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Environmental Tax Burden in a Vertical Relationship with Pollution-Abatement R&D

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Abstract

In contrast to the polluter-pays principle, environmental taxes are imposed at various points in the chain of production and distribution (e.g., the fuel and regulatory energy taxes in the Netherlands). To discuss the effects of environmental tax burden ratio on economic outcomes, we consider a market where there is one upstream firm and two downstream firms that pollute the environment. The government imposes environmental tax on the upstream and downstream firms at some tax burden ratio. Given the tax burden, the downstream firms invest in pollution-abatement technology. After investment, the upstream firm chooses a wholesale price, and then the downstream firms compete a la Cournot. We obtain the following results: First, the total amount of environmental damage increases with the tax burden in the downstream market if the pollution-abatement technology is inefficient. Second, the profit of downstream firms increases with their tax burden if the tax burden is small. Finally, in the optimal tax burden scenario, both upstream and downstream firms may have to pay tax.

Keywords: tax burden ratio, pollution-abatement R&D, vertical relationship, oligopoly

1. Introduction

In order to decrease pollution caused by emissions, governments often impose taxes on the economic activity of firms. These taxations aim to internalize externalities from production. Additional duty and an output tax on electricity in Finland; a carbon dioxide tax in Sweden, Norway, and Denmark; fuel and regulatory energy taxes in the Netherlands; mineral oil and electricity taxes in Germany; and a climate change levy in United Kingdom are all examples of this form of taxation. Since CO_2 and NO_X are exhausted when burning fossil fuels, one might think that taxes should be paid by companies that burn fossil fuels because of the polluter-pays principle. However, each tax is paid at all of the various points in the chain of production and distribution.

In the Netherlands, fuel tax is levied on firms that extract, produce, or import natural gas, and firms that distribute energy obtained from natural gas pay the regulatory energy tax. In Germany, the mineral oil tax is levied on companies selling petroleum-based fuels and the electricity tax is levied on firms supplying electricity. Hence, in these countries, companies pay these taxes even if they do not burn fossil fuels (Note 1).

Upstream energy tax is levied at the point where raw energy materials are mined or extracted (coal mines, oil wells, etc.). On the other hand, downstream energy tax is levied at the point where energy materials are converted into final fuel products (Pearson & Smith, 1992; Volleberg, 2008). Fuel and mineral oil taxes are closest to upstream tax, and regulatory energy and electricity taxes are closest to downstream tax.

Since the effect of taxation depends on its regime, it is important to understand the characteristics of the designed tax system. Thus, we evaluate the environmental tax burden levied on the upstream and downstream activities. However, we do not focus on the optimal level of tax. Instead, we discuss the effects of changing the tax burden ratio on economic outcomes.

Before explaining our model, let us consider a market where there are monopolistic upstream and monopolistic downstream firms. The downstream firm can invest in environmental technology that decreases emissions. The firms pay a lower tax if their activities cause less environmental damage. Under a constant-return-to-scale technology of production and a linear demand, a change in the tax burden ratio has no effect on the total amount of emission. This is because even if the government shifts the environmental tax from the downstream market to the upstream market, the upstream firm adds the tax to the wholesale price. Since the decrease in the environmental tax for the downstream firm is just equal to the increase in the wholesale price, the total amount of emission does not change.

However, when there are two downstream firms, the above result changes. When one downstream firm invests in the abatement technology, it reduces the total emissions, which reduces the tax paid by the upstream firm. As a result, the upstream firm reduces the price of the input, which reduces the costs for both downstream firms. Investing in abatement therefore indirectly reduces the rival firm's costs. Since a different tax burden ratio yields a different reduction in the rival firm's costs, the total amount of emission also changes.

Hence, we consider a simple model as follows. We consider a market with one upstream firm and two downstream firms. When the upstream and downstream firms manufacture their products, they discharge pollutants. The government imposes an environmental tax on the upstream and downstream firms. When the total amount of environmental damage is ED, the total amount of environmental tax is tED, where t denotes the tax rate. The tax burden ratios of the upstream and downstream firms are $1-\alpha$ and α, respectively. Based on the tax burden ratio, each downstream firm can reduce its emission by investing in pollution-abatement technologies. Thus, the larger the downstream firms' investment, the lower is the environmental tax. Based on the amount of investment, the upstream firm chooses the wholesale price, and then each downstream firm decides the quantity of sales.

An environmental policy has been investigated under a vertical industrial structure in a previous research (Note 2). Requate (2005) analyzes a model where competitive upstream industries have two types of inputs: clean input and dirty input. The downstream market is a monopoly. A regulator levies a charge for the use of the dirty input. He shows that in such a case, the optimal tax is lower than the marginal damage. He also suggests that if the regulator levies an environmental tax on the supplier using dirty input, the result will remain unchanged because of the monopoly distortion that arises from the downstream firm's behavior. Hence, it is important to consider the overall market structure, and not just the polluting industry. However, Requate (2005) does not consider firms' investment in pollution-abatement technology (Note 3).

Sugeta and Matsumoto (2007a) investigate a vertical relationship where there is an upstream firm and two polluting downstream firms. They investigate why the upstream firm has a different input price. They show that the existence of an environmental regulation and the fact that the downstream firms use different abatement technologies cause the difference in price. However, they do not analyze the case where an emission tax is imposed on the upstream firm (Note 4).

An analysis of the eco-industry (Canton et al., 2008; David & Sinclair, 2005) is one of the other studies investigating a vertical industry structure. In these analyses, a feature of the framework is that the polluting downstream firms do not invest to reduce their own pollution but purchase a cleaner technology from an upstream eco-industry. In this framework, because the upstream industry is not the polluter but the supplier of the cleaner technology, it is not important to consider the possibility of imposing the emission tax on the upstream industry.

Innes and Bial (2002) and Barrett (1991) explain the problem of over-compliance with environmental regulations from the perspective of firms' incentive with regard to R&D investment. Because a firm that has cleaner technology than its competitors can benefit from the strict environmental regulation that increases its rival firms' costs, firms have the incentive to invest in cleaner technology. Carlsson (2000) considers a market where there are two firms that can invest to reduce their costs. He shows that the optimal tax level is not necessarily lower than the marginal environmental costs (Note 5). However, these papers do not consider a market with a vertical industrial structure.

Banerjee and Lin (2003) consider a vertical relationship in monopolistic upstream and oligopolistic downstream markets. The downstream firms can invest in cost-reducing R&D. Based on the level of investment, the upstream firm chooses the wholesale price, and then, the downstream firms decide on their quantity of sales or price. Banerjee and Lin (2003) show that the downstream firms may have a greater incentive toward cost-reducing R&D in the oligopolistic downstream market than in the monopolistic downstream market. This is due to the effect of the increase in the costs of the rival firms.

In our model, if the downstream firms pay an environmental tax, the effect of increasing the rival firm's costs is considered. However, if the upstream firm pays the tax, the effect of reducing the rival firm's costs is considered. Banerjee and Lin (2003) do not discuss the environmental tax policy.

Apart from Banerjee and Lin (2003), some additional papers focus on the relationship between vertical market structures and cost-reducing R&D. Ishii (2004) and Milliou (2004) discuss the spillover effects of R&D in vertical relationships. Brocas (2003) and Buehler and Schmutzler (2008) consider endogenous vertical mergers in successive oligopolistic markets when firms reduce the costs involved in R&D. Brocas (2003) considers upstream R&D. On the other hand, Buehler and Schmutzler (2008) consider downstream R&D. However, the above papers do not consider pollution emission externalities and environmental tax policies.

The rest of this paper is organized as follows. Section 2 presents the model. Section 3 calculates the equilibrium. Section 4 considers the effects of environmental tax burden on market outcomes. Section 5 shows the optimal tax burden ratio. Section 6 provides the conclusion.

2. Model

This paper considers a vertical relationship in a homogeneous good market. There exist one upstream firm and two downstream firms. Hence, there are two distribution channels: one is through downstream firm 1 and the other is through downstream firm 2. We call the former channel 1 and the latter channel 2. The upstream firm produces an intermediate good, which we call input, at zero marginal cost, and sells it to the downstream firms at a wholesale price$w$. One unit of intermediate good pollutes the environment by $D^I(>0)$. The downstream firms turn one unit of the input into one unit of the final good at no cost. Hence, when the downstream firms sell the final good, their marginal costs are the purchase price$w$ of the input. Let x_i denote the amount of the final good sold by the downstream firms $i \in \{1,2\}$. One unit of the final good pollutes the environment by $D^F(>0)$. By each downstream firm's investment, technology for the environment can be more efficient. When the downstream firms$i$ invest in emission abatement technology by d_i, the environmental damage from channel$i$ reduces to $(D-d_i)x_i$, where $D=D^I+D^F$. That is, the investment reduces the environmental damage in the upstream and/or downstream markets. The cost of the investment is given by γd_i^2, and the marginal costs of the investment are denoted by $2\gamma d_i$. We denote the total amount of environmental damage by $ED=(D-d_1)x_1+(D-d_2)x_2$.

We assume that the government imposes an environmental tax and the total amount of tax is$t\ ED$, where $t>0$. The environmental tax burden ratio of the downstream firms is α and that of the upstream firm is $1-\alpha$. Thus, when the amount of channel i's environmental damage is $(D-d_i)x_i$, the environmental tax for the downstream firms$i$ is $\alpha t(D-d_i)x_i$ and that for the upstream firm is $(1-\alpha)t[(D-d_1)x_1+(D-d_2)x_2]$. To sum up, this study considers the following model.

Stage 1: Each downstream firm simultaneously chooses the level of investment in emission abatement $d_i (i \in \{1,2\})$.

Stage 2: The upstream firm chooses the wholesale price$w$.

Stage 3: Each downstream firm simultaneously chooses the amount of the good to be sold to consumers.

The market inverse demand function is given by $P=1-X$. Let$X$ be the aggregate amount of the good sold by the downstream firms. To satisfy the second-order condition at the investment stage, we assume $\gamma>49t^2/144$. The profit of the upstream firm is

$$\pi^U=w(x_1+x_2)-(1-\alpha)t[(D-d_1)x_1+(D-d_2)x_2] \qquad (1)$$

The profit of the downstream firms i $(i=1,2)$ is

$$\pi_i^D=(1-x_1-x_2-w)x_i-\alpha t(D-d_i)x_i-\gamma d_i^2 \qquad (2)$$

Social welfare SW is

$$SW=\frac{1}{2}X^2+\pi^U+\sum_{i=1}^{2}\pi_i^D+(t-1)[(D-d_1)x_1+(D-d_2)x_2] \qquad (3)$$

This study assumes complete information. The model is solved by backward induction and only pure strategies are considered throughout.

3. Calculating Equilibrium

From (2), the first-order condition at the third stage leads to

$$x_i=\frac{1-w-\alpha t(D-2d_i+d_j)}{3} \quad (i,j=1,2) \qquad (4)$$

We put (4) into (1). Then, the first-order condition at the second stage leads to

$$w = \frac{2 + (1 - 2\alpha)(2D - d_1 - d_2)t}{4} \tag{5}$$

We put (4) and (5) into (2). Then, the first-order condition at the first stage leads to

$$d_i = \frac{(1 + 6\alpha)(1 - tD)t}{72\gamma + (1 + 6\alpha)t^2}, (i = 1,2) \tag{6}$$

Then, we obtain the equilibrium outcomes as follows:

$$x_i = \frac{12(1 - tD)\gamma}{72\gamma - (1 + 6\alpha)t^2},\ w = \frac{36\gamma(1 + tD - 2\alpha tD) - (1 - \alpha)(1 + 6\alpha)t^2}{72\gamma - (1 + 6\alpha)t^2} \tag{7}$$

$$P = \frac{24\gamma(2 + tD) - (1 + 6\alpha)t^2}{72\gamma - (1 + 6\alpha)t^2},\ d_i = \frac{(1 + 6\alpha)(1 - tD)t}{72\gamma - (1 + 6\alpha)t^2} \tag{8}$$

$$\pi^U = \frac{864(1 - tD)^2\gamma^2}{[72\gamma - (1 + 6\alpha)t^2]^2},\ \pi_i^D = \frac{\gamma[144\gamma - (1 + 12\alpha + 36\alpha^2)t^2](1 - tD)^2}{[72\gamma - (1 + 6\alpha)t^2]^2} \tag{9}$$

$$ED = \frac{24\gamma(72\gamma D - 6\alpha t - t)(1 - tD)}{[72\gamma - (1 + 6\alpha)t^2]^2},\ SW = \frac{2\gamma(1 - tD)\Omega}{[72\gamma - (1 + 6\alpha)t^2]^2} \tag{10}$$

Where $i = 1,2$, SW denotes social welfare, and $\Omega = 36\alpha^2t^2D + 12\alpha t^3D + t^3D + 144\gamma tD - 864\gamma D - 36\alpha^2t^2 - 84\alpha t^2 - 13t^2 + 72\alpha t + 12t + 720\gamma$. Keeping positive outcomes, the following inequalities must be held.

$$D < \frac{1}{t},\ D > \frac{(6\alpha + 1)t}{24\gamma} - \frac{2}{t},\ D > \frac{(6\alpha + 1)t}{72\gamma} \tag{11}$$

Since we assume $\gamma > 49t^2/144$, the above inequalities are satisfied if $2(6\alpha + 1)/(49t) < D < 1/t$. Hence, we assume the sufficient condition: $D \in (2(6\alpha + 1)/(49t), 1/t)$.

In (7), the outputs of the downstream firms increase with their tax burden ratio (α). This is because there is a free-riding effect between two downstream firms. The mechanism is as follows: When one downstream firm invests in the abatement technology, it reduces the total emissions, which reduces the tax paid by the upstream firm. As a result, the upstream firm reduces the price of the input, which reduces the costs for both the downstream firms. Investing in abatement therefore indirectly reduces the rival firm's costs. Since an increase in α reduces the tax burden of the upstream firm, the free-riding effect becomes smaller. Hence, the amount of investment in the abatement technology increases, and then the outputs of the downstream firms also increase.

4. Effect of Environmental Tax Burden Ratio

In this section, we analyze comparative statics on the equilibrium outcomes.

4.1 Effect on the Total Amount of Environmental Damage

From (10), differentiating ED with respect to α yields

$$\frac{\partial ED}{\partial \alpha} = \frac{144\gamma t(1 - tD)(144\gamma tD - 6\alpha t^2 - t^2 - 72\gamma)}{(72\gamma - 6\alpha t^2 - t^2)^3} \tag{12}$$

Then, the sign of $\partial ED/\partial \alpha$ is the same as that of $144\gamma tD - 6\alpha t^2 - t^2 - 72\gamma$. Rearranging $144\gamma tD - 6\alpha t^2 - t^2 - 72\gamma \geq 0$ gives

$$\gamma \geq \frac{(6\alpha + 1)t^2}{144tD - 72} \tag{13}$$

Then, we obtain

$$\frac{\partial ED}{\partial \alpha} \geq 0 \text{ if } \gamma \geq \frac{(6\alpha + 1)t^2}{144tD - 72} \tag{14}$$

$$\frac{\partial ED}{\partial \alpha} < 0 \quad \text{otherwise} \tag{15}$$

Proposition 1 summarizes the above result.

Proposition 1: *The total amount of environmental damage increases with the tax burden ratio of downstream firms if* $\geq [(6\alpha + 1)t^2]/(144tD - 72)$*; otherwise, it decreases.*

The logic behind Proposition 1 is as follows: As mentioned earlier, an increase in α reduces the free-riding effect of investment in the abatement technology. Then, the investment and final output increase. An increase in the investment has a negative effect on the total amount of environmental damage, but an increase in the final output has a positive effect on it. Hence, it is ambiguous whether the total amount of environmental damage increases with α. Whenγ is large, an incentive to invest in the abatement technology is small because of inefficient technology. In this case, the positive effect on the total amount of environmental damage dominates the negative one. Therefore, we obtain Proposition 1.

According to Proposition 1, in order to effectively reduce environmental damage, we should impose environmental tax in the downstream market if the production process largely pollutes the environment. Otherwise, we should impose environmental tax in the upstream market. The result may justify the environmental tax policy in the Netherlands.

In the Netherlands, the fuel tax, which is an upstream tax, is levied on coal, but the regulatory energy tax, which is a downstream tax, is not levied. On the other hand, the regulatory energy tax is levied on natural gas, but the fuel tax is hardly levied (Vollebergh, 2008). Rearranging the condition in (14) yields $\geq [72\gamma + (6\alpha + 1)t^2]/(144\gamma t)$. Thus, since coal is a dirtier input than natural gas, in order to reduce environmental damage, the government should impose fuel tax on coal and regulatory energy tax on natural gas. Hence, our result is consistent with the environmental tax policy in the Netherlands.

From Proposition 1, we can easily derive the most effective tax burden ratio to reduce environmental damage. Proposition 1 implies that $\alpha = 0$ or $\alpha = 1$ yields the minimum value ofED. Then, we compareED between at $\alpha = 0$and $\alpha = 1$.

$$ED|_{\alpha=1} - ED|_{\alpha=0} = \frac{144\gamma t(1 - tD)(10368\gamma^2 tD - 5184\gamma^2 + 7t^4 - 576\gamma t^3 D)}{(72\gamma - t^2)^2(72\gamma - 7t^2)^2} \tag{16}$$

Rearranging $10368\gamma^2 tD - 5184\gamma^2 + 7t^4 - 576\gamma t^3 D \geq 0$ leads to Corollary 1.

Corollary 1: *The most effective tax burden ratio to reduce environmental damage is* $\alpha = 0$ *if* $\geq (5184\gamma^2 - 7t^4)/[576\gamma(18\gamma t - t^3)]$*, and* $\alpha = 1$ *otherwise.*

4.2Effect on the Profits of Upstream and Downstream Firms

First, we consider the effect of changing the environmental tax burden ratio on the profits of the upstream firm. From (9), differentiating π^U with respect to α gives

$$\frac{\partial \pi^U}{\partial \alpha} = \frac{10368\gamma^2 t^2 (1 - tD)^2}{(72\gamma - 6\alpha t^2 - t^2)^3} > 0 \tag{17}$$

Hence, a decrease in the environmental tax burden ratio of the upstream firm increases its profit.

Next, we consider the effect of changing the environmental tax burden ratio on the profits of the downstream firms. From (9), differentiating π_i^D with respect to α gives

$$\frac{\partial \pi_i^D}{\partial \alpha} = \frac{864(1 - 6\alpha)\gamma^2 t^2 (1 - tD)^2}{(72\gamma - 6\alpha t^2 - t^2)^3} \tag{18}$$

Hence, we obtain the following proposition.

Proposition 2: *The profit of the upstream firm always decreases with its environmental tax burden ratio* $1 - \alpha$*. On the other hand, the profits of the downstream firms increase with their environmental tax burden ratio*α*, if* $\alpha < 1/6$*, and decrease otherwise.*

The reason why the profit of upstream firms decreases with the tax burden on the upstream market $(1 - \alpha)$ is that a larger tax burden raises the costs of the upstream firm. The reason why the profits of the downstream firms may increase with the tax burden on the downstream market (α) is due to the decrease in the free-riding effect of investment in emission abatement. An increase inα has two effects on the profit of downstream firms. The positive effect is to reduce the free-riding effect, and the negative effect is to increase the amount of tax payment. Whenα is small, the free-riding effect is large, as mentioned earlier. Hence, an appropriate increase in α leads to larger profits for the downstream firms because it creates an incentive to invest in the abatement technology.

5. Optimal Tax Burden Ratio

In this section, we briefly discuss the optimal tax burden ratio. One might think that downstream firms should pay environmental tax because of the polluter-pays principle. In particular, one might think that when $D^I = 0$, this conjecture is true. However, in this section, we show that the conjecture is not always held.

To create a simple analysis, we assume $\gamma = 1$. From (10), differentiating SW with respect to α and substituting $\alpha = 1$ and $\gamma = 1$ into it yields

$$\left.\frac{\partial SW}{\partial \alpha}\right|_{\alpha=1,\gamma=1} = \frac{144t(1-tD)(108t^2D - 144tD - 7t^3 + 7t^2 - 36t + 72)}{(72-7t^2)^2} \tag{19}$$

The sign of the above equation is equal to the sign of $108t^2D - 144tD - 7t^3 + 7t^2 - 36t + 72$. Hence, solving $108t^2D - 144tD - 7t^3 + 7t^2 - 36t + 72 < 0$ for$D$ leads to

$$D > \frac{72 - 7t^3 + 7t^2 - 36t}{144t - 108t^2} \tag{20}$$

We plot the result in Figure 1. In Figure 1, there are three lines: $D = (72 - 7t^3 + 7t^2 - 36t)/(144t - 108t^2)$, $D = 2/(7t)$, and $D = 1/t$. Since to keep positive outcomes we assume $D \in (2(6\alpha+1)/(49t), 1/t)$, positive outcomes are ensured if $D$is in the area above $D = 2/(7t)$ and below $D = 1/t$. In Figure 1, if D is in the area above $D = (72 - 7t^3 + 7t^2 - 36t)/(144t - 108t^2)$, reducing the tax burden ratio of downstream firms (α) from 1 raises social welfare.

Next, we drive the optimal tax burden ratio. Solving$\partial SW/\partial\alpha = 0$ forα yields

$$\alpha^* = \frac{144tD + t^3 - 36t^2D - t^2 - 36t - 72}{6t(12tD - t^2 + t - 12)} \tag{21}$$

If the inequality in (20) is not satisfied, the optimal tax burden ratio is a corner solution; that is, $\alpha^* = 1$. Then, we obtain the following proposition.

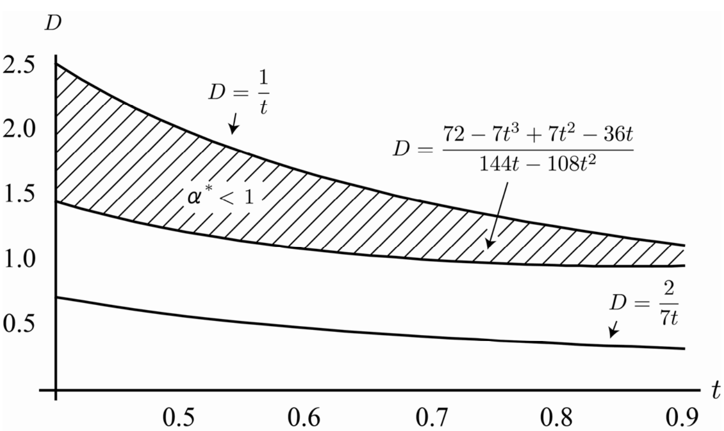

Figure 1. The area where the optimal tax burden ratio is smaller than 1

Proposition 3: *Assume that* $D \in (2(6\alpha+1)/(49t), 1/t)$*and*$\gamma = 1$. *Then, the optimal environmental tax burden ratio is* $\alpha^* = (144tD + t^3 - 36t^2D - t^2 - 36t - 72)/[6t(12tD - t^2 + t - 12)]$ *if* $D > (72 - 7t^3 + 7t^2 - 36t)/(144t - 108t^2)$*; otherwise, it is* $\alpha^* = 1$.

This result implies that the tax burden system may have an internal solution if the environmental tax rate(t) is high. The logic behind Proposition 3 is due to the free-riding effect. An increase in the tax burden ratio in the downstream market(α) reduces the free-riding effect. Moreover, when tax rate$t$ and amount of environmental damage$D$ are moderately large, downstream firms have a great incentive to invest. However, a very largeα

leads to excess investment in the abatement technology. Therefore, a very large α is socially inefficient.

6. Concluding Remarks

In this paper, we analyze the effect of environmental tax burden on polluting industries under a vertical industrial structure. A key feature of our model is that, by enhancing the tax burden for the downstream firms, the downstream firms' investment and output are promoted by reducing the free-riding effect. From this feature, we obtain the following results: First, the total amount of environmental damage increases with the tax burden in the downstream market if the pollution-abatement technology is inefficient. Second, the profit of the upstream firm always decreases with the tax burden in the upstream market. On the other hand, the profit of downstream firms increases with the tax burden in the downstream market if the tax burden is small. Finally, to achieve the optimal tax burden, both upstream and downstream firms may have to pay environmental tax, if the environmental tax rate is high and the production process leads to significant pollution.

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Notes

Note 1. For example, in Sweden there are taxes on the use of fossil fuel (energy tax) and on the emission of nitrogen oxide (NOx; environmental tax) generated through the use of fossil fuel. Energy tax is levied on the manufacturer of fossil oil or on the supplier, who is typically a wholesaler. On the other hand, environmental tax is levied on the polluter, depending on the emission level of NOx.

Note 2. Jaffe et al. (2002) conducted a survey investigating the relationship between environmental policy and firms' innovation.

Note 3. Ohori (2012) and Park et al. (2012) analyze environmental tax in vertical oligopolies. However, these studies also do not consider firms' investment in pollution-abatement technology.

Note 4. Sugeta and Matsumoto (2007b) show that in a vertical market structure, the prohibition of price discrimination reduces pollution emission.

Note 5. Simpson (1995) also shows that the optimal tax may be higher than the marginal environmental costs. This is because high tax transfers production from environmentally inefficient firms to environmentally efficient firms.