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Mori, Daiken
Faculty of Economics, Kyushu University

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Daiken Mori
九州大学

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Faculty of Economics
Kyushu University
Hakozaki, Higashi-ku, Fukuoka, 812-8581, Japan

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Daiken Mori[1]

Abstract

This paper seeks to examine the superiority of the mixed policy and uniform regulation on two distortions - markets power and negative externality - in the market and uncertainty. Contrary to Mandell's (2008) conclusion, we show that the mixed policy can be dominated when the price elasticity of demand is high. We also demonstrate that having pricing power by firms causes distortions in the market and the chosen domain of dominant mixed policy in imperfectly competitive markets shrinks compared to perfectly competitive markets.

l. Introduction

This study provides the practical condition of optimal environmental policy with uncertainty in imperfectly competitive markets with two distortions: pricing power by pollutant firm and externality. Weitzman (1974) examines which policy (quota or price regulation) is superior by using the relationship between the slope of marginal external cost (MEC) and that of marginal benefit (MB). The result reveals that quota (price regulation) is preferred when the slope of MEC is steeper (flatter) than that of MB.

The European Emission Trading Scheme (EU-ETS) is arguably one of the largest environmental policy measures while the Kyoto Protocol which preceded the EU-ETS no longer work effectively, as many countries (including Japan) have not complied in the second commitment period. Therefore, it is imperative for non-participating countries to consider substitute policy instead of the 1997 Kyoto Protocol. In Japan for instance, the economic instrument for conserving environment is rooted in the local environmental tax system. Although the uniform tax systems in the country started back

[1] Faculty of Economics, Kyushu University
dmori@econ.kyushu-u.ac.jp

in 2012, the policy has advanced rather slowly and the gains from the policy remain debatable.

Mandell (2008), Ambec and Coria (2013) and Roberts and Spence (1976) are some important papers, based on Weitzman (1974), that examine this issue using not only uniform policy but also mixed policy. Mandell (2008) shows that mixed policy, rather than uniform regulation, should be chosen when multiple pollutant firms are divided into two sectors. He also clarifies that the optimal number of taxed firm increases with the steeping of MEC's slope than that of the MB. Ambec and Coria (2013) examine the relationship between determined policy measures and the characteristic of pollutant. Consequently, mixed policy is chosen (dominated) if pollutants are complements (substitutes).

Against this backdrop, this paper extends Mandell (2008). Specifically, it attempts to elucidate the optimal environmental policy measures when the regulator faces two distortions, under-productivity since the firms are price maker and over-productivity by ignoring external pollutant damage. Not much is known about influencing the determination of optimal policy with the distortion by pricing power in imperfectly competitive markets. About dealing with uncertainty, we assume that the market demand function and production cost function have continuous stochastic variables. Bovenberg and de Mooij (1994), and Schoonbeek and de Vries (2009) including Buchanan (1969) and Barnett (1980) analyze optimal environmental policy in imperfectly competitive markets. Schoonbeek and de Vries (2009) in particular examine environmental tax under monopolistic market.

We compare the appropriate policy in terms of social welfare by using three types of policy measures - quota, price regulation and mixed policy. We also focus on change of policy measures with changing market structure. Establishing the relationship between scale of externality and the appropriate policy is important for policy makers and regulators.

Going forward, this paper is organized as follows: In Section 2, we outline the model we employ in this paper and analyze the relationship between uniform policy and externality emitted by a firm in imperfectly competitive markets. In Section 3, we verify the same approach with previous section based on perfectly competitive market to compare the result with Mandell (2008), and focus on the difference in the markets on whether they are perfectly competitive or not.

On the whole, our findings suggest that mixed policy is dominated by uniform regulation when external volume takes extreme value in imperfectly competitive markets with pricing power. This goes contrary to Mandell's (2008) conclusion that mixed policy dominates uniform regulation, but price regulation (quota) dominates other policies as externality is assumed small (large). Our findings appear to suggest that adaptable mixed policy is suitable about additional distortions which inhibit strong market structure with extending to imperfectly competitive markets. However, domain of the mixed policy shrinks compared to a case where the market is perfectly competitive.

2. The Model

Let us assume that there are N firms in this market and they are divided into two groups, A and B. Firms 1 to n belong to group A and firms $n+1$ to N belong to group B. Every firm is equivalent and all of them has the market power. Total output level of each group is denoted as $q_A = \sum_{n=1}^{n} q_i, q_B = \sum_{n+1=1}^{N} q_i$ where q_i indicates the output level by individual firm i which has market power. Total output level is defined as $q_{tot} = \sum_{n=1}^{N} q_i$ $(\equiv q_A + q_B)$ in the whole markets. We now assume that inverse demand function is defined as:

$$\delta(q_{tot}, \theta) = a - bq_{tot} + \theta \tag{1}$$

where a, b are constants $(a, b > 0)$, and θ is continuous stochastic variable. When individual cost function is same, we define the cost functions of firm i as $C_i(q_i, \varepsilon) = m{q_i}^2/2 + (k + \varepsilon)q_i$. The values k and m are constants $(k, m > 0)$, $a > k$, $a + \theta > k + \varepsilon$ and $dC_i(q_i, \varepsilon)/dq_i > 0$, $dC_i^2(q_i, \varepsilon)/dq_i^2 < 0$. The parameter ε is a continuous stochastic variable while θ and ε are independent and symmetrically distributed around zero. The regulator knows that the expected values of θ and ε are zero: $E(\theta) = 0$,

$E(\varepsilon) = 0$. The firm generates pollutants when producing a good. We can denote marginal external damage for society as $\lambda\,(\lambda > 0)$, and the social damage function as $D_i = (\lambda - m)q_i^2/2$ by firm i. Let us consider that the market has negative (positive) externality when $\lambda > m$ ($\lambda < m$). We can see that the marginal cost and social marginal cost equalize when $\lambda = m$. In this paper, we are not concerned with the case of $\lambda \leq m$.

We evaluate the superiority of three types of policies - price regulation (subsidy), quota and mixed policy - in terms of social welfare. Under mixed policy, one group is taxed while the other is regulated with a quota. Social Welfare comprises the consumer surplus ($CS = q_{tot}/2\,[(a+\theta) - \delta(q_{tot},\theta)]$) , the producer surplus ($PS = N[q_i\delta(q_{tot},\theta) - C_i(q_i,\varepsilon)]$), and external damage due to pollutants ($D = N(\lambda - m)q_i^2/2$). We define social welfare as $SW = CS + PS - D$. Thus, social welfare is indicated by the following equation:

$$SW = q_{tot}\left[(a - k + \theta - \varepsilon) - \frac{b}{2}q_{tot}\right] - \frac{N\lambda}{2}q_i^2 \tag{2}$$

We can get social optimal output level q_i^* by solving the maximum problem of (2) as follows:

$$q_i^* = \frac{(a - k + \theta - \varepsilon)}{bN + \lambda} \tag{3}$$

The second best output level E_i by taking expectation optimal level:

$$E_i = E[q_i^*] = \frac{(a-k)}{bN + \lambda} \tag{4}$$

Let us consider another policy measure, subsidy regulation. To achieve second best level, we assume that the regulator set subsidy rate s_i as $s_i = E[MC_i(E_i,\varepsilon) - MR_i(E_i,\theta)]$.

From the above equation, the subsidy rate of imposed firm i by regulator s_i is

$s_i = (2bN + m)E_i - (a - k)$.The output level after the price regulation q_i^s is gained by $MC_i^S(q_i,\varepsilon) = MR_i(q_i,q_j,\theta)$, here, $MC_i^S(q_i,\varepsilon) = MC_i(q_i,\varepsilon) - s_i$:

$$q_i^s = E_i + \frac{(\theta - \varepsilon)}{(2bN + m)} \tag{5}$$

3. Comparison of Policies under Perfectly or Imperfectly Competitive Markets

3.1 Output level under perfectly competitive markets

Let us analyze optimal environmental policy measures when all firms are price takers. Optimal and second best output level can be written as follows by using equation (3) and (4):

$$q_{tot}^{*} = \frac{N(a - k + \theta - \varepsilon)}{(bN + \lambda)} \tag{6}$$

$$E_{tot} = \frac{N(a - k)}{(bN + \lambda)} = q_{tot}^{*} - \frac{N(\theta - \varepsilon)}{(bN + \lambda)} \tag{7}$$

These markets are perfectly competitive now, indicating that all firms decide their own production behavior as the prices are given. Thus, we need to introduce the total marginal cost function. Total cost function is defined as:

$$C_{tot}(q_{tot}, \varepsilon) = \frac{m}{2N} q_{tot}^{2} + (k + \varepsilon) q_{tot}.$$

We can get the following maximum problem and first-order condition to suppose that the regulator implements subsidy regulation as giving subsidy s^{P} for firms per unit with decreasing their output volume from q_{tot}^{m}.

$$\max_{q_i} q(\delta, \theta) q_{tot} - C_{tot}(q_{tot}, \varepsilon) + s^{P}(q_{tot}^{m} - q_{tot})$$

$$q(\delta, \theta) = MC_{tot}(q_{tot}, \varepsilon) + \mathrm{s}^{p} \Leftrightarrow q(\delta, \theta) - MC_{tot}(q_{tot}, \varepsilon) = s^{p}$$

An actual determined output level and under mixed policy are indicated as follows because the regulator takes a decision of the subsidy rate at the second best level $\bar{q}_{tot}$.

$$q_{tot}^{price} = E_{tot} + \frac{N(\theta - \varepsilon)}{(bN + m)} \tag{8}$$

$$q_{tot}^{mix} = E_{tot} + \frac{N(\theta - \varepsilon)}{2(bN + m)} \tag{9}$$

The social welfare under perfectly competitive market SW^p is also defined as in equation (2). We denote the differences of social welfare that price regulation and quota, price regulation and mixed policy, and mixed policy and quota as $\Delta SW_1, \Delta SW_2$ and ΔSW_3 to examine the superiority of policies (A detailed explanation on how each social welfare is introduced is provided in Appendix 2. (a)).

$$\Delta SW_1^p = E\left[SW^p|_{q_{tot}^{price}}\right] - E\left[SW^p|_{q_{tot}^{quota}}\right] = \frac{N(bN + 2m - \lambda)(\sigma_\theta^2 + \sigma_\varepsilon^2)}{2(bN + m)^2}$$

$$\Delta SW_2^p = E\left[SW^p|_{q_{tot}^{price}}\right] - E\left[SW^p|_{q_{tot}^{mix}}\right] = \frac{N(bN + 4m - 3\lambda)(\sigma_\theta^2 + \sigma_\varepsilon^2)}{8(bN + m)^2}$$

$$\Delta SW_3^p = E\left[SW^p|_{q_{tot}^{mix}}\right] - E\left[SW^p|_{q_{tot}^{quota}}\right] = \frac{N(3bN + 4m - \lambda)(\sigma_\theta^2 + \sigma_\varepsilon^2)}{8(bN + m)^2}$$

Let us define a border of chosen policy, that is $\Delta SW_h^p = 0$ by λ as λ_h^p. Each λ_h^p are denoted and obtained following first lemma:

$$\lambda_1^p = \frac{bN + 4m}{3} \qquad (10)$$

$$\lambda_2^p = bN + 2m \qquad (11)$$

$$\lambda_3^p = 3bN + 4m \qquad (12)$$

Lemma 1. *The condition of implementing appropriate policy is set by using λ_h^p; determined policy is subsidy when $\lambda < \lambda_1^p$, mixed policy when $\lambda_1^p < \lambda < \lambda_2^p$ or $\lambda_2^p < \lambda < \lambda_3^p$ and quota regulation when $\lambda_3^p < \lambda$ in perfectly competitive markets.*

3.2 Output level under imperfectly competitive markets

Let us consider a case where the market is imperfectly competitive, and all firms are price-makers. Under imperfectly competitive markets, Optimal output level, second best one and the level after subsidy is expressed as in equations (3), (4) and (5) respectively. To define each difference of social welfare that price and quota, price and mixed, and mixed and quota as $\Delta SW_1^I, \Delta SW_2^I$ and ΔSW_3^I, the differences are denoted by the following equations (See Appendix 2 (b) for explanations on how to yield social welfare).

$$\Delta SW_1^I = \frac{N(bN + 2m - \lambda)\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{(bN + m)^2}$$

$$\Delta SW_2^I = \frac{N(bN + 4m - 2\lambda)\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{8(bN + m)^2}$$

$$\Delta SW_3^I = \frac{N(3bN + 2m - 2\lambda)\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{8(bN + m)^2}$$

Setting λ_h^I as $\Delta SW_h^I = 0$ by λ, the borders of determined policy λ and the lemma are obtained as follow:

$$\lambda_1^I = bn + 2m = \frac{bN + 4m}{2} \tag{13}$$

$$\lambda_2^I = 2(bn + m) = bN + 2m \tag{14}$$

$$\lambda_3^I = 3bn + 2m = \frac{3bN + 4m}{2} \tag{15}$$

Lemma 2. *Suppose that* $N = 2n$, $\alpha = \gamma = 1$ $(N \geq 2)$, *the condition of implementing appropriate policy is set by using* λ_h^I*; determined policy is subsidy when* $\lambda < \lambda_1^I$, *mixed policy when* $\lambda_1^I < \lambda < \lambda_2^I$ *or* $\lambda_2^I < \lambda < \lambda_3^I$ *and quota regulation when* $\lambda_3^I < \lambda$ *in imperfectly competitive markets.*

Comparing the borders of determined policy in each market structure, we can get the following proposition:

Proposition 1. *The domain in which mixed policy is chosen as second best policy shrinks in imperfectly competitive markets against perfectly competitive markets. On the other hand, the domain in which uniform regulation is effective expands in markets that are imperfect.*

When all firms are homogeneous in terms of production cost, the domain in which mixed policy is dominant shrinks (expands) with decrease (increase) in the value of *b* and/or *N*. This means that the firms produce necessary goods, or goods with no substitute, when b is large (price elasticity of demand is small). On the other hand, if price elasticity of demand is large, we can consider that the firms produce luxury goods. Pollutants increase in number of firms.

3.3 Optimal environmental policy measures

We clarified the relationship between marginal external damage and second best policy under two types of market structure. Here, we pay attention to differences in policy decision method with changing firms' type by comparing the two market structures. The border of preferred policy by λ is expressed in (10)～(12) when markets are competitive, while the border is given as in (13)～(15) when markets are not competitive.

As highlighted in the above proposition, the domain in which mixed policy is chosen as second best policy shrinks in imperfectly competitive markets against perfectly competitive markets.

How does the difference of market structure affect the range of efficient policy? Mandell (2008) examined how such system that price and quota regulation have different effects to firms works by using volume error. We also analyze the issue in terms of volume error just as in Mandell (2008).

In this paper, we examine how the value of volume error changes compared with perfectly competitive firms that are price-takers. To simplify the analysis, let us consider that the price and quota regulations are indifferent by using (11) and (14) is same ($\lambda = bN + 2m$). First, let us yield volume error under markets that are competitive as in Mandell (2008). Social welfare at optimal level under perfectly competitive markets is given by:

$$SW^{P*} = (a - k + \theta - \varepsilon)q_{tot}^{*} - \left(\frac{bN + \lambda}{2N}\right){q_{tot}^{*}}^{2} = \frac{N(a - k + \theta - \varepsilon)^{2}}{2(bN + \lambda)}$$

and the expectation value is:

$$E[SW^{P*}] = E\left[SW^{p}{}_{|E_{tot}}\right] + \frac{N\left(\sigma_{\theta}^{2} + \sigma_{\varepsilon}^{2}\right)}{2(bN + \lambda)}.$$

The volume error of social welfare under quota and optimal level is defined as:

$$E\left[SW^{p}_{|VE1}\right] = E[SW^{P*}] - E\left[SW^{p}{}_{|uniform}\right] = \frac{N\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{2(bN + \lambda)}. \qquad (16)$$

The volume error under mixed policy and optimal level is

$$E\left[SW^{p}_{|VE2}\right] = E[SW^{P*}] - E\left[SW^{p}{}_{|q^{mix}_{tot}}\right] = 0 \qquad (17)$$

Compared to (16) and (17), we can notice that the volume error equalizes to zero under mixed policy. That is, mixed policy makes volume error less than uniform regulation. This result is also obtained by Mandell (2008). Secondly, we examine volume error under imperfectly competitive markets. Social welfare at optimal level is

$$SW^{I*} = Nq_i^*(a - k + \theta - \varepsilon) - nq_i^{*2}(bN + \lambda) = \frac{N(a - k + \theta - \varepsilon)^2}{2(bN + \lambda)}$$

and taking expectation,

$$E[SW^{I*}] = E\left[SW_{E_i}\right] + \frac{N\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{2(bN + \lambda)}.$$

This expectation value equalizes when markets are competitive. The volume error under uniform regulation and mixed policy are derived as in (18) and (19) respectively.

$$E\left[SW^{I}_{|VE1}\right] = E[SW^{I*}] - E\left[SW^{I}_{uniform}\right] = \frac{N\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{2(bN + \lambda)} \qquad (18)$$

$$E\left[SW^{I}_{|VE2}\right] = E[SW^{I*}] - E[SW_{mix}] = \frac{N(bN + 4m)\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{8(bN + m)^2} \qquad (19)$$

Comparing to (18) and (19),

$$E\left[SW^{I}_{|VE1}\right] - E\left[SW^{I}_{|VE2}\right] = \frac{N(2m - bN)\left(\sigma_\theta^2 + \sigma_\varepsilon^2\right)}{8(bN + m)^2}.$$

From these examination, we can get the following proposition:

Proposition 2. *Mixed policy is dominant when the firms are price-*

taker, while mixed policy cannot always dominate other policies especially when the slope of demand function is steeper than that of total cost function.

Mixed policy seems to be adaptable policy than uniform regulation because firms show us different reply with price and quota regulation. From comparing (18) and (19), however, the difference of two volume errors yields $E[SW^{I}_{|VE1}] < E[SW^{I}_{|VE2}]$ when $b/2 > m/N$. Thus, we cannot say that mixed policy is always an efficient policy in imperfectly competitive markets.

Consequently, the superiority of the policy between the uniform regulation and the mixed policy depends on the variety of the goods, the price elasticity of demand. For instance, the mixed policy (uniform regulation) is appropriate when the price elasticity of demand is high (low). That is to say, the mixed policy holds the luxury goods since these are highly sensitive to the price. In contrast, the regulator can control the output level through the uniform regulation due to the necessity good is not affected excessively. We can consider that the gap between optimal level and price with pricing power by price-making firms causes detraction of volume error.

5. Conclusions and Remarks

We analyze appropriate policy in imperfectly competitive markets with two distortions; externality and pricing power under uncertainty. As a result, the regulator focus on making the firms increase their output level by giving them subsidy more than remedying the damage by externality. On the other hand, the regulator forces them to comply with the second best output level.

When externality is moderate, we get the result that mixed policy is appropriate. However, we clarify that the range by which mixed policy is optimal changes with the changing of market structures in this paper. By comparing whether markets are competitive or not, the range by which mixed policy is optimal shrinks when the markets are non-competitive. Interestingly, mixed policy is seemingly flexible but it is not appropriate for more distorted situations.

In this paper, two distortions, occurring under-productivity due to pricing power and degree of externalities, affects output level decisions. Proposing the superiority of environmental policy measures by using dynamics of gaps, determined output level and externality may be the clue to implementing realistic policy. We also use only firms which generate pollutant by themselves in our model, however, there are actual eco-industries which provide eco-goods and services for abating pollutants. We can show the representative study of eco-industry in David and Sinclair-Desgagné (2010). We would like to add such environmental industry into our model for ensuring the feasibility of implementation.

Appendix

Appendix 1. Calculation of social welfare

(*a*) *When market is perfectly competitive*:

Let us compare the social welfare when markets are competitive or not. First, we need to yield the value of social welfare under each policy. The social welfare under quota is from (8) and (11) which is given by

$$SW^p|_{q_{tot}^{quota}} = \frac{N(a-k)[(a-k)+2(\theta-\varepsilon)]}{2(bN+\lambda)}$$

By taking expectation, we have

$$E\left[SW^p|_{q_{tot}^{quota}}\right] = \frac{N(a-k)}{2(bN+\lambda)}.$$

The social welfare is denoted when the regulator implements subsidy regulation:

$$SW^p|_{q_{tot}^{price}} = SW^p|_{\bar{q}_{tot}} + \frac{N[2(bN+m)-(bN+\lambda)](\theta-\varepsilon)^2}{2(bN+m)^2}$$

The expectation value is defined as

$$E\left[SW^p|_{q_{tot}^{price}}\right] = E\left[SW^p|_{\bar{q}_{tot}}\right] + \frac{N(bN+2m-\lambda)\left(\sigma_\theta^2+\sigma_\varepsilon^2\right)}{2(bN+m)^2}.$$

Under mixed policy from (10) and (11), we have

$$SW^p|_{q_{tot}^{mix}} = SW^p|_{\bar{q}_{tot}} + \frac{N[(bN+m)-(bN+\lambda)](\theta-\varepsilon)^2}{8(bN+m)^2}$$

Taking expectation,

$$E\left[SW^p|_{q_{tot}^{mix}}\right] = E\left[SW^p|_{\bar{q}_{tot}}\right] + \frac{N(3bN+4m-\lambda)\left(\sigma_\theta^2+\sigma_\varepsilon^2\right)}{8(bN+m)^2}.$$

$\varDelta SW_h^p$ indicates the difference between each expectation value of social welfare.

(*b*) *When markets are not competitive*:

Let us compare with social welfare as well as (*a*) when all firms are price-maker. From (2),

$$E\left[SW_{quota}^I\right] = \frac{n(a-k)^2}{(2bn+\lambda)} = \frac{N(a-k)^2}{2(bN+\lambda)}$$

$$E\left[SW_{price}^I\right] = E[SW_{\bar{A}+\bar{B}}] + \frac{N(bN+2m-\lambda)\left(\sigma_\theta^2+\sigma_\varepsilon^2\right)}{(bN+m)^2}$$

$$E[SW_{mix}^I] = E[SW_{\bar{A}+\bar{B}}] + \frac{N(3bN+2m-2\lambda)\left(\sigma_\theta^2+\sigma_\varepsilon^2\right)}{8(bN+m)^2}$$

$\varDelta SW_h^I$ indicates the difference of each expectation value of social welfare.

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