Economics Bulletin

Volume 35, Issue 4

Determination of efficient environmental policy instruments under uncertainty with the dominant firm model

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Abstract

This paper reveals what the optimal environmental policy instruments under uncertainty are when there is one mighty (dominant) firm in a group of firms that produce homogeneous products. We extend and improve the research findings of Weitzman (1974). A dominant firm affects the decision making of other fringe firms. In this paper, we look at a case where a regulator implements environmental policy instruments, such as taxes or a quota, by focusing predominantly on the dominant firm. This paper estimates efficient policy by examining the deadweight loss caused by integrating the marginal abatement cost (MAC) to the marginal damage (MD). We set two parameters to measure the slope of the MD and that of the MAC for the fringe firms against that of the MAC for the dominant firm. This is done to estimate efficient policy and its preconditions. Consequently, the regulation adversely impacts each firm in the dominant firm model. Tax regulation is superior to the implementation of a quota when the slope of the MAC is equal to that of the MD, whereas the two policies have the same effect under the same conditions in the study by Weitzman (1974). Additionally, a quota policy is preferred when the MAC for the fringe firms is flatter than that of the dominant firm in contrast to the study by Weitzman (1974).

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Acknowledgements The author expresses sincere gratitude to Prof. Toshiyuki Fujita, Prof. Hsiao-Chi Chen, and Prof. Takashi Saito for constructive comments. All other remaining errors are my responsibility.
Citation: Daiken Mori, (2015) "Determination of efficient environmental policy instruments under uncertainty with the dominant firm model", *Economics Bulletin*, Volume 35, Issue 4, pages 2637-2644
Contact: Daiken Mori - daikenmori86@yahoo.co.jp.
Submitted: June 11, 2015. **Published:** December 13, 2015.

1. Introduction

Weitzman (1974) examines the appropriate policy to be chosen, price regulation or a quota, when there is uncertainty in the market. This paper clarifies the viewpoint that price regulation is preferred when the slope of the marginal benefit is flatter than that of the marginal cost, while a quota is preferred when the marginal benefit is steeper than that of the marginal cost. Weitzman's (1974) paper significantly contributes toward the determination of efficient regulation when the regulators cannot ascertain accurate information. Many studies have been based on Weitzman's prices vs. quantities analysis. Weitzman's analysis has been extended to two sectors (see Mandell (2008)) or to multiple pollutants (see Ambec and Coria (2013)) in recent years. In practice, however, the regulated targets are not all polluting firms.

Environmental policy schemes such as the European Union Emission Trading Scheme (EU-ETS) and the Carbon Reduction Commitment (CRC) Energy Efficient Scheme apply to only large facilities. For instance, the EU-ETS covers medium and large emitters such as power stations, cement production, and other installations greater than 20 MWh. The CRC also applies to large businesses and public sector organizations that have an electricity consumption greater than 6,000 MWh per year. The Tokyo Metropolitan Authority launched its emission trading system in 2010, and it required large tenants in commercial buildings to participate in the scheme.[1] We apply the dominant firm model to Weitzman's analysis since we can see that such large facilities have the market power over smaller ones.

Many authors have examined how market power functions in the dominant firm model in terms of efficiency of policy instruments (see Hahn (1984) and Maeda (2003)). Heuson (2010) and Mansur (2013) also examine efficient regulation by considering imperfectly competitive situations. The study by Weitzman (1974) is cited by both studies. Heuson (2010) concludes that the adoption of Weitzman's rule tends to propose the choosing of suboptimal policy instruments like emissions standards rather than taxes. Mansur (2013) assumes a market wherein there is one dominant firm and two types of fringe firms - one competes against the dominant firm while the other one does not - and argues that market power decreases emissions locally by simulation. In addition, the study suggests that tax regulation results in the deadweight loss due to the market power derived from imperfect competition.

We extend the analysis in the study by Weitzman (1974) to the dominant firm model in which there is a dominant firm and many fringe firms within the same market. We assume that the regulator imposes tax regulation or implements a quota only with the dominant firm to minimize the deadweight loss.

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[1] Hood (2010)

We can deduce three rational reasons why only the dominant firm is subject to the policy instruments as follows: (i) applying a policy scheme to the large firm that generates significant pollution or uses a lot energy is more efficient for decreasing social damage, (ii) the regulator could implement the regulation with the dominant firm without impairing other smaller firms' productions incentives, and (iii) the costs for implementing the policy instruments are less. However, it is not theoretically determined what the advantages and the policy implementation conditions are when only the dominant firm is subjected to such policies.

This paper constructs and presents a more simplified model compared with those by Heuson (2010) and Mansur (2013). We set two main objectives in this paper: to identify the optimal policy instruments for the dominant firm under uncertainty only and to clarify the point highlighted in Weitzman's theorem where the author introduced the regulated dominant firm scheme.

Consequently, we can show that the policy implications cause opposite effects on the dominant firm and fringe firms. Interestingly, our conclusions differ from those in Weitzman's theorem under the dominant firm model. The tax regulation is superior to the quota system when the slope of the marginal abatement cost (MAC) equals that of the marginal damage (MD), whereas the two policies have indifferent effects under the same conditions in Weitzman's (1974) study. Additionally, a quota is preferred when the MAC for the fringe firms is flatter than that of the dominant firm in this paper in contrast to the study by Weitzman (1974).

2. The Model

Let us consider a market with a dominant firm and *N* fringe firms. We assume that all firms, even the dominant firm, accepts and complies with the policy of the regulator. The dominant firm also does not influence the regulator. Suppose that each fringe firm has the same cost function. The market demand function is assumed to be $q^M(p) = h - jp$ $(h, j > 0)$, where p denotes price. If we suppose the marginal cost for an individual fringe firm is $MC_i^F(q) = k + mq$, the total supply function for *N* fringe firms is $q^F(p) = N(p-k)/m$ and the total marginal cost for fringe firms is $MC_{tot}^F(q) = k + mq/N$, where $k, m > 0$ are constants. Each fringe firm observes the demand function. The residual demand function for the dominant firm becomes $q^D(p) \equiv q^M(p) - q^F(q)$. Taking the inverse function of $q^D(p)$, we can get the relationship between output of the dominant firm and price as: $p^D(q) = a - bq + \theta$ with replacing $a \equiv (hm + kN)/(jm + N)$ and $b \equiv m/(jm + N)$ for simplicity and introduce the parameter θ to reflect uncertainty.

Let us assume that θ is a continuous stochastic variable and $E[\theta] = 0$. The true value of θ is known to the dominant firm but is unknown to the regulator. The revenue function is defined as $R^D(q) = p^D(q)q$. Following Church and Ware (2000), we define the marginal production cost for the fringe firms as linear function; $C^D(q) = cq$. Here, let us assume that a, b and c are constants, $a - c > 0$. The output level for the dominant firm q^D is determined by equalizing $MR^D(q) = MC^D$. Replacing $a - c = \beta$, we obtain $q^D = (\beta + \theta)/2b$. The market price $\hat{p}$ is given by $\hat{p} \equiv p^D(q^D) = (a + c + \theta)/2$. The individual fringe firm i determines its own output level q_i^F where $MC_i^F(q)$ corresponds to $\hat{p}$ as $q_i^F = (a + c + \theta - 2k)/2m$. Supposing that the total output level for the fringe firms $q^F = \sum_{i=1}^{N} q_i^F$, we can obtain $q^F = N(a + c + \theta - 2k)/2m$.

Here, to hold $q^F \geq 0$, we assume that $(a + c)/2 \geq k$.[2] The regulator tries to make the dominant firm achieve an efficient output level by implementing the policy. We now define the MAC for the dominant firm as $MAC^D(q) = MR^D(q) - MC^D = \beta - 2bq + \theta$. Similarly, the total MAC for the fringe firms is given by $MAC^F(q) = p - MC_{tot}^F(q) \equiv \gamma - mq/N$ where $\gamma = p - k$. The intercept of each MAC takes positive values. Let us make some assumptions as $MC^D < MC^F(0)$, $MC_{tot}^F(0) < \hat{p} < p^D(0) < q^M(p) = 0$.[3]

Both types of firms generate pollution damage through their production activities. We define the social damage due to pollution as a function of output: $D(q) = fq^2/2 + \varepsilon q$. Thus, the social marginal damage is $MD(q) = fq + \varepsilon$ $(f > 0)$. Here, we introduce again the parameter ε which is a continuous stochastic variable with $E[\varepsilon] = 0$. Two stochastic variables θ and ε are independent. The efficient output level e_D^* for the dominant firm is obtained from $MAC^D(q) = MD$:

$$q_D^* = \frac{\beta + \theta - \varepsilon}{2b + f}. \tag{1}$$

The regulator expects an efficient output level of the dominant firm by taking expectation as follows:

$$E[q_D^*] = \frac{\beta}{2b + f} \equiv q_Q^D. \tag{2}$$

We assume that the regulated dominant firm accepts the regulations without objections. From the next section, we clarify which comparative policy instruments have the advantage in terms of the deadweight losses.

3. The Equilibrium with Environmental Policy Instruments

Let us consider the first case, i.e., when the regulator imposes a tax on the dominant firm. When

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[2] This assumption means $MC_{tot}^F(0) \leq \hat{p}$, in short, the intercept of the total marginal costs for the fringe firms is lower than the market price.

[3] Church and Ware (2000) note that if assumption $MC_{tot}^F(0) < \hat{p}$ does not hold, the dominant firm can ignore the fringe's behavior.

the regulator sets the optimal tax rate t^D for the dominant firm by adjusting up to q_Q^D, that equalizes its expected MAC to the tax rate: $t^D = E\left[MAC^D\left(q_Q^D\right)\right] = f\beta/2b + f$. This tax rate shows us that it becomes higher with steeper MD. Under the tax rate t^D, the dominant firm determines its own output level q_t^D where its MAC corresponds to the tax rate: $t^D = MAC^D(q)$. The market price p^t after tax regulation is indicated as $p^t = p^D(q_t^D)$. We can show q_t^D and p^t in Table 1.

Table 1. Equilibrium of the Dominant Firm Model and Market Price

	Determined output level	Market price
Tax	$q_t^D = \dfrac{2b\beta + \theta(2b+f)}{2b(2b+f)}$	$p^t = p^D(q_t^D) = \dfrac{(2b+f)(2a+\theta) - 2b\beta}{2(2b+f)}$
Quota	$q_Q^D = \dfrac{\beta}{2b+f}$	$p^Q = p^D(E^D) = \dfrac{(a+\theta)(2b+f) - b\beta}{(2b+f)}$

Under the market price p^t, the total MAC for the fringe firms changes to $MAC_t^F\ (q)(= \gamma_t - mq/N)$, by supposing $\gamma_t \equiv p^t - k$. We now can introduce the efficient total output level for the fringe firms from $MAC_t^F(q) = MD(q)$: Solving for q, we can obtain q_t^{F*}. When the dominant firm is regulated with tax, the total output level for the fringe firms q_t^F is determined by $p^t = MC_{tot}^F(q)$. We can now show the efficient and determined output level under each regulation in Table 2.

Table 2. Equilibrium of Fringe Firms under Each Regulation

	Efficient level	Actual determined level
Tax	$q_t^{F*} = \dfrac{N[(2b+f)(2a-2k+\theta-2\varepsilon) - 2b\beta]}{2(2b+f)(fN+m)}$	$q_t^F = \dfrac{N[(2b+f)(2a-2k+\theta) - 2b\beta]}{2m(2b+f)}$
Quota	$q_Q^{F*} = \dfrac{N[(2b+f)(a-k+\theta-\varepsilon) - b\beta]}{(2b+f)(fN+m)}$	$q_Q^F = \dfrac{N[(a-k+\theta)(2b+f) - b\beta]}{m(2b+f)}$

Second, let us consider that the regulator implements a quota with the dominant firm. The regulated dominant firm with the quota policy respects the second best output level q_Q^D as in equation (2). Thus, the market price under the quota is established as $p^Q = p^D\left(q_Q^D\right)$ in Table 1.

Similar to the case of tax regulation, the total MAC for the fringe firms changes to $MAC_Q^F\ (q)\left(= \gamma_Q - mq/N\right)$, with $\gamma_Q \equiv p^Q - k$. We can show that the efficient total output level q_Q^{F*} for the dominant firm by $MAC_Q^F\ (q) = MD(q)$. When the dominant firm is regulated with a quota system, the total output level for the fringe firms q_Q^F is determined by $p^Q = MC_{tot}^F(q)$, and is indicated in Table 2. We calculate the deadweight loss and provide the efficient regulation conditions using the above equilibrium in the next section.

4. Result

We can show the inefficiency IE_r^l with regulation, where index *r* means the types of the regulation, *t* or Q, and index l denotes the types of firms. First, the inefficiency of the dominant firm is indicated by integrating $MAC^D - MD^D$ from q_r^D to q_D^*. Under the tax regulation policy,

$$E[IE_t^D] = \left(\frac{f}{2b}\right)^2 \frac{\sigma_\theta^2}{2(2b+f)} + \frac{\sigma_\varepsilon^2}{2(2b+f)}, \tag{3}$$

where σ_θ^2 and σ_ε^2 denote the variance of each parameter θ and ε. From equation (3), we can see that the taxed inefficiency is affected by the slope of the MD and that of the MAC. That is, the inefficiency is improved with decreasing (increasing) MD (MAC). Similarly, under the quota system

$$E\left[IE_Q^D\right] = \frac{\sigma_\theta^2}{2(2b+f)} + \frac{\sigma_\varepsilon^2}{2(2b+f)}. \tag{4}$$

The expected inefficiency of the fringe firms is given by integrating $MAC_r^F - MD^D$ from q_r^F to q_r^{F*} as follows. Under tax regulation

$$E[IE_t^F] = \frac{f^2N^3[b\beta - (a-k)(2b+f)]^2}{2m^2(2b+f)^2(fN+m)} + \frac{f^2N^3\sigma_\theta^2}{8m^2(fN+m)} + \frac{N\sigma_\varepsilon^2}{2(fN+m)}. \tag{5}$$

Under quota

$$E\left[IE_Q^F\right] = \frac{f^2N^3[b\beta - (a-k)(2b+f)]^2}{2m^2(2b+f)^2(fN+m)} + \frac{f^2N^3\sigma_\theta^2}{2m^2(fN+m)} + \frac{N\sigma_\varepsilon^2}{2(fN+m)}. \tag{6}$$

Here, we assume that $f = 2b\lambda$. The parameter $\lambda(>0)$ shows the relationship between the MAC and the MD for the dominant firm. In short, when $\lambda < 1$, the slope of the MD is relatively flatter while it gets steeper when $\lambda > 1$. We can denote the superiority of the policy for the dominant firm using the parameter λ and equation (3) and (4) as follows:

$$E\left[IE_Q^D - IE_t^D\right] = \frac{(1-\lambda)\sigma_\theta^2}{4b}. \tag{7}$$

As is well known, equation (7) represents Weitzman's theorem. The tax should be preferred if $\lambda < 1$. The quota is chosen if the reverse holds. The two policies are indifferent in terms of efficiency when $\lambda = 1$. Here, to clarify the relationship between each MAC and MD between the dominant firm and the fringe firms, we define $m/N = 2bs$. The slope of the MAC for the fringe firms is flatter (steeper) than that of the dominant firm when $s < 1$ $(s > 1)$. The expected deadweight loss with the tax policy is indicated by adding equation (3) and (5). In contrast, the expected deadweight loss with the quota policy is shown by adding equation (4) and (6). Substituting $f = 2b\lambda$ and $m/N = 2bs$ into each expected deadweight loss, we now obtain the following equation:

$$E[DWL^Q - DWL^T] = \frac{[4s^2(\lambda + s)(1-\lambda) + 3\lambda^2]\sigma_\theta^2}{16bs^2(\lambda + s)}. \quad (8)$$

Equation (8) shows the difference of the expected deadweight loss between the tax and quota policies. The superiority of the policy in the dominant firm model depends only on the uncertainty of the MAC. We define the conditional expression in equation (8) as $g(s,\lambda)$:

$$g(s,\lambda) = 4s^2(\lambda + s)(1-\lambda) + 3\lambda^2. \quad (9)$$

So, $g(s,\lambda) > 0$ when $\lambda \leq 1$. The tax should be preferred if $g(s,\lambda) > 0$ while the quota is chosen if the reverse holds. We now describe Figure 1 and 2 to show that taking the value of $g(s,\lambda)$ when changing the parameters s and λ. In Figure 1, the line on the plane indicates the implicit function of $g(s,\lambda)$, it denotes the border of the recommendable policy. The light grey area expresses $g(s,\lambda) > 0$, and the dark grey area shows $g(s,\lambda) < 0$. Figure 2 shows Figure 1 viewed directly from above. From equation (9) and Figure 1, we can obtain the following proposition:

Figure 1 Preferred Policy Zone with the Change in the Parameters s and λ

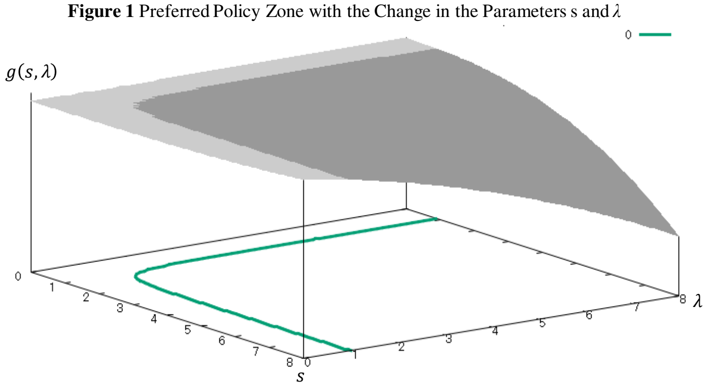
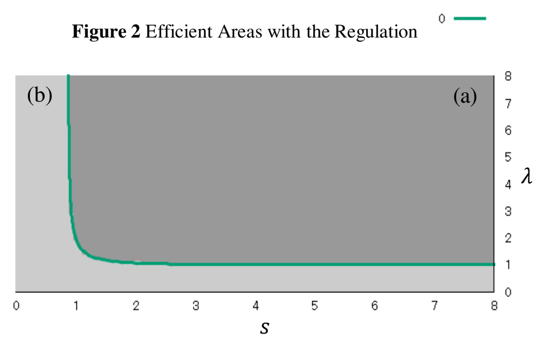


Figure 2 Efficient Areas with the Regulation



Proposition: *When the parameter λ or s takes a small value while another one takes a large value, or both parameters take a small value, the regulator should undertake the tax regulation. However, if both parameters take large values, the quota regulation is preferred.*

Under the dominant firm model, Weitzman's theorem is revised as above, and this proposition provides us with some interesting findings. First, when the slopes of the MAC and the MD are equal $(f = 2b)$, the tax regulation system is superior to the quota system. Additionally, the tax policy is preferred when the MAC for the fringe firms is flatter than that of the dominant firm in this paper $(1 < \lambda \ and \ s < 1)$. This conclusion is at variance with that of Weitzman (1974).

The dominant firm needs to consider the fringe firms' behavior, unlike in the case of a monopolistic market. The market power of the dominant firm and market price are influenced by the fringe firms' marginal cost and output level.[4] Intuitively, the fringe firms could get the opportunity to expand their output level if the output level of the dominant firm is decreased through regulation.[5]

Let us consider two simple examples. One is where the fringe firms have very good environmental technology while social damage is serious. In this case, both parameters, s and λ, take reasonably large values (in Figure 2 (a)). In this case, we understand that the dominant firm triggers serious social harm without environmental production technology.[6] To control the dominant firm's output level, even while the fringe firms keep the incentive for extending their output level, the regulator should choose the quota system. The other case is where the social damage is not large but where the fringe firms' technology is environmentally unfriendly (in Figure 2 (b)).[7] In this instance, the regulator should prefer the price regulation system since the tax can decrease the output level of the fringe firms and increase that of the eco-friendly dominant firm.

5. Conclusions

This paper considers efficient policies, including tax regulation or a quota system in the dominant firm model. Weitzman's theorem can be adopted when there is only one type of firm in the market. However, once the market power is exercised, different types of firms need to consider each other's behavior through market prices and output levels. Consequently, regulation adversely impacts each firm in terms of the determination of output level. The quota should be preferred when the slopes of the MD and the MAC for fringe firms are steeper. In contrast, the tax policy is chosen when the MD is large while at the same time the MAC for fringe firms is relatively small if the inverse is true. The dominant firm seemingly can affect the fringe firms in a unilateral way through their market power. However, in this model, the dominant firm and fringe firms interact with each other in practice. This paper contributes by way of revising Weitzman's theorem model and using the

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4 Church and Ware (2000)

5 We can confirm this exercise in terms of integration of marginal damage easily. Let us define the expected aggregate marginal damage as $E[AMD_r^l] = E\left[\int_0^{q_r^l} MD\, dq\right]$. Compare to the aggregate marginal damage of each type of firm under the regulation, we can obtain following results: $E\left[AMD_Q^F - AMD_T^F\right] = \frac{fN^2\sigma_\theta^2}{8m^2} > 0$, and $E\left[AMD_Q^D - AMD_T^D\right] = -\frac{f\sigma_\theta^2}{8b^2} < 0$. From these equations, we can show that the regulation causes opposite work in each firm.

6 In this case, the environmental technology of the firm is less mature (although it has the potential to develop it further in the future).

7 For instance, this case shows that the mighty firm takes the lead in green action.

distinctive interaction in the dominant firm model.

We do not consider the influence of altruistic firms in this paper. In terms of future direction, it would be interesting to consider the existence of irrational firms in our model. We assume that all firms, not only the dominant firm but also the fringe firms, have a profit-maximizing strategy. However, recently, large firms have become highly interested in environmental conservation activities. Our model could approximate an actual business environment, which emphasizes ecological behavior, by considering altruism in the future.

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