and $\partial\Pi/\partial\lambda = -tZ < 0$, this effect is positive, leading to a higher λ. An increase in λ affects the median voter's welfare through profit in two ways: one is the reduction in his income extracted by the polluting firm, and the other is the decline in his profit income. Because the former effect is stronger for the median voter, he endorses a larger λ.

With the help of $\alpha^m = e^m/N\bar{e}$, equation (27) becomes

$$\frac{\partial U^m}{\partial \lambda} = \frac{\bar{e}tZ}{Nl(1-\varepsilon)}[\varepsilon l - (1-\sigma)\bar{e} + (1-\sigma)(1-\varepsilon)l]. \qquad (28)$$

A comparison of equations (28) and (22) reveals that $\partial U^m/\partial\lambda$ has the same sign as $\partial t^\circ/\partial\lambda$. This implies that whenever the pollution tax rate decreases with λ, the equilibrium λ is equal to zero. When the two dividends reinforce each other, the equilibrium λ is equal to unity.

By endogenizing both the income tax and the pollution tax, Jacobs and de Mooij (2015) find that the two taxes can be set at their optimal level.

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[31] This assumption is to avoid the problem of multiple issues. When multiple issues need to be determined through majority voting, the median voter theorem might fail, even when all voters' preferences are single-peaked. See Chapter 5 in Mueller (2003) for more details.

[32] In the sequential case, the determination of λ has an indirect effect, which is equal to $(\partial U^m/\partial t)(\partial t^\circ/\partial\lambda)$. Because the median voter makes the decision optimally in the stage of choosing t°, $\partial U^m/\partial t$ is equal to zero, and the indirect effect vanishes. Thus, the equilibrium λ is the same under the sequential and the simultaneous voting cases.

Unlike this paper, their taxes are determined by a benevolent government.[33] In this paper, the environmental tax reflects the preferences of the individual with the median labor endowment. The vote-determined environmental tax rate along with λ determines the effective labor tax rate. Given the skewed distribution of the labor endowment, the ideal policy of the median individual is not the same as that of the average individual, so that the vote-determined environmental tax is inefficient. If the model is extended to allow both the income tax and the environmental tax to be determined through majority voting, the two taxes will not be efficient because of the skewed distribution of endowments.

Non-Separable Utility Function

This paper specifies a separable utility function, in which the whole of the income effect is absorbed by the consumption of x. Such a setting enables us to derive the analytical solutions more easily.

The analysis becomes more complicated once the income effect is involved. For example, in the current setting, the consumption of the dirty good only depends on its price. In a more general setting, in which the demand for the dirty good increases with income, a cut in the labor tax increases incomes, and thus enlarges the consumption of the dirty good. The same thing also occurs in the labor supply.

Heterogeneous Preference for Pollution

Preferences toward pollution have been assumed to be identical. I relax this assumption by setting individual i's marginal disutility from pollution as $-\theta^i \phi'(Z)$. The variable θ either increases or decreases with productivity. If θ increases (resp. decreases) with productivity, then the relatively rich (resp. poor) individuals receive greater benefit from environmental regulation.

Given this specification, the equilibrium pollution tax rate becomes

$$t^{\circ} = (N\theta^m \phi') \left[1 - \frac{\lambda\varepsilon(1-\eta)}{\eta(1-\varepsilon)} + (1-\sigma) \times \left\{ \frac{\lambda(1-\eta)\bar{e}}{\eta(1-\varepsilon)l} - [1-(1-\lambda)(1-\eta)] \right\} \right]^{-1}, \tag{29}$$

[33] Another reason why the two policies can be set optimally in their paper is because of the non-conventional definition of the marginal cost of public funds (MCF) that they adopt. Their definition of the MCF also includes the environmental distortion caused by the income tax, which is not contained in the conventional definition.

where θ^m denotes the median voter's θ. The above equation shows that t° increases with θ. Given the positive relationship between θ^m and t°, if θ is an increasing function of the productivity, then t° increases with e^m, whereas if θ is a decreasing function of productivity, then t° decreases with e^m.

The empirical works do not have a definite answer to whether the benefit from environmental regulation is pro-poor or pro-rich (Cropper and Oates, 1992), because the distribution of benefit is generally complicated and uncertain. Cropper and Oates (1992) argue that even when the distribution of benefit is pro-poor, it is likely to be offset (or more than offset) by a regressive pattern of the cost.[34]

Finally, we note that the specification of heterogeneous preferences for pollution only affects the level of t°, while it does not change the effect of λ on t°.

The Clean-Goods Sector Earning Profits

The assumption of linear technology in the clean-goods sector can fix the wage rate, and simplify the analysis. One might wonder what would occur if the clean-goods sector were also to earn profits. To address this question, I consider the situation where the clean-goods sector uses the labor input and a sector-specific input. After subtracting the labor cost, the remaining total revenue (or the profit) accrues to the owners of the sector-specific input. An individual's share of the sector-specific factor is proportional to their productivity.

Allowing the clean-goods sector to earn profits endogenizes the wage rate. With this modification, there emerge at least three additional effects. First, an increase in the pollution tax rate reduces L_y, and some labor shifts to the clean-goods sector, causing the wage rate to fall. Thus, the reverse relationship between the wage rate and the pollution tax rate induces the median voter to choose a lower t.

Second, compared to the case where the wage rate is fixed, the lower wage rate enlarges the dirty firm's profit, and strengthens the profit effect. This causes the median voter to select a higher pollution tax rate.

Third, the lower wage rate increases the profit of the clean-goods sector. However, the income effect due to an increase in t reduces the demand for the clean goods, and thus lowers the profit of the clean-goods sector. The two opposite forces result in an ambiguous effect of t on the profit of the clean-goods sector. Taking the three effects together indicates that allowing

[34] Cropper and Oates (1992) mention several empirical works showing that lower-income groups bear costs that constitute a larger fraction of their income than higher-income classes do.

the clean-goods sector to earn profits introduces more ambiguity. To obtain more definite results, we need more specific forms of the functions.

VII. Concluding Remarks

The double-dividend hypothesis implicitly assumes that the two dividends embedded in the hypothesis are independent. In practice, however, they are closely related to each other. In this paper, I investigate the relationship between the two dividends. If an instrument exploiting a greater revenue-recycling effect results in a lower level of environmental protection, then the double-dividend hypothesis is not upheld.

To address this issue, I set up a model containing heterogeneous individuals, who are endowed with different labor productivity. Given the type of the policy instrument (i.e., the value of λ), individuals vote for the pollution tax rate. The equilibrium pollution tax rate reflects the ideal policy of the individual with median productivity. In addition to the revenue-recycling effect, there are two politically related factors that affect the median voter's decision: the tax-cutting effect and the profit effect. These two effects arise from the voting mechanism and the unequal distribution of the labor endowments. The tax-cutting effect leads the median voter to choose a tax rate lower than the optimal level, and the profit effect brings about an opposite result. The equilibrium pollution tax rate is either above or below the optimal tax rate, depending on which force is stronger.

I find that an instrument that exploits a greater revenue-recycling effect has an ambiguous effect on the pollution tax rate. An increase in λ enlarges both the revenue-recycling effect and the profit effect, increasing the pollution tax rate. A larger λ also strengthens the tax-cutting effect, leading to a lower tax rate. These forces working in opposite directions give rise to the ambiguous relationship between λ and the pollution tax rate.

The above result is also associated with the relative efficiency of the policy instruments. Given the stringency of environmental regulation, the double-dividend hypothesis claims that the RR instruments are more efficient than the NRR instruments, because of the revenue-recycling effect. Once the interdependence of the two dividends is introduced, the opposite consequence can occur. This indicates that the presence or absence of the interdependence can generate different policy implications.

The parameter σ is essential in the analysis. However, it describes the relative income of the median voter, and it is unable to fully characterize the distribution of the income. A better index that can measure the inequality of income would be the variance of income distribution. We can construct a model that contains the variance of income distribution, and also allows people to have different preferences for the equality (i.e., the variance of income distribution). This model can better characterize people's heterogeneous preferences for equality. I believe that this would merit further research.

Appendix

1. *The equivalence between the overall resource constraint and the balance-of-trade constraint*

The balance-of-trade constraint is given by

$$X^d + pY^d + G = X + pY, \tag{A1}$$

where the superscript d denotes the aggregate demand for the two goods. Summing up all individuals' private budget constraints (7) gives

$$X^d + pY^d = (1-\tau)\sum_i l^i + \Pi. \tag{A2}$$

Inserting the above equation into equation (A1) gives

$$(1-\tau)\sum_i l^i + \Pi + G = X^s + pY^s. \tag{A3}$$

Then we insert equations (2) (3) (4), and (12) into equation (A3), and after some manipulation we can obtain equation (11).

2. *The derivation of equation* (14)

Totally differentiating U^i gives

$$dU^i = dx^i + pdy - (1-\tau)dl - \phi' dZ. \tag{A4}$$

From individual i's private budget constraint, we obtain

$$dx^i = (1-\tau)dl - ld\tau - pdy + (\bar{e} - e_i)d\tau + \alpha^i d\Pi. \tag{A5}$$

The aggregate demand for the clean good, which is denoted by X^d, is equal to

$$\sum_j x^j = (1-\tau)\sum_j l^j - p\sum_j y^j + \Pi. \tag{A6}$$

Totally differentiating the above equation gives

$$dX^d = N[(1-\tau)dl - ld\tau - pdy] + d\Pi. \tag{A7}$$

From equation (A7), we solve $(1-\tau)dl - ld\tau - pdy = [dX^d - d\Pi]/N$. Then we insert this relationship into equation (A5) to obtain the following equation:

$$dx^i = \frac{dX^d}{N} + (\bar{e} - e_i)d\tau + \left(\alpha^i - \frac{1}{N}\right) d\Pi. \tag{A8}$$

The next step is to derive dX^d/N. To this end, we totally differentiate the balance-of-trade constraint (A1), and we obtain

$$dX^d = dX^s + pdY^s - pNdy. \tag{A9}$$

Then, by inserting $dX^s = dL_x$ and $dY^s = F'dL_y$ into the above equation, after some algebra, we have

$$\frac{dX^d}{N} = dl + \frac{tZ'}{N} dL_y - pdy. \tag{A10}$$

Finally, by inserting equation (A10) into equation (A8), then by substituting the resulting dx^i into equation (A4), and after some manipulation, we can obtain equation (14).

3. *The derivation of the condition that $dW(\lambda = 0)/d\lambda < 0$.*

Inserting $\lambda = 0$ into equations (20) and (22) gives

$$t^\circ = \frac{N\phi'}{\sigma}, \tag{A11}$$

$$\frac{\partial t^\circ}{\partial \lambda} = \frac{N\phi'(1-\eta)\gamma}{\sigma^2(1-\varepsilon)\eta l}. \tag{A12}$$

In addition, when $\lambda = 0$, we have

$$\frac{\partial W}{\partial t} = -\frac{\eta^2(1-\sigma)Z}{N}. \tag{A13}$$

Then, after inserting these equations and equation (24) into equation (23), and after some manipulations, we obtain

$$\frac{dW(\lambda = 0)}{d\lambda} = \frac{Z\phi'\eta[\varepsilon\sigma l - \eta(1-\sigma)(1-\eta)\gamma]}{(1-\varepsilon)\sigma^2\eta l}. \tag{A14}$$

Because the denominator is positive, equation (A14) has the same sign as $\varepsilon\sigma l - \eta(1-\sigma)(1-\eta)\gamma$.

4. *The sources of data in deriving $\hat{\sigma}$*

The data on labor hours are obtained from the OECD.Stat, and the effective labor tax rates are from Carey and Tchilinguirian (2000). The labor elasticity is taken from Table 2 of Jantti *et al.* (2015), who estimate the net wage elasticity of labor supply for seven countries, including Australia, Canada, Germany, the Netherlands, Sweden, the UK, and the US. Because the estimated labor supply elasticity for the UK is negative (although it is statistically significant), I exclude it from the calculation of $\hat{\sigma}$. Moreover, l has been normalized in deriving $\hat{\sigma}$.

5. *The derivation of equation* (27)

By using the method presented in item 2, we have

$$\frac{\partial U^m}{\partial \lambda} = \tau \frac{\partial l}{\partial \lambda} + \frac{1}{N}(t - N\phi')Z' \frac{\partial L_y}{\partial \lambda} + (\bar{e} - e^m)\frac{\partial \tau}{\partial \lambda} + \left(\alpha^m - \frac{1}{N}\right)\frac{\partial \Pi}{\partial \lambda}. \tag{A15}$$

As L_y only depends on t, $\partial L_y/\partial\lambda$ in the second term on the right-hand side is equal to zero. The first term can be rewritten as $\tau \cdot (\partial l/\partial\tau)\cdot(\partial\tau/\partial\lambda)$. By inserting $\partial\tau/\partial\lambda$ in footnote 27 into the first term, we have

$$\tau \frac{\partial l}{\partial \lambda} = \frac{\varepsilon t Z}{N(1-\varepsilon)} > 0. \tag{A16}$$

Similarly, by inserting $\partial\tau/\partial\lambda$ into the third term, we have

$$(\bar{e} - e^m)\frac{\partial \tau}{\partial \lambda} = -\frac{(\bar{e} - e^m)tZ}{Nl(1-\varepsilon)}. \tag{A17}$$

In addition, as $\partial\Pi/\partial\lambda = -tZ$, the last term can be written as

$$\left(\alpha^m - \frac{1}{N}\right)\frac{\partial \Pi}{\partial \lambda} = -\left(\alpha^m - \frac{1}{N}\right)tZ. \tag{A18}$$

Finally, inserting equations (A16)–(A18) into equation (A15) gives equation (27).

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First version submitted October 2014;
final version received May 2016.