Optimal Green Taxation with Both Emission and Commodity Taxes

Basharat A. K. Pitafi

James A. Roumasset

University of Hawaii at Manoa[φ]

2002 AAEA-WAEA Annual Meeting, Long Beach, CA

JEL Classification: D62, H21, H23

Keywords: Second-best environmental taxation, Pigouvian taxation, tax normalization, Revenue recycling, Tax interaction

Abstract:

Several authors have argued that the second-best environmental tax on a "dirty good" is less than the marginal emission damage associated with its consumption. These studies limit their analysis to cases in which emissions can only be reduced by a proportional reduction of the "dirty" good. With a more general specification of technology that allows emissions to be directly as well as indirectly taxed, we show that the direct emission tax cannot be less than its marginal emission damage, regardless of the normalization.

[φ] 542 SSB, 2424 Maile Way, Honolulu, HI 96822. Fax: (808) 956-4347. basharat@hawaii.edu.
Authors want to thank Kwong Soo Cheong, Gerard Russo, and Katerina Sherstyuk for helpful comments.

1. Introduction

The question of the second-best environmental taxation has become important during the past decade, especially as it relates to the moderation of global warming. The size of the optimal environmental tax in relation to the marginal environmental damage and whether the tax provides a "double dividend" remains controversial however.

Early contributions stressed the additional benefits (denoted as the "revenue-recycling" effect by Parry, 1995) of using environmental tax revenue to reduce the excess burden of pre-existing taxes [Nichols 1984, Terkla 1984, Lee and Misiolek 1986, Pearce 1991, Repetto *et. al.* 1992]. Nordhaus (1993), for example, using the DICE framework, empirically derived large carbon taxes when such revenue recycling was allowed, and much smaller taxes when it was not allowed. These studies implicitly assumed that environmental taxes have no excess burden as initially suggested by Tullock (1967).

In contrast, Bovenberg and de Mooij (1994) showed that when other taxes are present in the system, environmental taxes may exacerbate pre-existing distortions and that this unfavorable "tax-interaction" effect may outweigh the favorable "revenue-recycling" effect. They used a model involving taxation of two commodities, "clean" and "dirty" goods, and sole input, labor. Using a similar model, but with a dirty intermediate input in addition to a dirty good, Bovenberg and Goulder (1996) derived optimal taxes on the dirty good (or input) as a ratio of the corresponding MED to the marginal cost of public funds

(MCPF). Since MCPF exceeds unity in the presence of distortionary taxation, the tax on the "dirty" good (or input) must be less that the MED.

On the other hand, Fullerton,[1] (1997) and Schöb (1997) have shown in the context of the first model (no intermediate good) that environmental taxes can be greater or smaller than the MED depending on whether the price/tax system is normalized to set the clean good tax to zero or the labor tax to zero. [2]

These analyses, while useful in understanding the interactions of taxes in a general equilibrium system, have focused on emissions that are proportional to output of one of the commodities or inputs. Therefore, they do not allow for separate taxation of emissions and the final or intermediate good that causes emissions[3]. The only way to reduce emissions is to reduce the production of the "dirty" good. However, since there are other ways of reducing emissions, such as changing the input mix in favor of less polluting inputs or using some of the inputs to "clean-up" emissions, it is important to examine a second-best tax on emissions themselves that allows a more general specification of abatement measures.

[1] Fullerton also clarifies how the results of Boveberg and de Mooij (1994) depend on the complementarity between dirty good and labor. Fuest and Huber (1999) show that when there is gross substitutability between the dirty good and the other tax base (labor/clean good), the optimal tax on the dirty good always exceeds the Pigovian tax.

[2] Even in this case, however, the corrective part of the dirty good tax is considered to be less than the MED [Williams 2001].

[3] Fullerton and Metcalf (2001) do consider a direct emissions tax but do not compare the tax with the MED. They show that environmental instruments decrease welfare if they generate rents not captured by government

We set up a model that allows separate taxation of goods and emissions and by treating emissions as an "input" in production. In this model, we show that the optimal emission tax is equal to or larger than the MED, regardless of tax normalization.

The rest of the paper is organized as follows. The model and derivation of the central result are provided in section 2. Section 3 explains the effect of price/tax normalization and shows that our result is robust under a change of normalization. Section 4 interprets the results and section 5 concludes.

2. Comparing Emissions Tax and the Marginal Emissions Damage

In this section, we set up a simple model of an economy with two goods, one of which is a "dirty" in the sense that its production causes emissions, while the other is a "clean" good. While the generation of emissions in the production of the dirty good can be modeled as a by-product, it is not uncommon in environmental tax literature to treat emissions as an input in such cases e [e.g., Fullerton and Metcalf (2001) and Oates and Strassmann (1984)][4], and we follow this approach. With a government revenue constraint, we can have a tax on each of the two goods and two inputs.

To find the optimal emissions tax, we use a two step procedure, for clarity. First, we establish a hypothetical market for emissions that gives us an emissions price, just like the price of labor, i.e., the payment from producers to consumers for the use of a factor of production. The two goods and inputs are taxed on the consumer side to raise the revenue

[4] This allows for flexible emissions abatement by changing the input mix. Fullerton and Metcalf use this technology in comparing the rent-generating and rent-capturing emissions control policies. Oates and Strassmann use it to compare the efficiency of effluent fees under different non-competitive market structures.

to meet the government constraint. In the second step, the emissions price is replaced by an equal tax on producers that is transferred to the consumer (in other words, the government takes over the function of the market, hypothetically, of course). This tax is the equivalent of a Pigouvian tax in the second-best (similar to the Pigouvian component of the environmental tax pointed out by Fullerton, (1997), while the consumer tax on emissions is the Ramsey component that is used to raise revenue). We compare this emissions price/tax with the marginal emissions damage (MED) and show that the former can not be less than the latter.

2.1. The Model

Consider a simple economy with two private goods, *c* and *d*, whose production increases in labor, *l*, and allowable emissions, so that:

$$(1) \qquad c = c(l_c, e_c), \qquad d = d(l_d, e_d),$$

where l_c and l_d are labor inputs to sector c and d respectively and e_c and e_d are corresponding emissions inputs.

In order to simplify and render the derivation more transparent, we employ a two-step procedure by first solving for the optimal emission price as if an emission market exists and then replacing that market with an equivalent emissions tax. The consumer owns the total endowment of pollution rights and sells part of it to the producers through an emissions market[5] and consumes the rest, just as he/she sells part of the total labor

[5] Here, the emissions amount sold is determined by supply and demand of consumer and producers. In the usual emissions permits market with an emissions quota traded among the emissions generators, the government acts on behalf of the consumer in issuing the permits.

endowment and consumes the rest as leisure. Thus, $l_c + l_d = l = (1\text{-}v)$ and $e_c + e_d = e = (1\text{-}n)$, where v is leisure and n is the quantity of rights reserved by the consumer (the total endowment of labor, $l + v$, is normalized to unity, as is the total endowment of natural environment, $e + n$).

The producers' profit-maximizing first-order conditions (FOCs) are:

(2) $$p_c.\frac{\partial c}{\partial l_c} = w, \quad p_c.\frac{\partial c}{\partial e_c} = p_e, \quad p_d.\frac{\partial d}{\partial l_d} = w, \quad p_d.\frac{\partial d}{\partial e_d} = p_e$$

where w is the wage rate, p_e is the emissions market price, and p_c and p_d are the producer prices of the good c and d respectively.

The representative consumer's utility is $u(c, d, v, n, G)$, where G is a government good financed through taxes, is weakly separable in the utility function and is held constant (following e.g., Bovenberg and de Mooij 1994).

The consumer maximizes utility subject to the budget constraint:

(3) $$l.w.(1-t_l) + e.p_e.(1-t_e) = c.(1+t_c) + d.p_d.(1+t_d)$$

where p_d is the producer price of the good, d, and we have normalized the producer price, p_c, of the good c, to unity. The resulting first-order conditions (FOCs) are:

(4) $$\frac{\partial u}{\partial c} = \lambda.(1+t_c), \quad \frac{\partial u}{\partial d} = \lambda.p_d.(1+t_d), \quad \frac{\partial u}{\partial v} = \lambda.w.(1-t_l), \quad \frac{\partial u}{\partial n} = \lambda.p_e.(1-t_e)$$

where λ is the marginal utility of income. The government revenue constraint to finance G is:

(5) $$l.w.t_l + e.p_e.t_e + c.t_c + d.p_d.t_d \geq G$$

Having set up the model, we next explain the replacement of the emissions price with an equivalent tax on the producers of the dirty good.

2.2. Emissions Tax without Emissions Market

When an emissions market does not exist, an equivalent solution can be obtained by replacing the emissions price, p_e, with an equal emissions tax, T_e, that is imposed by the government[6] on the producers and paid to the consumer. Therefore, we can use the emissions price as a proxy for this emissions tax on producers to compare it with the first-best MED or Pigouvian tax.

Notice that this emissions tax on producers (T_e) is different from the emissions tax (t_e) on the consumer that is used just like a labor tax to raise revenue but not to internalize the externality. The emissions tax on producers, T_e, is primarily a mechanism to internalize the emissions externality in the absence of a market. However, its revenue can also be used by the government rather than returning it to the consumer, and that would be equivalent to an additional tax on the consumers. Thus we can translate the emissions price into a emissions tax on producers. Until the revenue requirement (*G)* exceeds this producer tax revenue, we remain in the first-best world and afterwards second-best taxation is indicated.

[6] Abstracting away from the information constraints of the government.

Next, we can compare the emissions price with the Pigouvian tax, and know, from the above discussions, that the same comparison would apply to the emissions tax on producers in place of the emissions price.

2.3. Comparing the Emissions Price/Tax with the Pigouvian Tax

Now we use the consumer first-order conditions to obtain an expression for the emissions price that would allow us to compare it with the marginal emissions damage. As we have argued in the previous section, this comparison would also apply to the emissions tax on producers, allowing us to determine whether such emissions tax is equal to, or smaller or larger than the MED.

The consumer FOCs in (3) above are:

i) $\frac{\partial u}{\partial c} = \lambda.(1+t_c)$, ii) $\frac{\partial u}{\partial d} = \lambda.p_d.(1+t_d)$, iii) $\frac{\partial u}{\partial v} = \lambda.w.(1-t_l)$, iv) $\frac{\partial u}{\partial n} = \lambda.p_e.(1-t_e)$

The marginal utility of income, λ, can be derived from (i) as

(6) $$\lambda = \frac{\partial u}{\partial c} \Big/ (1+t_c)$$

Plugging (6) in (iv) gives:

(7) $$\frac{p_e.(1-t_e)}{(1+t_c)} = \frac{\partial u}{\partial n}\Big/\frac{\partial u}{\partial c} = t_p$$

where t_p on the R.H.S. is just the first-best marginal emissions damage (MED) or Pigouvian Tax[7]. Re-arranging (7), we get:

(8) $$p_e.(1-t_e) = \left(\frac{\partial u}{\partial n}\Big/\frac{\partial u}{\partial c}\right)(1+t_c) = t_p\,(1+t_c)$$

(9) $$p_e = \left(\frac{\partial u}{\partial n}\Big/\frac{\partial u}{\partial c}\right)\frac{(1+t_c)}{(1-t_e)} = (t_p).\frac{(1+t_c)}{(1-t_e)}$$

(10) $\Rightarrow p_e \geq t_p$ **when** $t_c \in [0,1]$ and $t_e \in [0,1)$ [8]

Thus, when either of the taxes t_c or t_e is positive, the emissions price is larger than the (first-best) MED or Pigouvian tax. When there are no other taxes, the two are equal and we get the Pigouvian principle. Any positive commodity tax would reduce the producer prices of the consumer goods and increase the relative price of emissions. This is because a consumer commodity tax reduces the marginal utility of income [see (6) above] and increases the resulting second-best marginal emissions damage [the R.H.S. of (8) above] above its first-best level. If there is a consumer emissions tax, the emissions price [L.H.S. of (9) above] is even higher than the second-best MED. Thus, the emissions price (implemented as a emissions tax on producers) is also larger than the first-best MED.

In the next section, we examine whether there is any effect of tax normalization on this result.

---

[7] $\frac{\partial u}{\partial n}\Big/\frac{\partial u}{\partial c} = -\frac{\partial u}{\partial e}\Big/\frac{\partial u}{\partial c} = MED_{FB}$

[8] $t_e < 1$ is required to avoid division by zero.

3. Tax Normalization Effects

In the prototypical model in the literature, there are three tax instruments - two commodity taxes (on the clean and dirty goods) and one tax on the sole input (labor). When we normalize[9] such that the numeraire for both consumer and producer prices is the 1clean good, there is no tax on it. Emissions reduction is achieved by the dirty good tax, and revenue-raising is done by the labor tax. This is an input tax system. The dirty good tax in this case is less than the MED, because of the additional excess burden it generates by distorting the consumption mix. Thus the Bovenberg and de Mooij (1994) result holds. On the other hand, when we normalize such that the numeraire is labor, there is no tax on it. The revenue-raising as well as emissions reduction has to be done by the two commodity taxes. This is a commodity tax system. In this case, the dirty good tax can be larger than the MED because the revenue requirement dictates an additional tax on the dirty good, as pointed out by Fullerton (1997).

With emissions modeled as an input, the revenue is generated by commodity or input taxes on consumers and emissions reduction is done by the emissions price (imposed as a producer tax). Whether we normalize to get a commodity tax system or an input tax system (also see footnote 8), the emissions tax on producers must be greater than or equal to the MED. With commodity taxes, the marginal utility of income falls and factor prices

[9] Because demand has the property of being homogeneous of degree zero in consumer prices, only relative prices matter. Thus, one of the goods can be chosen as anumeraire with its price normalized to unity by dividing all prices by the price of this good. The same is true of producer prices. With the presence of taxes, however, the consumer and producer prices are differentiated. For convenience and ease of interpretation, we often use the samenumeraire for both consumer and producer prices, causing the tax wedge between the two to disappear through this "tax normalization". Other normalizations are possible, however, and while a change of normalization does not affect any quantities, relative consumer prices or relative producer prices, relative consumer to producer prices and relative taxes can change.

(including the emissions tax on producers) become higher than in the absence of commodity taxes. With input taxes, the tax wedge forces the producer prices of inputs (including the emissions tax on producers) higher than in the absence of input taxes. In both cases, the emissions tax on producers can not fall below the MED at the first-best (no-tax) optimum. This is shown below.

Multiplying through the consumer budget constraint by a constant, Q[10], increases all prices by the same proportion i.e., causes a change of normalization. The consumer FOCs in (4) now become:

i) $\frac{\partial u}{\partial c} = \lambda . p_c.(1+t_c).Q$, ii) $\frac{\partial u}{\partial d} = \lambda . p_d.(1+t_d).Q$, iii) $\frac{\partial u}{\partial v} = \lambda . w.(1-t_l).Q$, iv) $\frac{\partial u}{\partial n} = \lambda . p_e.(1-t_e).Q$

i) $\Rightarrow \lambda = \frac{\partial u}{\partial c} \Big/ p_c.(1+t_c).\mathrm{Q}$

Plug it in (iv) to get:

$$\frac{p_e.(1-t_e).Q}{(1+t_c).Q} = \frac{\partial u}{\partial n} \Big/ \frac{\partial u}{\partial c} = t_p \qquad \text{where} \qquad p_c = 1^{11}$$

$$\Rightarrow p_e = \left(\frac{\partial u}{\partial n} \Big/ \frac{\partial u}{\partial c} \right) \frac{(1+t_c)}{(1-t_e)} = (t_p).\frac{(1+t_c)}{(1-t_e)}$$

$$\Rightarrow p_e \geq t_p \qquad \text{when } t_c \in [0,1] \text{ and } t_e \in [0,1)$$

---

10 We can set $\mathrm{Q} = 1/(1+t_c)$ to get an input tax system or $\mathrm{Q} = 1/(1-t_l)$ to get a commodity tax system.

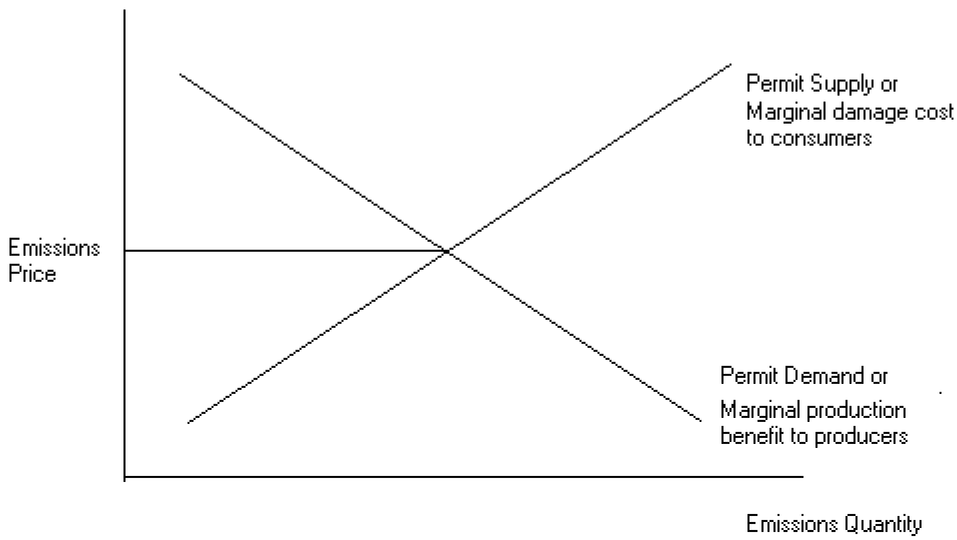
11 In standard models of the literature, a commodity tax system entails setting $w=1$ in addition to $t_l=0$. Then, the definition of marginal utility of income can be changed to $\lambda = \frac{\partial u}{\partial v}$, but using the FOCs in (4), it is simple to show that we still have $p_e \geq$ MED.

Thus, despite a change of normalization, the emissions price compares the same way with the first-best MED as before, i.e., it is greater than or equal to the MED.

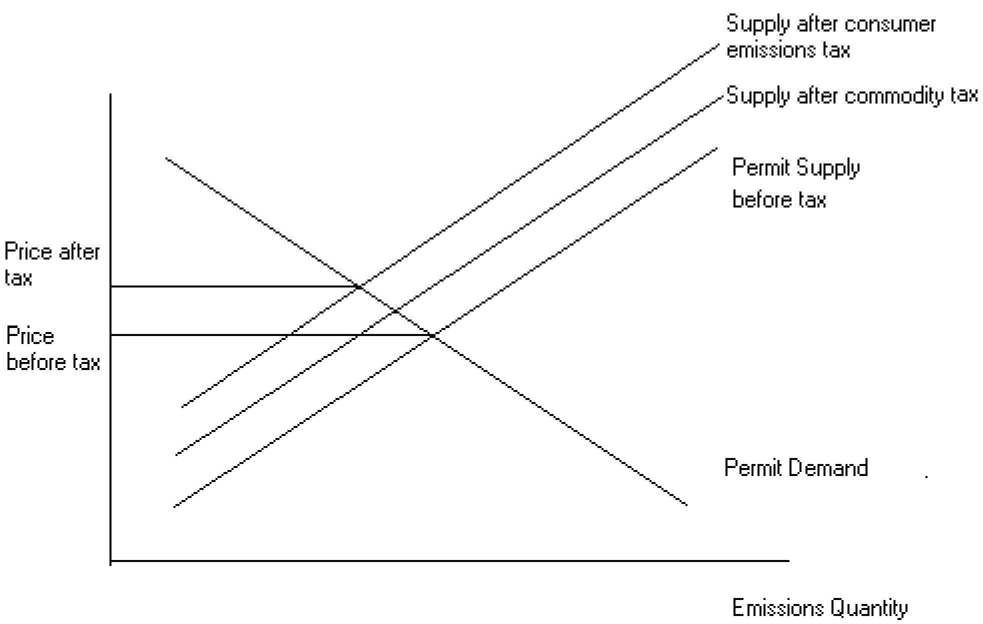
4. Interpretation

This section explains graphically how the emissions market is converted into an equivalent emissions tax system and how this emissions tax becomes larger in the presence of other taxes than it is in the absence of those taxes.

Consider the model with an emissions market where the consumer sells emissions permits to the producers as described in section 2. There are no taxes anywhere in the system. We plot the producers' demand for permits as a downward sloping (marginal benefit or value of marginal product of emissions) curve and the consumer's supply of permits as an upward sloping (marginal cost of damage from emissions or marginal utility of permits reserved by the consumer) curve.

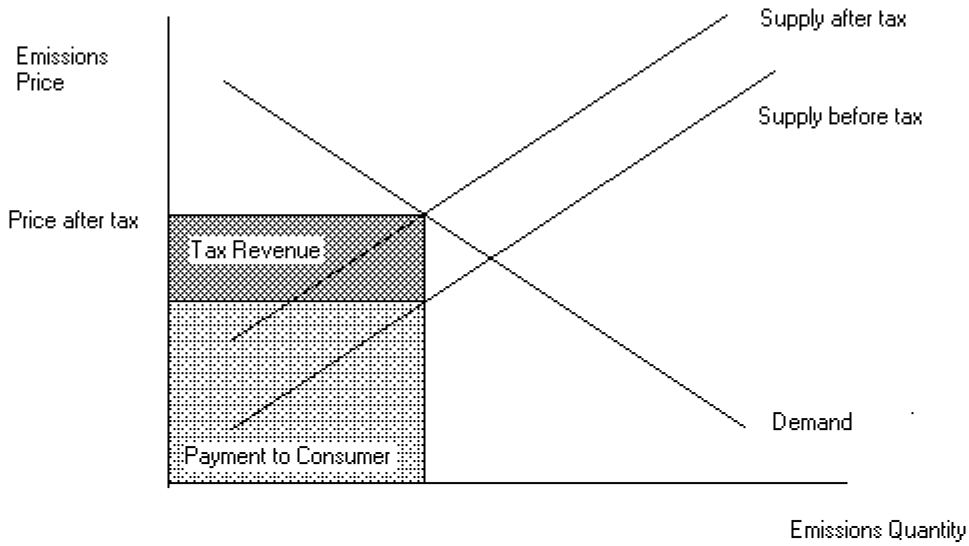


Now, we impose a consumer tax on the two commodities. This causes a substitution away from their consumption and toward the consumption of untaxed leisure and environment. Increased consumption of environmental amenities by the consumer implies reduced supply of permits to the producers, i.e., the supply curve shifts upward. Next, if we impose a consumer tax on the inputs sold by the consumer, i.e., labor and emissions, the consumer price of inputs goes down and he/she substitutes more leisure and environmental amenities. Again the permits supply curve shifts upward, as shown in the figure below.

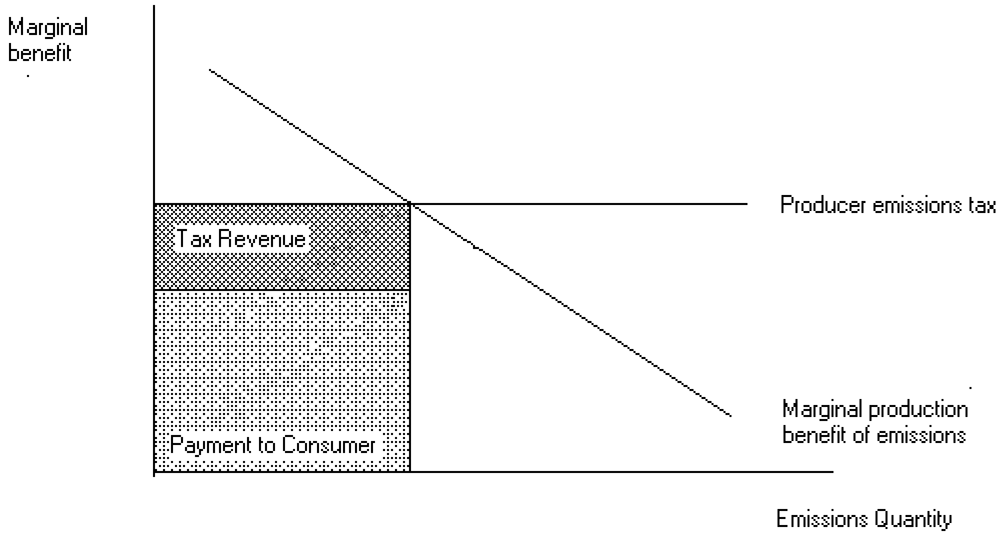


In other words, regardless of whether the tax system is normalized as a commodity tax system or as an input tax system, the supply curve shifts upward and the emissions/permit price goes up.

The tax causes a wedge between the producer price and the consumer price of emissions permits, that differentiates the payment to the government and the payment to the consumer as shown below:



Now, we take away the emissions permit market and replace it with a tax on producers that equals the permit price in the market case. In terms of the above figures, it means there is no supply curve but there is a marginal benefits curve as the producers use emissions as input. The revenue from this producer tax is divided exactly according to the above figure.



This tax is exactly equal to the emissions price in the market case, and the revenue from this tax is divided between the government and the consumer in the same way as well. Since the emissions price goes up with the imposition of commodity or input taxes, the producer emissions tax also does the same.

5. Conclusions

Modeling emissions a taxable production input, we show that the optimal emissions tax is not less than the first-best Pigouvian tax. This is because of two reasons, either of which can raise the emissions tax on producers in the second-best case above the first-best level.

In the second-best, to meet the revenue requirement, when commodity taxes are imposed, the marginal utility of income falls. The consumer's incentive to earn income falls, causing him/her to consumer more leisure and also more pollution rights (environment). Since the utility function is concave, the marginal disutility of labor (marginal utility of leisure) increases, and similarly, the marginal disutility of emissions (the marginal emissions damage) also increases.

Also, to raise the revenue, when emissions tax on consumer is imposed, the wedge between the consumer price of emissions and the producer price of emissions drives the producer price up (since producers are the buyers of input). Thus when this price is implemented as an emissions tax on producers, it is also larger (in the presence of the emissions tax on consumers) .

Finally, our conclusion (that the emissions tax on producers is not less than the MED) does not vary with the change of tax normalization, i.e., whether we have a commodity tax system or input tax system. This is simply because the first reason above applies in a commodity tax system and the second reason above applies in an input tax system, each of which causes the emissions tax on producers to be higher than the MED (the first-best tax).

References

Bovenberg, A. L. and R. A. de Mooij, 1994, Environmental Levies and Distortionary Taxation, *American Economic Review* 84, 1085-1089.

Bovenberg, A. L. and R. A. de Mooij, 1997, Environmental Levies and Distortionary Taxation: Reply, *American Economic Review* 87, 252-253.

Bovenberg, A. L. and L. H. Goulder, 1996, Optimal Taxation in the presence of Other Taxes: General Equilibrium Analyses, *American Economic Review* 4, 985-1000.

Fuest, C. and B. Huber, 1999, Second-Best Pollution Taxes: An Analytical Framework and some New results, *Bulletin of Economic Research* 51, 31-38.

Fullerton, D., 1997, Environmental Levies and Distortionary Taxation: Comment, *American Economic Review* 1, 245-251.

Fullerton , D., G. E. Metcalf, 2001, Environmental controls, scarcity rents, and pre-existing distortions, Journal of Public Economics 80, 249–267.

Lee, D. R. and W. S. Misiolek, 1986, Substituting Pollution Taxation for General Taxation: Some Implications for Efficiency in Pollution Taxation, *Journal of Environmental Economics and Management* 13, 338-347.

Nordhaus, W., 1993, Optimal Greenhouse-Gas Reduction and Tax Policy in the “DICE” Model, *American Economic Review* 83, 313-317.

Oates, W. E. and D. L. Strassmann, 1984, Effluent Fees and Market Structure, *Journal of Public Economics* 24, 29-46.

Parry, I. W. H., 1995, Pollution Taxes and Revenue Recycling, *Journal of Environmental Economics and Management* 29, S64-77.

Pearce, D., 1991, The Role of Carbon Taxes in Adjusting to Global Warming, *Economic Journal* 101, 938-948.

Repetto, R., R. C. Dower, R. Jenkins, and J. Geoghegan, 1992, *Green Fees: How a Tax Shift Can Work for the Environment and the Economy*, Washington, DC: World Resources Institute.

Schöb, R., 1997, Environmental Taxes and Pre-Existing Distortions: The Normalization Trap, *International Tax and Public Finance* 4, 167-176.

Terkla, D., 1984, The Efficiency Value of Effluent Tax Revenues, *Journal of Environmental Economics and Management* 11, 107-123.

Tullock, G., 1967. Excess benefit. *Water Resources Research* 3, 643–644.

Williams III, Roberton C., 2001, Tax normalizations, the marginal cost of funds, and optimal environmental taxes, *Economics Letters* 71, 137–142.