Pollution Tax under Lobbying Duopolists

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Abstract. We study a model which explains an politically determined pollution tax outcome under asymmetric duopoly. We assume an asymmetry of firms in the pollution emissions per unit of output. The polluting duopoly and three-stage political game are considered. We derive the equilibrium tax rate and show that it might excess the marginal external damages, even without an environmental group. The politically determined tax rate is decomposed to the marginal external damages, the imperfect competition effect, and the lobbying effect. Under linear demand and cost functions, we derive the condition that Pigouvian taxation is politically determined. The effect on the equilibrium tax of firm heterogeneity is discussed.

KEYWORDS: Cournot duopoly, firm heterogeneity, lobbying activity, political economy, pollution tax

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1 Introduction

It is well known that environmental policy is affected by special interest groups in political process. This paper investigates an politically determined pollution tax in an oligopolistic context. The importance of this analysis is that oligopolistic firms form a lobby group and influence environmental policy making and that there is strategic interactions in political and product stages.

Our analysis is part of a growing literature on a political economy approach to environmental policy. It emphasizes influence of interest groups on government policy choices. The effects of lobbying on environmental policy are usually examined by the common-agency model (Grossman and Helpman 1994) in which self-interested government maximizes a weighted sum of social welfare and contributions from lobby groups. The political contributions considered are contingent on a pollution tax policy. There have been many investigations of environmental policy choice and lobbying effects. (see Aidt 1998, Aidt and Dutta 2004, Fredriksson 1997,1999, Fredriksson and Svensson 2003). Most studies assume perfect competition. Exceptionally, a few papers assume imperfect competition. Damania(1999) and Damania and Fredriksson (2000) consider pollution tax on oligopolistic firms [1]. But, the former focuses on political lobbying on the choice of environmental policy instruments (a emission standard or an emission taxes), and the later focuses on lobby group formation in an

[1] Dijkstra(2004) elaborates and modifies the model of Damania(1999).

infinitely repeated game. Hence, their central concerns are not the equilibrium tax rate itself in imperfect competition. Not much attention has been paid to to the properties of the politically determined pollution tax under oligopoly, especially under heterogeneous case. The importance of the exploring of environmental policy under heterogeneous oligopoly relates to the problem that the government have to meet the abatement commitments agreed to in the international environmental agreement, such as the Kyoto global warming treaty.

We study a model which explains an politically determined pollution tax outcome under an asymmetric duopoly. This paper extends the existing literature by incorporating endogenous environmental policy model and pollution taxation under oligopoly (Simpson 1995). Because abatement technologies actually differ among firms within the same industry, we allow firm heterogeneity in the model. Heterogeneity affects not only product amounts in output market but also lobbying activities in political process. This means that oligopolists generate not only imperfect competition distortion but also political distortion. We derive the equilibrium tax rate and show that it may excess the marginal environmental damages, even without an environmental lobby group. Assuming linear demand and cost functions, we derive the condition that politically determined tax equals the marginal external damages (Pigouvian tax). In this paper, we consider the following three-stage game. In the first stage, both firms simultaneously and independently offer the government contribution schedules. In the second stage, the government chooses a tax policy which maximizes the government utility taking the contribution schedules as given. In the third stage, the two firms compete à la Cournot in the output market, taking the tax as given.

When we treat lobbying by heterogeneous firms, it is necessary to consider the problems how to decide whether each firm participates in a lobby group and how the lobby group including heterogeneous members makes decisions. Consider the following two firms: one firm uses a clean technology and another firm uses a dirty. They differ in pollution emissions per unit of output. If the difference of cleanliness between these firms is small, the difference of attitudes about stringency of environmental regulation will be also small. But, if the difference of cleanliness is large, the difference of attitudes will be also large. Whereas the dirtier firm never prefer stringent environmental policy, the cleaner firm may prefer it because it will increase its share of the market. Then, if we suppose that two firms always participate in the same lobby group, they can not make decision-making in the latter case. Avoiding these difficulties, we assume that each firm *independently* offers the government contribution as in Damania and Fredriksson(2000). If two firms have the same direction of the contribution schedules in the equilibrium, we consider that they form a lobby group. On the other hand, if they have the opposite directions, we regard one firm as one lobby group. This approach is useful when firm heterogeneity is allowed. Moreover, it alleviates the traditional free rider problem (Olson 1965), because political contributions of each firm are considered to be sort of private contributions of public goods.

The paper is organized as follows. Section 2 describes the model, and Section 3 derives the political equilibrium pollution tax. Section 4 investigates property of the equilibrium under linear cost and demand function. Finally, Section 5 concludes the paper.

2 The Model

Consider an economy with two sectors: duopoly by producing a homogenous good Q with pollution, and a competitive sector by producing a numeraire good z without pollution [2]. The economy has N identical consumers. N is normalized to one. The consumers derive disutility from total pollution emissions e and utility from consumption of good z and Q. A representative consumer has utility given by:

$$U = z + u(Q) - PQ - D(e) \tag{1}$$

where z is consumption of the numeraire good, Q is output of the duopoly, P is the price of good Q, and $D(e)$ is pollution damage where $D' > 0$ and $D'' > 0$. We assume that $u' > 0$ and $u'' < 0$. There are no income effects, and thus we can perform partial equilibrium analysis.

Let q_i denote firm i's output. Each of two Cournot duopolists, firm 1 and 2, has same cost function $c(q_i), c' > 0, c'' \geq 0$. For simplicity, we restrict our attention to difference of pollution emissions, we assume that the only difference across firms is on emissions per unit of output. Firm i's

[2] For simplicity, we analysis duopoly case in the model. However, the results in this section can generalize to $n(n \geq 3)$ firms case.

pollution emissions is $e_i = \theta_i q_i$, where θ_i is the firm-specific constant and we assume that $\theta_1 \leq \theta_2$. If the strict inequality $\theta_1 < \theta_2$ holds, it implies that firm 2 is dirtier than firm 1. Firms cannot reduce their emissions without reducing outputs.

From the utility function (1), we get the inverse demand function $P(Q)$, which satisfies

$$P'(Q) < 0. \tag{2}$$

For stability of the Cournot-Nash equilibrium, we assume

$$P'(Q) + P''(Q)q_i < 0. \tag{3}$$

The profit function for firm i is :

$$\pi^i(q_1, q_2, t) = P(Q)q_i - c(q_i) - t\theta_i q_i \tag{4}$$

where $Q = q_1 + q_2$, and t is a pollution tax per unit of emissions. Given the pollution tax and output of the rival, the first-order condition of profit maximization is

$$P(Q) + P'(Q)q_i - c'(q_i) - t\theta_i = 0. \tag{5}$$

We assume the following two assumptions on firms. Firstly, we identify a firm with owners of the firm's specific factor. This is true as far as the owners of the specific factor represent a negligible fraction of the population. Secondly, we assume that each firm i separately chooses its political contribution s^i to maximize

$$W_i = \pi^i - s^i. \tag{6}$$

Social welfare, ignoring contributions, is given by:

$$W(t) = \int_0^Q P(Q)dQ - c(q_1) - c(q_2) - D(e), \tag{7}$$

where $e = e_1 + e_2$ [3]. For future reference, we define the optimal second-best pollution tax rate t^* which maximizes (7). Differentiating (7) with respect to t, using (5), and then solving for t: we get:

$$t^* = D' + \frac{P'(q_1\frac{dq_1}{dt} + q_2\frac{dq_2}{dt})}{\theta_1\frac{dq_1}{dt} + \theta_2\frac{dq_2}{dt}}. \tag{8}$$

As already pointed by Simpson(1995), the second-best pollution tax rate is not equal to the marginal external damages because of imperfect competition. We assume throughout that the tax reduces total emissions: $\theta_1\frac{dq_1}{dt} + \theta_2\frac{dq_2}{dt} < 0$ [4].

3 The Political Equilibrium

An environmental tax policy is modeled as a three-stage game between the government and the firms. In the first stage, both firms simultaneously and independently offer the government contribution schedules, $(s^1(t), s^2(t))$, as nonnegative differentiable functions of t, taking the other firm's contribution schedule as given. In the second stage, the government chooses a tax policy; t maximizes the government utility, taking the contribution schedules as given. In the third stage, the two firms

[3] We do not discriminate each pollution.

[4] This is always not the case, because the emissions can be increasing in the tax.

compete à la Cournot in the output market ,taking the tax as given [5]. Following Grossman and Helpman (1994), the government assumed to be self-interested and maximizes a weighted sum of political contributions and social welfare. The government's utility function is given by:

$$G(t) = \alpha W(t) + \sum_{i=1}^{2} s^i(t), \tag{9}$$

where α is the given weight on social welfare relative to contributions. Contributions are used by the incumbent politicians to finance the election campaign.

Next we consider an equilibrium conditions. Following Lemma 2 of Bernheim and Whinston (1986), the subgame perfect Nash equilibrium $(t^o, \{s^{io}(t)\}_{i\in\{1,2\}})$ is characterized by the two necessary conditions,

$$(Condition\ 1) \quad t^o \in Argmax\ \alpha W(t) + \sum_{i=1}^{2} s^{io}(t),$$

$$(Condition\ 2) \quad t^o \in Argmax\ \pi^j(t) - s^{jo}(t) + \alpha W(t) + \sum_{i=1}^{2} s^{io}(t), j = 1, 2.$$

Condition 1 states that the government sets a tax policy to maximize its payoff, given the contribution schedules. Condition 2 states that the government sets a tax policy to maximize the joint payoff of firm j and the government, given the contribution schedule offered by the other firm. If this condition were not satisfied, firm j could modify its contribution schedule to induce the government to choose the jointly optimal policy and capture nearly all the surplus from the change.

[5] We ruled out that two firms cooperatively act as a monopoly firm. Because we focus on difference of pollution abatement technology in same industry and cartels are prohibited by antitrust laws in most countries.

Using the first-order conditions of Condition 1 and 2 , a simple calculation yields:

$$\frac{ds^{io}}{dt} = \frac{d\pi^i}{dt}. \tag{10}$$

Eq.(10) implies that contribution schedules are *locally truthful* around the equilibrium tax rate, that is, the marginal change in the firm's contribution for a small change in tax policy equals the marginal change in its profit. Substituting (10) into the first-order condition of (9), we obtain

$$\alpha\frac{dW}{dt} + \sum_{i=1}^{2}\frac{d\pi^i}{dt} = 0 \tag{11}$$

From (5) and (11), we obtain the following proposition.

PROPOSITION 1 *The politically determined environmental tax rate under duopoly is satisfies*

$$t^o = D' + \frac{P'(q_1\frac{dq_1}{dt} + q_2\frac{dq_2}{dt})}{\theta_1\frac{dq_1}{dt} + \theta_2\frac{dq_2}{dt}} + \frac{-(\frac{d\pi^1}{dt} + \frac{d\pi^2}{dt})}{\alpha(\theta_1\frac{dq_1}{dt} + \theta_2\frac{dq_2}{dt})}. \tag{12}$$

The above result is explained as follows. The first term on the right-hand side of (12) denotes the marginal external damages. The second term denotes *the imperfect competition effect*, which is the difference between the second best pollution tax rate under oligopoly (8) and the Pigouvian tax rate. This reflects a correction due to the underproduction resulting from imperfect competition. The third term denotes *the lobbying effect*, which represents political pressures from firms. The numerator of this term is the sum of the marginal change in each firm's profit reduction for a small change in tax policy. Its sign is undetermined. Then, while the sign of the denominator of this term is negative, the sign of the third term is ambiguous. Hence, according to the difference of cleanliness, pressures from lobby groups may reinforce each other or may offset each other.

Let us first state a straightforward corollary.

Corollary 1 *If the sum of the imperfect competition effect and the lobbying effect in the equilibrium equals zero, then Pigouvian tax will be realized in the political equilibrium.*

Next, we consider a symmetric duopoly case ($\theta^1 = \theta^2$), (12) is reduced to

$$t^0 = D' + \frac{P' q_i}{\theta_i} + \frac{-\frac{d\pi^i}{dt}}{\alpha \theta_i \frac{dq_i}{dt}}. \tag{13}$$

Because the sign of dq_i/dt and $d\pi^i/dt$ are negative in symmetric case [6]. The second and third terms on the right-hand side of (13) is always negative respectively. In symmetric case, firms' lobbying pressures always reinforce each other. In this case, it appears that two firms form one lobby group.

Corollary 2

If two firms are symmetric, then the political equilibrium tax must be less than the marginal external damages of pollution.

[6] See,Simpson(1995),p.362 and p.365.

Let us consider the over-internalization case. Sufficient conditions for inequality $t^o > D'$ to hold are that the numerators of the second and third term of the right-hand side of (12) have positive signs. Differentiating (4) with respect to t, we obtain:

$$\frac{d\pi^i}{dt} = [P(Q) + P'(Q)q_i - c'(q_i) - t\theta_i]\frac{dq_i}{dt} + P'q_i\frac{dq_j}{dt} - \theta_i q_i. \qquad (14)$$

where the term in square brackets in the right-hand side is zero from the first-order condition (5) of profit maximization. From (12) and (14), the sufficient conditions of $t^o > D'$ are

$$q_1\frac{dq_1}{dt} + q_2\frac{dq_2}{dt} > 0 \qquad (15)$$

and

$$q_1\frac{dq_2}{dt} + q_2\frac{dq_1}{dt} < \frac{\theta_1 q_1 + \theta_2 q_2}{P'}. \qquad (16)$$

According to the discussion of Simpson(1995), only firm 1 can have positive sign of both dq_1/dt , because in our model firm 1 has a cost advantage to firm 2. Then, dq_1/dt may be positive, while dq_2/dt is always negative. Accordingly, when dq_1/dt and q_1 is sufficiently large, we can expect that $t^o > D'$ holds.

Last in this section, we note that the result that the politically determined tax may exceed the Pigouvian level is the oligopoly-specific phenomenon. First, consider perfect competition. By $P' = 0$, the imperfect competition effect term in (12) is zero. Moreover the lobbying effect is always negative because $d\pi^i/dt = -t\theta_i$. Hence $t^o < D'$. Under perfect competition, lobbying of firms always tends to push the tax rate below the marginal external damages [7]. Second, consider monopoly. It is easy to derive that the tax rate under monopoly is $t^o = D' + (P'q/\theta) + (\theta q/(\alpha dq/dt))$. Hence also $t^o < D'$. Under monopoly, lobbying of a monopoly firm also does. Consequently, politically over-internalization may occur only under oligopoly case.

4 The Equilibrium Tax and Firm Heterogeneity

In this section, we focus on the relationship between a pollution tax policy and firm heterogeneity. We seek the value of emission coefficients under which the equilibrium tax becomes the Pigouvian level, and examine the change in tax policy for a change in emission coefficients.

In order to clear results, we introduce linear assumptions hereafter: $P(Q) = a - bQ$, $c(q_i) = cq_i$, and $D' = d$. Under these assumptions, from the standard derivation of Cournot duopoly, we now obtain

$$q_i = \frac{a - c - 2\theta_i t + \theta_j t}{3b}. \tag{17}$$

Using (17), we can calculate (12) as follows.

$$t^o = d + (\frac{b}{2} + \frac{b}{\alpha})\frac{q_1(2\theta_1 - \theta_2) + q_2(2\theta_2 - \theta_1)}{\theta_1\theta_2 - \theta_1^2 - \theta_2^2} \tag{18}$$

In (18), the product of $(b/2)$ and the last fraction term on the right-hand side is the imperfect competition effect and the product of (b/α) and the

[7] Fredriksson(1997) considers a perfectly competitive firms in a small open economy.

last fraction term is the lobbying effect. The following proposition can therefore be stated.

Proposition 2 *Assume demand and cost functions are linear. The imperfect competition effect and the lobbying effect have the same sign. And the value of the lobbying effect is* $2/\alpha$ *times as large as the imperfect competition effect.*

Without loss of generality, let θ_1 be fixed. Output of firm i can be expressed as $q_i(t, \theta_2)$. Putting $t = d$, we solve for θ_2 that satisfies

$$q_1(d, \theta_2)(2\theta_1 - \theta_2) + q_2(d, \theta_2)(2\theta_2 - \theta_1) = 0. \tag{19}$$

Using (17), the solution of (19) is

$$\hat{\theta}_2 = \frac{1}{10d}\left\{a - c + 8\theta_1 d + \sqrt{(a-c)^2 + 36\theta_1 d(a - c - \theta_1 d)}\right\} \tag{20}$$

In the Appendix, we prove that $\hat{\theta}_2$ is a unique solution to the equation (19) s.t. $\theta_2 \geq \theta_1$. Under $\theta_2 = \hat{\theta}_2$, the imperfect competition effect and the lobbying effect are vanished. Then the equilibrium tax become the Pigouvian level.

Proposition 3 We assume demand and cost functions are linear. If $\theta_2 = \hat{\theta}_2$, then the political equilibrium tax is equal to the marginal external damages , $t^o = D'$.

Substituting (17) into (18), We can solve the equilibrium tax as a function of parameters:

$$t^o = \frac{6\alpha d(\theta_1^2 - \theta_1\theta_2 + \theta_2^2) - (a-c)(2+\alpha)(\theta_1+\theta_2)}{2\theta_1\theta_2(8+\alpha) - (10-\alpha)(\theta_1^2+\theta_2^2)}. \qquad (21)$$

We assume that the second-order condition of (9) is satisfied, the denominator of (21) has positive sign. From (21), it is clear that the equilibrium tax does not depend on the slope of the demand function [8].

With (21), it is straightforward to compute the effects of the equilibrium tax as the exogenous parameters change.

$$\frac{dt^o}{dc} = \frac{(\alpha+2)(\theta_1+\theta_2)}{2\theta_1\theta_2(8+\alpha) - (10-\alpha)(\theta_1^2+\theta_2^2)} > 0 \qquad (22)$$

$$\frac{dt^o}{dd} = \frac{6\alpha(\theta_1^2 - \theta_1\theta_2 + \theta_2^2)}{2\theta_1\theta_2(8+\alpha) - (10-\alpha)(\theta_1^2+\theta_2^2)} > 0 \qquad (23)$$

By (22) and (23), the equilibrium tax is increasing in the marginal cost and the marginal external damages [9].

A numerical example Last in this section, we consider the effect on the equilibrium tax of firm heterogeneity by a numerical example. Let be $a = 6, b = c = d = \theta_1 = 1$, and $\alpha = 3$. When $\theta_2 = \hat{\theta}_2 = 2.6$, the politically equilibrium tax coincides with the marginal external damages, $t^o = d = 1$. Table I shows what occur when the value of the emission coefficient of firm 2 is varied around $\hat{\theta}_2$.

From the viewpoint of the firm 1, an increase in the tax rate causes its own cost to increase, and its rival's cost to increase more than that. Since

[8]This property holds only linear demand function case.

[9]The derivation of $dt^o/d\theta_2$ is omitted because it is complex and its sign is ambiguous.

this raises the market share of firm 1 in the final stage, firm 1 benefits from an increase in the tax. If so, firm 1 takes strategic action that favor a higher pollution tax ($ds^1/dt = d\pi^1/dt > 0$). On the other hand, from the viewpoint of the firm 2 , an increase in the tax rate always decreases in its profit. Since firm 2 benefits from a decrease in the pollution tax in the final stage, firm 2 favors a lower pollution tax . Hence, firm 2 favors a lower pollution tax ($ds^2/dt = d\pi^2/dt < 0$) in the first stage.

Whether the equilibrium tax is larger or less than the marginal external damages depends on difference in emissions per unit of output across two firms. Implication of the three cases is as follows. In case (i), lobbying effort by firm 2 dominates that by firm 1 ($ds^1/dt < |ds^2/dt|$) , the equilibrium tax is less than the marginal external damages. Case (ii) is the critical state where firm 1's contribution counterbalances with firm 2's that ($ds^1/dt = |ds^2/dt|$). Because both firm's lobbying effort cancel out each other, Hence, the lobbing effect is vanished. From Proposition 2, the imperfect competition effect is also vanished. The equilibrium tax is exactly the marginal external damages. It implies that if firm heterogeneity is a certain level, the social optimum is achieved. Note that this full internalization realized without lobbying of an environmental organization or other industries. In case (iii), lobbying effort by firm 2 dominates that of firm 1 ($ds^1/dt > |ds^2/dt|$) , the equilibrium tax is larger than the marginal external damages.

5 Conclusions

This paper presents a model in which the pollution tax is determined endogenously. The paper focuses on the politically determined pollution tax under the asymmetric duopoly. The value of the equilibrium tax is decomposed of the marginal external damage term, the imperfect competition effect term, and the lobbying effect term. If the sum of the last two terms are zero, the equilibrium tax coincides with Pigouvian tax. This property is an oligopoly-specific phenomenon. Under the linearity of demand and cost functions, we solve the equilibrium tax rate which is expressed as a function of the emissions per unit output and other parameters. We derive the condition of the emission coefficient that the politically determined pollution tax is just the marginal external damages where the political and imperfect competition distortion are vanished.

Implications of this paper is to analyze the role of strategic behaviors of oligopolistic firms. Each firm has to choose not only output level but also political contribution. The choice of political contributions influences a pollution tax policy, and then the tax policy influences outputs and profits of firms. Another implication of this paper is to show a relationship between firm heterogeneity and the equilibrium tax. The numerical example in the last section shows the following results. If firm heterogeneity is so large, the effort of the cleaner firm dominates that of the dirtier firm and the equilibrium tax is larger than Pigouvian level. In this case, the cleaner firm may lead to adopt an environment-friendly policy like an environmental group in the political process, whereas an environmental group does not appear in our model unlike many studies in the political approach to environmental policy.

In future research, the model should be extended and improved in several directions. The first extension is related to the asymmetric regulation in imperfect markets. Recent studies about pollution tax on an asymmetric oligopoly consider firm-specific taxes on pollution emissions. For example, Long and Soubeyran (2005) advocate that optimal tax rates per unit of emissions are not the same for heterogeneous oligopolists,i.e., an inefficient firm must incur a higher tax rate. However, if firm-specific taxes are affected by lobbying activities of firms, the theoretical result should be modified. An inefficient firm may be successful in getting a lower tax rate. Second extension incorporates environmental R&D to alter emission coefficients per unit of output. When cleanliness of each firm is endogenized, each firm reasonably spends R&D investment and political contributions. This will make strategic interaction between firms more complex.

Appendix

Proof of Proposition 3

We prove that $\hat{\theta}_2$ is a unique solution to the equation $\lambda(\hat{\theta}_2) = 0$ s.t. $\theta_2 \geq \theta_1$. Since the left hand side of (19) is a quadratic function of θ_2, we can find two solutions:

$$\hat{\theta}_2 = \frac{1}{10d} \left\{ a - c + 8\theta_1 d + \sqrt{(a-c)^2 + 36\theta_1 d(a - c - \theta_1 d)} \right\}$$

and

$$\tilde{\theta}_2 = \frac{1}{10d}\left\{a - c + 8\theta_1 d - \sqrt{(a-c)^2 + 36\theta_1 d(a - c - \theta_1 d)}\right\}.$$

But, a simple proof by contradiction shows that $\tilde{\theta}_2$ does not satisfied the assumption that $\theta_2 \geq \theta_1$. $(1/10d)(a-c+8\theta_1 d - \sqrt{(a-c)^2 + 36\theta_1 d(a-c-\theta_1 d)}) \geq \theta_1 \iff a - c - 2d\theta_1 \geq \sqrt{(a-c)^2 + 36\theta_1 d(a-c-\theta_1 d)} \iff (a - c - 2d\theta_1)^2 \geq (a-c)^2 + 36\theta_1 d(a - c - \theta_1 d \iff -40d\theta_1(a - c - d\theta_1) \geq 0$. But, from the assumptions that both firms produce positive amounts, $q_2 = (a - c - 2\theta_2 d + \theta_1 d)/3b > 0$, and $\theta_2 \geq \theta_1$, the sign of $(a - c - d\theta_1)$ must be positive. A contradiction occurs.

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Table I Impact of firm 2 's emission coefficient on tax, outputs, and contribution schedules

Case	θ_2	t^o	q_1	q_2	$\frac{ds^{1o}}{dt}$	$\frac{ds^{2o}}{dt}$
(i) Under-internalization	2.595	0.89	1.843	0.423	0.731	-1.183
(ii) Full-internalization	2.6	1	1.867	0.267	0.747	-0.747
(iii) Over-internalization	2.605	1.116	1.892	0.101	0.763	-0.282