

Environmental Policy and Firm Agglomeration under Mixed Duopoly*

Tohru Naito
The University of Tokushima,
Graduate Schools of Integrated Arts and Sciences
Minamijosanjima-cho Tokushima, 7708502 JAPAN
E-mail: naito@ias.tokushima-u.ac.jp

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Abstract

In this paper, we analyze the mixed duopoly, in which the private firm maximizing profit competes with the public firm maximizing social welfare under the linear city. This model is not price competition like Hotelling (1929) but quantity competition like Anderson and Neven (1991) or Matsushima and Matsumura (2003), both firms face the quantity competition of homogeneous goods at each location in the city. Moreover, those firms emit pollution in the manufacturing process similar to Naito and Ogawa (2009). The purpose of this paper compares the case without environmental regulation with the case regulated by government and analyze the effect of environmental regulation on firm agglomeration. As the result of analysis, we show that the environmental regulation affects the location pattern of each firm in the city.

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1 Introduction

Spatial competition model has been extended from various points of view since Hotelling(1929) specified it, applied in spatial location theory or horizontal goods differentiation of industrial organization, political economy, and so on, and affected those greatly. Hotelling(1929) sets up a linear city and analyze the location competition and price competition. As for location competition, Hotelling(1929) shows that both firms located at the center of linear city under the case, in which they supply homogeneous good for consumer at same price. Many researches studies how the firms choose their behavior under the two stage game, which is location and price competition. d'Aspremont, Gabszewicz, and Thisse (1979) shows that no equilibrium does not exist under the two-stage game taking account of a linear transportation cost. On the other hand, Capozza and Van Order(1982) assume the transportation cost rises with the square of distance and show that nonoperative equilibrium location is the configuration, in which one firm located at one edge of city and the other firm located at the other edge of city, that is, maximum differentiation.

The studies of typical Hotelling model assume that each consumer in the city purchases a unit of goods inelastically and focus on price competition. On the other hand, Anderson and Neven(1991) set up quantity-location competition and analyze the equilibrium price and location. They show that both firm locate at the center of city in equilibrium. This result is contrary to Capozza and Van Order(1982). Though Anderson and Neven(1991) assume that the consumers are distributed uniformly in the city, Gupta, Pal, and Sarkar(1997) relax the assumption of distribution shows that firms can agglomerate the center of city with a part of exception when the consumers are not distributed uniformly. On the other hand, Pal(1998) set up not a linear city, which Anderson and Neven(1991) assume, but a circular city and show that each firm locates with the same distance to the other firm. Moreover, Matsushima(2001) shows that the half of total firms locate at one point in the circular city and the others located at the opposite side when there are plural firms in circular city.

Most of these studies analyze the behavior of firm maximizing his profit. On the other hand, recently many researchers have analyzed the mixed oligopoly, in which the public firm maximizes the social welfare and the private firm maximizes his profit, since De Fraja and Delbono (1990) constructed the mixed oligopoly model. Moreover, this mixed oligopoly model has also been extended from various points of view. De Fraja and Delbono (1990) consider the case

where the public firm and the private firm have the same cost function and both firms face Cournot competition. They show that the social welfare in mixed oligopoly is larger than that in pure oligopoly when the number of firm is enough small. This is because the public firm determines his production to be equal to marginal cost.

Many studies applied this mixed oligopoly model, which was constructed by De Fraja and Delbono (1990), to other various categories. Cremer and Marchand and Thisse (1991) introduce the products differentiation into mixed oligopoly model. Moreover, Ogawa (2006) extends to the case of not only substitute goods but also complement goods and analyzes the scale of production chosen by firms. Though De Fraja and Delbono (1990) consider the simultaneous move game, some papers, which is like Pal (1998), argue with the timing of game in the mixed oligopoly and attempt to determine the move in the game endogenously. Ogawa and Sanjo (2007) consider the Hotelling model with the quadratic transportation cost with respect to distance used in Capozza and Van Order(1982) and show that the public firm and the private firm do not locate on the edge of city. This result is different from that of Capozza and Van Order(1982). Moreover, Matsushima and Matsumura (2003) analyze the quantity-location competition under the circular city specified in Pal (1998) and show that the private firms locate in the opposite side to public firm location and they agglomerate in the same location.

Some studies consider the case where the firms emit any pollution in the process of production and its pollution damages the environment and analyze the relationship between the firm behavior and the government's environmental policy under the mixed oligopoly. Under this setting, Bárcena-Ruiz and Garzón (2006) compare the mixed oligopoly market with the pure oligopoly market with only private firms and refer to the difference of pollution tax and the privatization. Kato (2006) compare the mixed oligopoly market with emissions trade with that without it. Though their studies argue with the privatization of public firm in the mixed oligopoly, they just compare the mixed oligopoly with the pure oligopoly and do not refer to the partial privatization which Matsumura (1998) sets up and nay environmental regulation. However Matsumura (1998) does not deal with the environmental regulation. Naito and Ogawa(2009) combine the environmental regulation in Bárcena-Ruiz and Garzón (2006) with the partial privatization model in Matsumura (1998) and analyze the effect of each environmental regulation on the emission of pollution or social welfare in equilibrium and compare among some environmental

regulations. They show that neither full public management the partial privatization maximize the social welfare under each environmental regulation and that the direct environmental regulation, in which the government controls the abatement investment of both firm, maximize the social welfare.

This paper is organized as follows. We construct the basic model, which combines the mixed duopoly market with Hotelling type linear city with environmental factor. In section 3 we analyze the case without any environmental regulation as bench mark. In section 4 we consider the case with environmental regulation by government and compare the equilibrium without regulation with that with regulation. Finally we refer to the conclusion obtained in this paper and the remained subjects in our analysis.

2 The model

We consider the linear city whose length is from zero to one. Households reside uniformly in the city and purchase the homogeneous goods produced by either the public firm or the private firm. We consider not the pure duopoly, in which both firms maximize their own profit, but the mixed duopoly, in which the public firm maximizes the social welfare and the private firm maximizes his profit. We denote the public firm by firm 0 and the private firm by firm 1. Let x_i , ($i = 0, 1$) represent the location of firm i in the city. Each firm emits the pollution in the production process.

2.1 Consumption

Though households reside uniformly in the city and purchase the homogeneous goods produced by either the public firm or the private firm, we relax the assumption that each household buy one unit of goods inelastically, which Hotelling (1929) sets up, and both firms compete the quantity each other at each location in the city. Here following Anderson and Neven (1991), let $p(x)$ represent the inverse demand function at location x in the city.

$$p(x) = \alpha - q_0(x) - q_1(x), \quad (1)$$

where α and $q_i(x)$ denote the scale of demand and the firm i 's production of goods for the market at $x \in [0, 1]$, respectively.¹ Moreover, we assume that

¹Here we assume that the scale of demand α is large enough as well as Anderson and Neven (1991)

each firm bears the transportation cost of goods from his firm location to each market and define $t|x_i - x|$, ($i = 0, 1$) as a unit cost.

2.2 Production

Though we normalize the production cost to zero, each firm emits any pollution in the process of production and bears the cost $\frac{1}{2}y_i^2$ for the pollution reduction investment y_i ($i = 0, 1$). Presuming that each firm pays for the transportation cost of goods from his firm's location to each market, we can describe $C_i(x)$ ($i = 0, 1$) as the cost to supply his goods for market at x , that is,

$$C_i(x) = t|x_i - x|q_i(x), \quad (i = 0, 1) \quad (2)$$

Here let x_0 and x_1 represent the public firm's location and the private firm's location, respectively. Moreover, we assume that $x_0 \leq x_1$ without generality. Taking account of (1) and (2) We can describe the profit of firm i at x as follows.

$$\pi_0(x) = (\alpha - q_0(x) - q_1(x))q_0(x) - t|x_0 - x|q_0(x) - \frac{1}{2}y_0^2 \quad (3)$$

$$\pi_1(x) = (\alpha - q_0(x) - q_1(x))q_1(x) - t|x_1 - x|q_1(x) - \frac{1}{2}y_1^2 \quad (4)$$

Moreover, the consumer surplus at x , $CS(x)$, is given by

$$CS(x) = \frac{1}{2}(q_0(x) + q_1(x))^2. \quad (5)$$

2.3 Environment

We assume that both firms emit any pollution in the process of production and the environmental damage is caused by this pollution. Each firm can decrease the pollution with his pollution reduction function. Defining y_i as the pollution reduction function of firm i ($i = 0, 1$). Thus, the amount of pollution emitted by firm i is given by $q_i(x) - y_i(x)$. Thus, the total amount of pollution at x is as follows.

$$\sum_{i=0}^1 (q_i(x) - y_i(x)) \quad (6)$$

Moreover, we specify the environmental damage caused by emission at x as follows.

$$ED(x) = \frac{1}{2} \left(\sum_{i=0}^1 (q_i(x) - y_i(x)) \right)^2 = \frac{1}{2} (q_0(x) + q_1(x) - y_0(x) - y_1(x))^2 \quad (7)$$

2.4 The timing of game

The game in this model is as follows. First each firm determines his location in the city. Second they determine his production and pollution reduction investment. Therefore, following backward induction, each firm deals with each firm's location as given and determine his production and investment. Moreover each firm determines his location in the city to maximize his profit.

3 Non regulation case

We consider the non-regulation case as benchmark, in which the government does not impose the environmental regulation on both firms in the city, in this section. As we explain above section, the public firm determine his location, production, and pollution reduction investment to maximize the social welfare. On the other hand, the private firm determine them to maximize his profit. According to (5), (3), (4), (7), we define the social welfare at x as follows.

$$SW(x) = \frac{1}{2} (q_0(x) + q_1(x))^2 + \sum_{i=0}^1 \pi_i(x) - ED(x) \quad (8)$$

To begin with, we consider the behavior of the private firms (firm 1). Differentiating (4) with respect to $q_1(x)$ and $y_1(x)$, the first order conditions to maximize the profit with respect to $q_1(x)$ and $y_1(x)$ are as follows.

$$\alpha - q_0(x) - 2q_1(x) - t|x_1 - x| = 0 \quad (9)$$

$$-y_1(x) = 0 \quad (10)$$

On the other hand, because the public firm determines $q_0(x)$ and $y_0(x)$ to maximize the social welfare, the first order conditions to maximize it are given by

$$\alpha - 2q_0(x) - 2q_1(x) - t|x_0 - x| + y_0(x) + y_1(x) = 0. \quad (11)$$

$$q_0(x) + q_1(x) - 2y_0(x) - y_1(x) = 0 \quad (12)$$

Solving (9), (10), (11), and (12), the equilibrium under non-regulation is derived as follows.

$$q_1^n(x) = \frac{\alpha + 2t|x_0 - x| - 3t|x_1 - x|}{3} \quad (13)$$

$$y_1^n(x) = 0 \quad (14)$$

$$q_0^n(x) = \frac{\alpha - 4t|x_0 - x| + 3t|x_1 - x|}{3} \quad (15)$$

$$y_0^n(x) = \frac{\alpha - t|x_0 - x|}{3} \quad (16)$$

Recall that consumer surplus at x , $CS(x)$, is given by (5). Substituting (15) and (13) into (5), $CS_n(x)$ under consumer surplus under non-regulation is given by

$$CS^n(x) = \frac{1}{2} \left(\frac{2(\alpha - t|x_0 - x|)}{3} \right)^2. \quad (17)$$

Thus, integrating (17) from zero to one, we can derive the following total consumer surplus in the city under non regulation, that is,

$$\begin{aligned} \bar{CS}^n &= \int_0^{x_0} \frac{1}{2} \left(\frac{2(\alpha - tx_0 + tm)}{3} \right)^2 dm + \int_{x_0}^1 \frac{1}{2} \left(\frac{2(\alpha - tm + tx_0)}{3} \right)^2 dm \\ &= \frac{2}{27} [(3t^2 - 6\alpha t)x^2 + (6\alpha t - 3t^2)x_0 + t^2 + 3\alpha^2 - 3\alpha t] \end{aligned} \quad (18)$$

As we know from (18), total consumer surplus in the city depends on not the location of the private firm but that of the public firm. Moreover, differentiating (18) with respect to x_0 , we know that the public firm's location to maximize CS^n is $x_0 = \frac{1}{2}$. Therefore, we derive the following lemma.

Lemma 1 *The total consumer surplus depends on not the private firm's location but the public firm's location under non-environmental regulation and is the largest when the public firm locates in the center of city.*

On the other hand, as for the damage caused by pollution, substituting (13), (14), (15), and (16) into (7), we can derive the damage caused by pollution.

3.1 The firm's location under non-environmental regulation

Next we consider the profits of each firm. Since the locations of firm 0 and firm 1 are denoted by x_0 and x_1 , respectively and we assume $x_0 \leq x_1$, the total profit of firm 1 is given by $\bar{\pi}_1$.

$$\begin{aligned}\bar{\pi}_1 &= \int_0^{x_0} \left(\frac{\alpha - 2t(x_0 - m) - 3t(x_1 - m)}{3} \right)^2 dm \\ &+ \int_{x_0}^{x_1} \left(\frac{\alpha - 2t(m - x_0) - 3t(x_1 - m)}{3} \right)^2 dm \\ &+ \int_{x_1}^1 \left(\frac{\alpha - 2t(m - x_0) - 3t(m - x_1)}{3} \right)^2 dm\end{aligned}\quad (19)$$

Differentiating $\bar{\pi}_1$ with respect to x_1 , the first order condition to maximize $\bar{\pi}_1$ is as follows.

$$\frac{\partial \bar{\pi}_1}{\partial x_1} = \frac{1}{3}t [\alpha(2 - 4x_1) + t(-5 + 4x_0^2 + x_0(4 - x_1) + 6x_1 + 4x_1^2)] = 0 \quad (20)$$

When the environmental regulation is not imposed, the total profit of public firm at equilibrium is given by

$$\bar{\pi}_0 = \int_0^1 \frac{1}{18}(\alpha - t|x_0 - m|)(\alpha - 7t|x_0 - m| + 6t|x_1 - m|)dm. \quad (21)$$

Finally we derive \bar{ED}^n , which is total pollution in the city under non-environmental regulation. Substituting (13), (14), (15), and (16) into (7), \bar{ED}^n is given by

$$\begin{aligned}\bar{ED}^n &= \int_0^1 \frac{1}{2} \left(\frac{\alpha - t|x_0 - m|}{3} \right)^2 dm \\ &= \frac{1}{54t} [3\alpha^2 - 3\alpha t(1 - 2x_0 + 2x_0^2) + t^2(1 - 3x_0 + 3x_0^2)]\end{aligned}\quad (22)$$

Differentiating \bar{ED}^n with respect to x_0 , we know that the total pollution in the city maximizes at $x_0 = 0.5$. Thus, we derive the following lemma.

Lemma 2 *The total pollution in the city is the largest when the public firm locates in the center of city under non environmental regulation.*

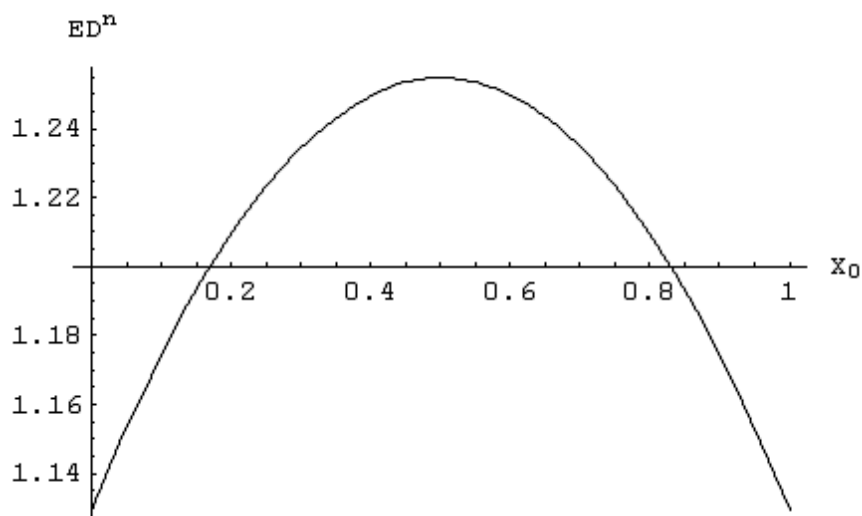


Figure 1: The public firm's location and the environmental damage in the city under non environmental regulation

Since the public firm determines his location to maximize (8), $\partial SW/\partial x_0$ is as follows.

$$\begin{aligned} \frac{\partial SW}{\partial x_0} &= \frac{1}{54}(1 - 3\alpha^2 + 6\alpha t(12 - 23x_0) - 3t^2(28 - 38x_0 + 19x_0^2 \\ &\quad - 18x_1 - 36x_0x_1 + 18x_1^2)) = 0 \end{aligned} \quad (23)$$

Solving (20) and (23), we can derive the equilibrium location of each firm. Particularly, we analyze this equilibrium by numerical simulation with appropriate value.²

From Fig.2, the public firm and the private firm do not agglomerate each other when the environmental regulation is not imposed. The result is different from that derived in Anderson and Neven (1991), which is pure duopoly. Moreover, we know that it is not the same result which is derived under the circular city like Matsushima and Matsumura (2003) and that the pollution

²Here we adopt $\alpha = 5$, $t = 1$ and $x_0, x_1 \in [0, 1]$, respectively. The specific method of simulation is as follows. To begin with, we differentiate (20) and (23) with respect to $w_i (i = 0, 1)$, respectively. Substituting $\alpha = 5$ and $t = 1$ into both response functions, we describe them within $x_i \in [0, 1]$

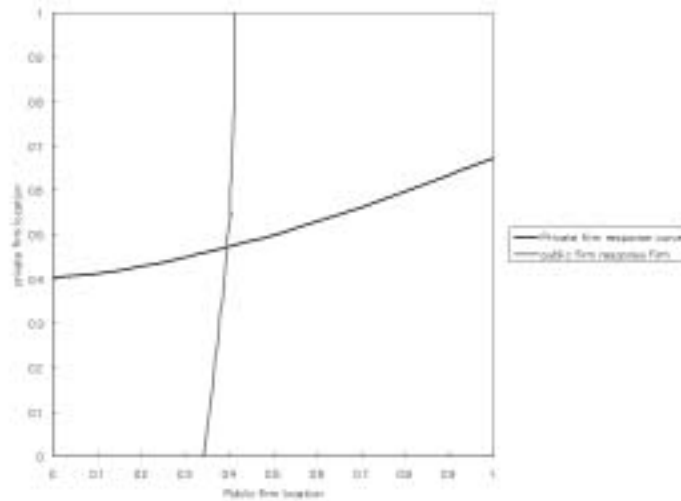


Figure 2: The equilibrium firms' location under non-environmental regulation

in the city is not the largest at equilibrium. Thus, the following proposition is derived.

Proposition 1 *There is no agglomeration of firms under non-environmental regulation. Moreover, the pollution in the city is not the largest at equilibrium.*

4 Environmental regulation

We have analyzed the case where each firm emits any pollution in the process of production and the government imposes no regulation on those firms. The private firm does not carry out the investment about pollution reduction and only public firm invests in the pollution reduction to maximize the social welfare under non-regulation.

In this section we consider the case where the government takes account of environmental regulation and can control the environmental investment level of both firms and consider the location behavior of each firm. Since we add the government to the model in the previous section, we need to specify the timing of game again. In this section the timing of game is as follows, that

is, firstly, both firm their location simultaneously. Secondly the government determines the environmental investments of both firms. Finally, both firms compete with the other in Cournot duopoly at each market. Though we refer to the environmental regulation, we follow the direct environmental regulation in Naito and Ogawa (2009). Let y and $\pi_i^r(x)$, ($i = 0, 1$) represent the regulated investment level and the profit of both firms under this regulation. Thus, the following profit function of both firms is given by

$$\pi_0^r(x) = (\alpha - q_0(x) - q_1(x))q_0(x) - t|x_0 - x|q_0(x) - \frac{1}{2}y^2 \quad (24)$$

$$\pi_1^r(x) = (\alpha - q_0(x) - q_1(x))q_1(x) - t|x_1 - x|q_1(x) - \frac{1}{2}y^2 \quad (25)$$

We derive the equilibrium of this game with backward induction. Each firm determines his production level because the environmental investment is regulated by the government in this section. The first order condition of private firm to maximize his profit is as follows, respectively.

$$\frac{\partial \pi_1^r(x)}{\partial q_1(x)} = \alpha - q_0(x) - 2q_1(x) - t|x_1 - x| = 0 \quad (26)$$

The social welfare function at x under the environmental regulation is as follows, that is,

$$SW^r(x) = \frac{1}{2}(q_0(x) + q_1(x))^2 + \sum_{i=0}^2 \pi_i^r(x) - \frac{1}{2}(q_0(x) + q_1(x) - 2y)^2 \quad (27)$$

Since the public firm determines only production to maximize the social welfare, the first order condition to maximize the social welfare is given by

$$\frac{\partial SW^r(x)}{\partial q_0(x)} = \alpha - 2q_0(x) - 2q_1(x) - t|x_0 - x| + 2y = 0. \quad (28)$$

Solving (26) and (28), we derive the production of each firm at x under environmental regulation in equilibrium.

$$q_1(x) = \frac{\alpha - 2t|x_1 - x| + t|x_0 - x| - 2y}{2} \quad (29)$$

$$q_0(x) = 2y + t|x_1 - x| - t|x_0 - x| \quad (30)$$

Substituting (29) and (30) into (1), the equilibrium price under environmental regulation is given by

$$p^{r*}(x) = \frac{\alpha + t|x_0 - x| - 2y}{2}. \quad (31)$$

From (31), we know that the price at x under environmental regulation does not depend on the location of private firm but depends on the location of public firm and the environmental investment regulated by the government.

$$\begin{aligned} \pi_1^{r*}(x) &= \left(\frac{\alpha + 2t|x_0 - x| - 2t|x_1 - x| - 2y}{2} \right) \left(\frac{\alpha - 2t|x_1 - x| + t|x_0 - x| - 2y}{2} \right) \\ &\quad - \frac{1}{2}y^2 \end{aligned} \quad (32)$$

$$\pi_0^{r*}(x) = \left(\frac{\alpha - 2y}{2} \right) (t|x_1 - x| - t|x_0 - x| + 2y) - \frac{1}{2}y^2 \quad (33)$$

Taking account of (29) and (30), the following consumer surplus $CS^r(x)$ under environmental regulation is given by

$$CS^r(x) = \frac{1}{2} \left(\frac{\alpha - t|x_0 - x| + 2y}{2} \right)^2. \quad (34)$$

Moreover, the damage caused by pollution at x is as follows.

$$ED^r(x) = \frac{1}{2} \left(\frac{\alpha - t|x_0 - x| + 2y}{2} - 2y \right)^2 \quad (35)$$

From (32), (33), (34), and (35), the social welfare under environmental regulation is described by the function of location of both firms and the environmental investment regulated by the government.

$$SW^{r*} = CS^r(x) + \sum_{i=0}^1 \pi_i^{r*}(x) - ED^r(x) \quad (36)$$

Differentiation SW^{r*} with respect to $y(x)$, the first order condition as to the environmental investment of each firm to maximize the social welfare is as follows.

$$\frac{\partial SW^{r*}}{\partial y(x)} = \frac{1}{2} (\alpha - t|x_0 - x| - 8y(x)) = 0 \quad (37)$$

Thus, the environmental investment to maximize the social welfare at x is derived due to (37), that is,

$$y^{r*}(x) = \frac{\alpha - t|x_0 - x|}{8} \quad (38)$$

We know that the environmental regulation at each market is the decreasing function of the distance from the public firm's location to the private firm's location due to (38). Moreover, substituting (38) into (36), the social welfare under environmental regulation is given by the function of location of each firm (x_0, x_1) .

4.1 The equilibrium firm's location under the environmental regulation

We derive the production of each firm and the environmental investment regulated by the government. Substituting (29), (30), and (38) into (26), the profit function of private firm at x is as follows.

$$\begin{aligned} \pi^{r*}(x) &= \frac{1}{128} (17\alpha^2 + 69t^2(|x_0 - x|)^2 - 224t^2|x_0 - x||x_1 - x| \\ &+ 128t^2(|x_1 - x|)^2 + 86\alpha t|x_0 - x| - 96\alpha t|x_1 - x|) \end{aligned} \quad (39)$$

Thus, integrating (39) from zero to one, we derive the total profit of private firm in the city as follows.

$$\bar{\pi}_1^{r*} = \int_0^1 \pi^{r*}(m) dm \quad (40)$$

Supposed that $x_0 \leq x_1$ similar to the previous section, we divide the three areas in the city and integrate them respectively. Integrating those areas with the appropriate range for them, we can derive the total profit of private firm in the city $\bar{\pi}_1^{r*}$. Moreover, differentiating them with respect to x_1 , the first order condition of location to maximize the profit of private firm is as follows.

$$\begin{aligned} \frac{\partial \bar{\pi}_1^{r*}}{\partial x_1} &= \frac{1}{384} \{(\alpha t(96 - 192x_1) + t^2[-48 - 672x_0 + 768x_1 - 672x_1^2 \\ &+ x_0(1344x_1 - 672)]\} = 0 \end{aligned} \quad (41)$$

Next we consider the profit of public firm to derive the optimal location for public firm. Let $\bar{\pi}_0^{r*}$ represent the total profit of public firm in the city, that

is,

$$\bar{\pi}_0^{r*}(x) = \frac{1}{128}(\alpha - t|x_0 - x|)(11\alpha - 59t|x_0 - x| + 48t|x_1 - x|) \quad (42)$$

The following social welfare at x under environmental regulation is given by (42).

$$\begin{aligned} SW^{r*}(x) &= \frac{1}{128}(\alpha^2 + \alpha(11 + 59t|x_0 - x| - 48t|x_1 - x|) + t^2(112(|x_0 - x|)^2 \\ &+ 128(|x_1 - x|)^2) - 272t^2|x_0 - x||x_1 - x| - 11t|x_0 - x|) \end{aligned} \quad (43)$$

Integrating $SW^{r*}(x)$ from zero to one, we derive $S\bar{W}^{r*}$ as the total social welfare.

$$S\bar{W}^{r*} = \int_0^1 SW^{r*}(m)dm \quad (44)$$

Differentiating (44) with respect to x_0 , the first order condition of public firm's location to maximize the social welfare is as follows.

$$\begin{aligned} \frac{\partial SW^{r*}}{\partial x_0} &= \frac{1}{768} \{3\alpha t(236x_0 - 118) + t(66 - 12x_0(11 + 136x_1) \\ &+ 16t(102x_0^2 + 2x_0(42 - 51x_1) + 3(3 - 34xx_1 + 34x_1^2)))\} \\ &= 0 \end{aligned} \quad (45)$$

Solving (41) and (45), we derive the equilibrium location of each firm under environmental regulation. We analyze the equilibrium under this situation and adopt the same parameter in the previous section to compare with the equilibrium under non-regulation.³ We derive each firm's response function from (41) and (45) and describe them in Fig.3 As you know from Fig.3, the private firm keeps any distance from public firm and agglomerate in one point each other. On the other hand, each firm agglomerates in the center of city, in which x_0 and x_1 are equal to 0.5. Though the private firm does not carry out the environmental investment and determine his production and location under non-regulation, he has to carry out the environmental investment at the level regulated by the government, which depends on the location of public firm. Thus, the equilibrium location under environmental regulation is different from that under non-regulation. Therefore we derive the following proposition.

³Here α is equal to 5 and t is equal to one, respectively.

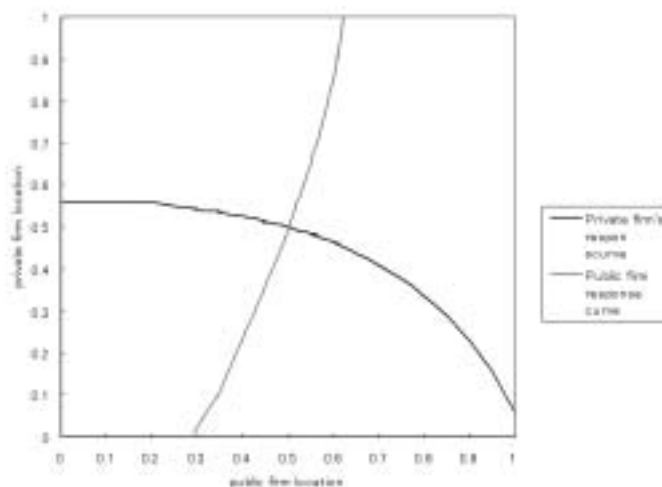


Figure 3: The equilibrium location under environmental regulation

Proposition 2 *Each firm agglomerates in the center of city, in which x_0 and x_1 are equal to 0.5, under any environmental regulation by the government.*

5 Concluding remarks

In this paper we applied Bárcena-Ruiz and Garzón (2006) or Naito and Ogawa (2009), in which each firm emits any pollution and invest for pollution reduction in the mixed duopoly, to the quantity and location competition like Anderson and Neven (1991) and analyze the effect of environmental regulation on the firm's agglomeration in the city. As the result of analysis, the amount of pollution in the city depends on only public firm's location. Moreover, we show that the amount of pollution maximizes when the public firm locates on the center of city, that is, $x_0 = 0.5$. As for equilibrium location, the maximum differentiation location in Matsushima and Matsumura (2003) does not emerge under non-regulation. Next we consider the case where the government imposes any environmental regulation on each firm and analyze the effect of environmental regulation on each firm's location in equilibrium.

We show that it is possible to emerge the firm location in the center of city under environmental regulation, that is, both firms located in the center of city ($x_0 = x_1 = 0.5$)

Since we focused our interest on the effect of environmental regulation on firm's agglomeration in this paper, we do not argue with the case about partial privatization, which is analyzed in Naito and Ogawa (2009) or Matsumura (1998). We deal with only direct regulation and do not refer to economic method like pollution tax. We have to compare the equilibrium location under the regulation in this paper with that under other environmental regulation. Those points are remained in the future subjects.

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