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The Siting Problem of a Waste Treatment Facility in the Cities

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While the waste treatment is a very serious problem in modern society, the facilities for the treatment of waste are indispensable. Such facilities are considered undesirable ones because of the resulting noise, odors and rodents. In this paper, we try to discuss the factors that affect the decision making of the city governments concerning the location of waste treatment facilities, and to investigate the optimal locations in the context of the maximization of social welfare. We also try to compare two burden systems of waste treatment cost; lump sum charge system and unit pricing system.

The main results are as follows: First, the optimal location of the facility is in the middle of the city. Second, in the context of welfare maximization, the lump sum charge system is more effective than the unit pricing system.

Key Words: Waste Management, Facility Location, Unit Pricing System

Ⅰ. Introduction

While the waste treatment is a very serious problem in modern society, the facilities for the treatment of waste are indispensable. Such facilities are considered undesirable ones because of the resulting noise, odors and rodents. Thus, it is common that governments face the opposition from residents when they try to determine the location of such facilities. This kind of opposition, which is often called NIMBY (Not In My Back Yard), is one of the influences that can make policy decisions of the government difficult.

The Japanese government established various standards or laws when the formulation of the Waste Management Law came into being. Simultaneously, policy measures are developed for the waste treatment, for instance, subsidies for the disposal facilities or special tax measures. Moreover, there is a procedure in which a prefectural governor hears the opinions of the municipality leaders and concerned residents before determining the policy, and the residents' opinion is supposed to be valued in the policy implementation in recent years.

On the other hand, it is not the case that every municipality has sufficient capacity to dispose of its own waste. This has been an issue as people will object to the transportation and treatment of waste from outside regions. One such example was the "waste war" in Tokyo in 1970's which resulted due to the shortage of waste disposal sites. As a result, it led to the "self-sufficiency principle" that the waste should be managed within the area where it is generated.

A lot of research has dealt with the location problem theoretically and empirically since 1990's. Most researches have made an effort to investigate this problem from two sides mainly. The first is a

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compensation scheme for the region where the undesirable facility is built applying the auction theory and robbing model in the context of political economics; the other is a siting problem through the theory of urban and regional spatial economics.

Markusen et al. (1995) analyzed two types of pollution tax competition which are cooperative and noncooperative on the location of firm that generates pollution. They showed some cases relating to the number of plants and to the degree of pollution, and referred the possibility of NIMBY in the case of too few plants and too little pollution. Feinerman et al. (2004) introduced the concept of land market into the facility siting problem. They considered not the local government but the landlords as the lobby group, and found that the political equilibrium and socially optimal siting differ though a smaller difference, which can be expected by the more equitable the distribution of landownership in the region.

Though most research has analyzed the bargaining between cities without taking into consideration the spatial conception, Highfill et al. (1998) researched the location problem of recycling center in the city in the context of the minimization of transportation cost. They also investigated the relationship between the location of a recycling center and that of the landfill, but lacked in the analysis about the relationship between the location of the facilities and economic behaviors of the residents. When the government sets up the waste treatment facilities in an arbitrary place in the city, the negative externality or the treatment cost might influence the residents' economic behaviors. Such a change is expected to bring the changes in the price of land and the urban size. In this paper, we focus on these issues through the analysis of the location of the facilities.

In this paper, we try to discuss the factors that affect the decision making of the city governments concerning the location of waste treatment facilities, and to investigate the optimal locations in the context of the maximization of social welfare. We also try to compare two burden systems of waste treatment cost; lump sum charge system and unit pricing system. The municipal government should basically procure the waste treatment cost which can be considered as two systems due to the cost burden mechanisms. The first is that the local government levies the lump sum charge from the residents evenly, and the other is that the residents pay the charge for their waste and the deficit is covered from the lump sum charge. The latter is called unit pricing system in Japan.

There are various factors when the municipal government decides the provision of the waste treatment facility: physical, sociological, and economics factors, etc. As for the economic factors, it can be raised the negative externality from the facility and management cost of the waste. The transportation cost from each household to the facility and the treatment cost at the facility can be included in the management cost. Additionally, the cost burden rule of the residents can be considered as the economic factor. The construction cost can be disregarded because it is thought that this doesn't have a significant influence on the location decision even though the land rent varies according to the location.

This paper is organized as follows: Section 2 describes the basic model on which this paper is based and in section 3, the equilibrium solutions are derived under the arbitrary facility location. In section 4, the optimal location of the facility is analyzed when the residents evenly bear all the management cost of the waste in the city. Section 5 concerns the case that the unit pricing system in which each resident shoulders the expense of their own waste, and section 6 concludes.

Ⅱ. The Model

Consider a city that tries to establish a waste treatment facility. All the waste from the households in the city is transported to this facility for incinerating or recycling; the rest, after treatment, is transported to the final disposal facility like a landfill[1]. It is common that this kind of facility can cause negative externalities such as environmental damage, for instance, noise, odor, etc. We consider that the externality reflects the spatial variation, i.e., the influence of externality decreases along with the distance from the facility. Moreover, we also consider the pecuniary externality: each household, which is near the facility, should pay the cost to protect its residential condition from the environmental damage, and the cost marginally decreases with the distance from the facility. In addition, the areas and the magnitude that are affected by the externality depend on the total amount of the waste in the city. Let the cost at the location which is the nearest from the facility e_1, and the marginal cost e_2, then we can define the externality as follows[2]

$$E(x, Z_T) = e_1(Z_T) - e_2 |f - x| \tag{1}$$

where f is the location of the facility, and x is the distance from central business district (CBD) of which location is zero, and e_1 depends on the total amount of the waste in the city, Z_T.

Figure 1 shows the image of Eq. (1), where x_f is the urban boundary, and f_1, f_2 are the locations where the influence of externality is fully diminished, respectively. Since the larger Z_T becomes, the higher e_1 becomes, accordingly the interval $[f_1, f_2]$ also becomes wide. Under this assumption, various cases can be considered according to the f: the case that area 1 does not exist, or that area 4 does not exist, or all of the 4 areas exist, etc.

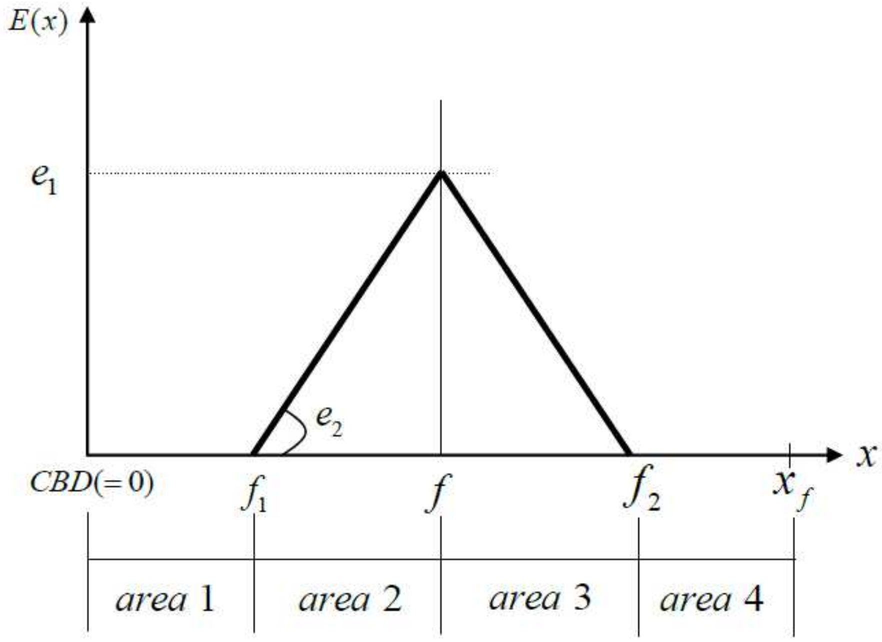
Therefore, it can be defined f_1 and f_2 as,

$$\begin{aligned}
f_1 &= \frac{e_2 f - e_1}{e_2} && \text{for } f_1 \geq 0 \\
f_1 &= 0 && \text{for } f_1 < 0 \\
f_2 &= \frac{e_2 f + e_1}{e_2} && \text{for } f_2 \leq x_f \\
f_2 &= x_f && \text{for } f_2 < x_f
\end{aligned}$$

In this section, we consider the case that the city government levies the lump sum charge from each household to allot for the management cost of the waste. So the charge for each household becomes T_m / N, where T_m represents the total management cost, and N is the population size of the city. As we assume the closed city model, N is exogenous.

1) In this paper, the siting problem of landfill will be disregarded so that we may emphasize the issue of the location of the waste treatment facility. Actually, about 90% of the general waste is treated at the facility and only about 10% is transported to the landfill in Japan.

2) Eq. (1) is based on Fujita (1989, Ch.6) and Sasaki and Moon (2000, Ch. 4). Fujita (1989) introduced the exponential function as the externality from superneighborhood goods, and Sasaki and Moon (2000) suggested the definition of pecuniary externality which is similar to our model.



<Fig. 1> Negative externality by the facility

Each household should determine its residence x that maximizes its utility subject to a budget constraint. We assume that the utility function of a household is given by the following log-linear function,

$$u = \alpha \log z + \beta \log h,\ \alpha + \beta = 1 \tag{2}$$

where z refers the amount of composite consumer good which generates waste, and h refers the housing lot size. The composite consumer good is chosen as numeraire, so its price is unity. All the households get their job at CBD and earn the income Y. The income Y is spent on the composite consumer good, land rent, commuting, and lump sum charge. So the budget constraint is given as

$$Y = z(x) + R(x)h(x) + t_c x + \frac{T_m}{N} + E(x) \tag{3}$$

where $R(x)$ is the land rent at x, and t_c is the marginal commuting cost.

The total management cost, T_m, can be defined as the sum of the transportation cost, C_T, and the treatment cost, C_Z. C_T depends on the facility location, f and the amount of waste at each x. Also C_Z depends on the total amount of the waste in the city. When we denote by $n(x)$ the population distribution at x, the amount of waste at x becomes $n(x)z(x)$. The management cost, T_m, therefore, can be defined as[3)]

$$T_m = C_T + C_Z$$
$$C_T = \int_0^{f_1} t_m(f-x)n_1(x)z_1(x)dx + \int_{f_1}^{f} t_m(f-x)n_2(x)z_2(x)dx$$

3) The superscript i in Eq. (4) indicates the area $i\,(i = 1, 2, 3, 4)$ in Fig. 1.

$$+\int_{f}^{f_2} t_m(f-x)n_3(x)z_3(x)dx+\int_{f_2}^{x_f} t_m(f-x)n_4(x)z_4(x)dx, \quad (4)$$

$$C_Z=\int_{0}^{f_1} cn_1(x)z_1(x)dx+\int_{f_1}^{f} cn_2(x)z_2(x)dx$$

$$+\int_{f}^{f_2} cn_3(x)z_3(x)dx+\int_{f_2}^{x_f} cn_4(x)z_4(x)dx$$

where t_m is the marginal transportation cost to the distance from f, and c is the marginal treatment cost.

Ⅲ. Equilibrium Under Arbitrary Location of the Facility

In this section, we investigate the equilibrium land use with using the bid rent function approach. At first, solving the utility function $u(\bullet)=u$ for z, we can get the amount of composite good z under the utility level, u and lot size, h. Let the solution as Z,

$$Z=h^{-\frac{\beta}{\alpha}}e^{\frac{u}{\alpha}}$$

Then, from Eq. (3) and Z, we can define the bid rent function as follows:

$$\Psi(x,u)=\max_h\left\{\frac{Y-\frac{T_m}{N}-t_cx-E(x)-Z}{h}\right\}$$

From the F.O.C. of the bid rent function, we have Z and bid-max lot size h,

$$Z=\alpha\left(Y-\frac{T_m}{N}-t_cx-E(x)\right) \quad (5)$$

$$h=\alpha^{\frac{-\alpha}{\beta}}e^{\frac{u}{\beta}}\left(Y-\frac{T_m}{n}-t_cx-E(x)\right)^{\frac{-\alpha}{\beta}} \quad (6)$$

Substituting Eqs. (5) and (6) to the bid rent function, we can get the land rent function under given u as,

$$R(x)=\alpha^{\frac{\alpha}{\beta}}\beta e^{\frac{-u}{\beta}}\left(Y-\frac{T_m}{n}-t_cx-E(x)\right)^{\frac{1}{\beta}} \quad (7)$$

The composition good Z, lot size h, and land rent R are different according to the each area i because of the assumption of $E(x)$. Hence, Z, h, R at each area can be given as

$$
\begin{aligned}
&Z_1(x)=\alpha\left(Y-\frac{T_m}{N}-t_c x\right) && \text{for } 0\le x\le f_1\\
&Z_2(x)=\alpha\ \ A_1-(t_c+e_2)x && \text{for } f_1< x\le f\\
&Z_3(x)=\alpha\ \ A_2-(t_c-e_2)x && \text{for } f< x\le f_2\\
&Z_4(x)=Z_1(x) && \text{for } f_2< x\le x_f
\end{aligned}
$$

$$
\begin{aligned}
&h_1(x)=\alpha^{\frac{-\alpha}{\beta}}e^{\frac{u}{\beta}}\left(Y-\frac{T_m}{N}-t_c x\right)^{\frac{-\alpha}{\beta}} && \text{for } 0\le x\le f_1\\
&h_2(x)=\alpha^{\frac{-\alpha}{\beta}}e^{\frac{u}{\beta}}\ \ A_1-(t_c+e_2)x^{\frac{-\alpha}{\beta}} && \text{for } f_1< x\le f\\
&h_3(x)=\alpha^{\frac{-\alpha}{\beta}}e^{\frac{u}{\beta}}\ \ A_2-(t_c+e_2)x^{\frac{-\alpha}{\beta}} && \text{for } f< x\le f_2\\
&h_4(x)=h_1(x) && \text{for } f_2< x\le x_f
\end{aligned}
$$

$$
\begin{aligned}
&R_1(x)=\alpha^{\frac{\alpha}{\beta}}\beta e^{\frac{-u}{\beta}}\left(Y-\frac{T_m}{N}-t_c x\right)^{\frac{1}{\beta}} && \text{for } 0\le x\le f_1\\
&R_2(x)=\alpha^{\frac{\alpha}{\beta}}\beta e^{\frac{-u}{\beta}}\ \ A_1-(t_c+e_2)x^{\frac{1}{\beta}} && \text{for } f_1< x\le f\\
&R_3(x)=\alpha^{\frac{\alpha}{\beta}}\beta e^{\frac{-u}{\beta}}\ \ A_2-(t_c-e_2)x^{\frac{1}{\beta}} && \text{for } f< x\le f_2\\
&R_4(x)=R_1(x) && \text{for } f_2< x\le x_f
\end{aligned}
$$

$$
\begin{aligned}
&where\\
&A_1=Y-\frac{T_m}{N}-e_1+e_2 f,\\
&A_2=Y-\frac{T_m}{N}-e_1-e_2 f.
\end{aligned}
$$

Though the lot size h and land rent R at area 1 and 4 are not affected by the externality directly, they are affected indirectly through the change of T_m and u. At the area 2 and 3, however, they are affected directly. When the marginal cost e_2 increases, each household decreases the lot size h and increases Z so that the land rent R decreases.

$$
\frac{\partial h_i}{\partial e_2}<0,\ \ \frac{\partial Z_i}{\partial e_2}>0,\ \ \frac{\partial R_i}{\partial e_2}<0,\ \ i=2,3
$$

The slope of land rent $R(x)$ in area 3 depends on the marginal commuting cost t_c and marginal environmental cost e_2. We obtain the following relations from the land rent function,

$$
\frac{\partial R_3(x)}{\partial x}\ge(<)0 \ \ \text{if}\ \ t_c\le(>)e_2,
$$

which implies that the rent can increase if the marginal environmental cost dominates over the corresponding marginal commuting cost[4].

Under the closed city model, the endogenous variables in equilibrium are the urban boundary x_f and the utility level u. Here, we assume that the land in the city is distributed uniformly, and let $L(x)= L$. Thus, the population at x can be expressed as $n(x)= L/h(x)$, and the population constraint in the city is given as

$$\int_0^{f_1}\frac{L}{h_1(x)}dx+\int_{f_1}^{f}\frac{L}{h_2(x)}dx+\int_{f}^{f_2}\frac{L}{h_3(x)}dx+\int_{f_2}^{x_f}\frac{L}{h_4(x)}dx= N. \tag{8}$$

Meanwhile, the urban boundary condition is varied by the case whether the area 4 exists ($f_2 < x_f$),or does not($f_2 \geq x_f$). Let the opportunity cost of the land, R_a, the land rent at urban boundary x_f is consisted with R_a. So the urban boundary conditions for each case is given as[5)]

$$R_3(x_f)= \alpha^{\frac{\alpha}{\beta}}\beta e^{\frac{-u}{\beta}}\ A_2-(t_c-e_2)x_f^{\frac{1}{\beta}} = R_a,$$

$$R_4(x_f)= \alpha^{\frac{\alpha}{\beta}}\beta e^{\frac{-u}{\beta}}\left(Y-\frac{T_m}{N}-t_c x_f\right)^{\frac{1}{\beta}} = R_a$$

Solving these equations to x_f, we can obtain the urban boundary as follows.

$$x_f^3 = \frac{A_2-\alpha^{-\alpha}\beta^{-\beta}e^u R_a^\beta}{t_c-e_2}, \tag{9}$$

$$x_f^4 = \frac{Y-\frac{T_m}{N}-\alpha^{-\alpha}\beta^{-\beta}e^u R_a^\beta}{t_c}. \tag{10}$$

Combining Eq. (8) and (10), the equilibrium utility level can be obtained as[6)]

$$u_3 = \beta\log\left[\frac{\alpha^{\frac{\beta}{\alpha}}(e_2-t_c)B_4-\beta B_5}{(e_2-t_c)\frac{N}{L}-R_a}\right], \tag{11}$$

$$u_4 = \beta\log\left[\frac{\alpha^{\frac{\beta}{\alpha}}t_c B_2+\beta B_1}{R_a+t_c\frac{N}{L}}\right]. \tag{12}$$

Moreover, the equilibrium solutions under T_m, e_1 and f are given can be obtained by substituting Eqs.

4) Papageorgiou and Pines (1999) showed the similar results in the case of positive externality. In the case of negative externality, Sasaki and Moon (2000) found the same result as this paper.

5) Subscript 3 means the case that area 4 does not exist and 4 means the case that it exists.

6) The case of $f_1=0$, $f_2=x_f$ and $f_1=0$, $f_2<x_f$ can be obtained in the same way as u_4.

(10) and (11) or (9) and (12) into Eqs. (5), (6) and (7). Next, we consider the determination of the total management cost of waste in the city, T_m and the externality, e_1. T_m and e_1 are endogenous variables, and they depend on the amount of composite good $Z(x)$ and the population $n(x)$ at each x.

Since $n(x)=L/h(x)$, the amount of waste at x can be written by $Z(x)n(x)=Z(x)L/h(x)$. Thus, we can rewrite the definition of T_m as follows.

$$T_m = t_m L\left[\int_0^{f_1}(f-x)\frac{Z_1(x)}{h_1(x)}dx+\int_{f_1}^{f}(f-x)\frac{Z_2(x)}{h_2(x)}dx+\int_{f}^{f_2}(f-x)\frac{Z_3(x)}{h_3(x)}dx+\int_{f_2}^{x_f}(f-x)\frac{Z_4(x)}{h_4(x)}dx\right]$$
$$+cL\left[\int_0^{f_1}\frac{Z_1(x)}{h_1(x)}dx+\int_{f_1}^{f}\frac{Z_2(x)}{h_2(x)}dx+\int_{f}^{f_2}\frac{Z_3(x)}{h_3(x)}dx+\int_{f_2}^{x_f}\frac{Z_4(x)}{h_4(x)}dx\right] \qquad (13)$$

Also, e_1 can be defined as,

$$e_1 = eL\left[\int_0^{f_1}\frac{Z_1(x)}{h_1(x)}dx+\int_{f_1}^{f}\frac{Z_2(x)}{h_2(x)}dx+\int_{f}^{f_2}\frac{Z_3(x)}{h_3(x)}dx+\int_{f_2}^{x_f}\frac{Z_4(x)}{h_4(x)}dx\right] \qquad (14)$$

where e refers the parameter of the externality.

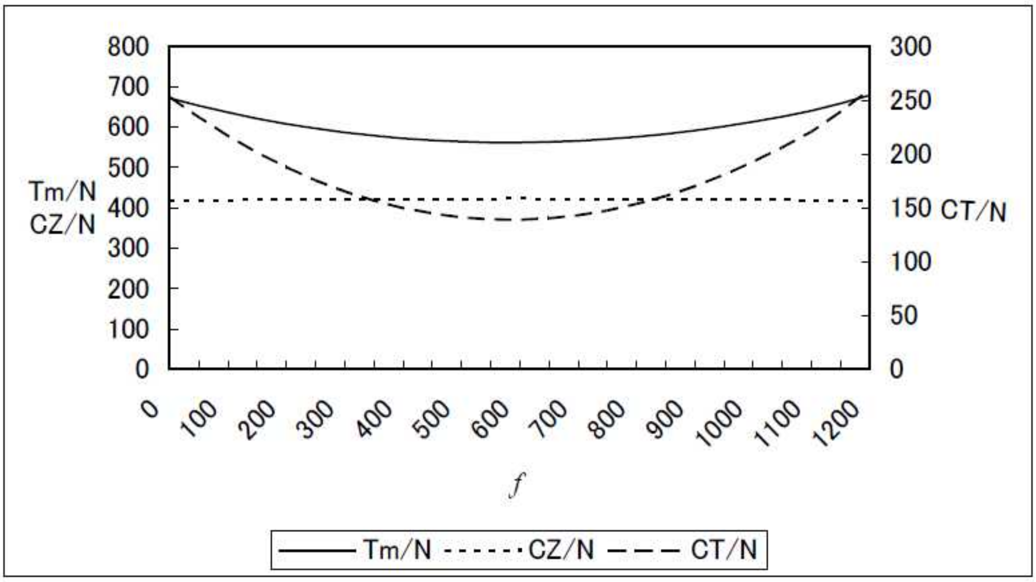
From Eqs. (5)-(14), the composition good Z, lot size h, land rent R can be expressed by the function of the residential location x and the facility location f, and the utility level u, urban boundary x_f, and transportation cost T_m can also be expressed by the function of f. Using T_m and e_1 which are determined by Eqs. (13) and (14), we can obtain all the endogenous variables, $\{Z(x), h(x), R(x), E(x), u, x_f\}$ under the arbitrary location of facility, f.

Ⅳ. Optimal Location under the Lump Sum Charge System

In this section, we investigate the optimal location of the waste treatment facility, f, which is the city government's policy variable. The government should decide the optimal location that maximizes the social welfare. We assume that all the households in the city are identical, so that the social welfare could be regarded as the utility level of the representative household. The utility function in equilibrium, Eq. (11) or (12), depends on the facility location f. Therefore, we can obtain the optimal f in which maximizes the utility level, u.

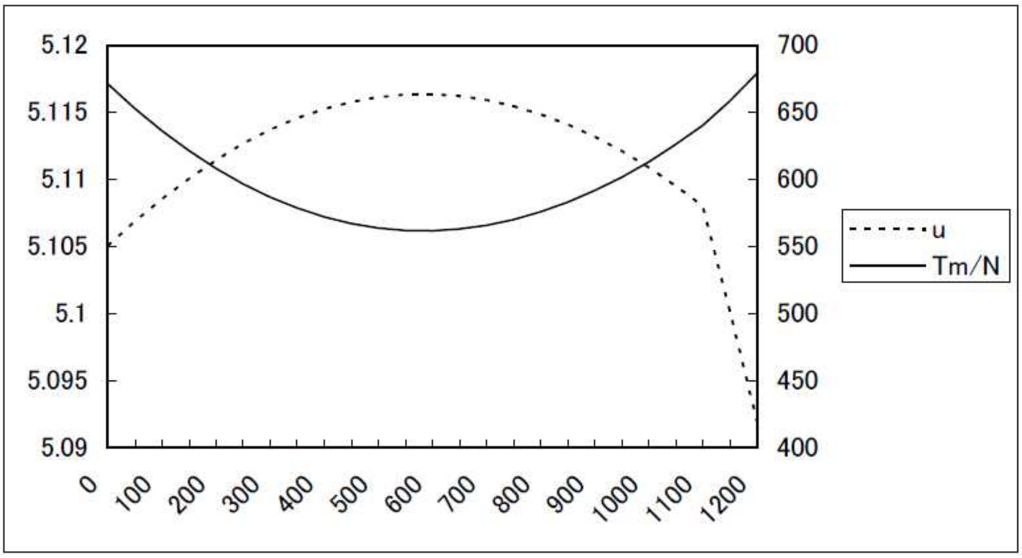
We try to numerical analysis to clarify the results of our analysis. The results are obtained for the following parameter values: $\alpha=0.5$, $t_c=1.5$, $t_m=0.0001$, $c=0.1$, $e_2=1$, $e_3=0.0000005$, $N=100000$, $Y=10000$, $R_a=500$, $L=500$.

If f moves to the urban boundary from CBD, the area 2 and 3 in Fig. 1 which are affected by negative externality also move to the urban boundary. Households around the facility move to area 1 or area 4 and hence, the urban boundary is extended. This means that the population density becomes high in area 1 and area 4, so that the land rent $R(x)$ in these areas becomes high, and it brings about the increase of $Z(x)$ and the decrease of $h(x)$. The total amount of the waste becomes the most when f is located almost in the middle of the city. At this location, the treatment cost, C_Z, becomes the highest but the transportation cost, C_T, becomes the lowest. However, the change of C_Z is not more intense than that of C_T, so that the management cost, T_m becomes the lowest at this location. Fig. 2 shows this. The solid line represents T_m/N, the dotted line represents C_Z/N and the dashed line represents C_T/N. If f moves to the middle of the city, the burden of C_T decreases and this leads to the increase of the disposal income. Thus, the consumption of $Z(x)$ increases and this leads to the increase of C_Z. Fig. 2 shows that the T_m becomes the lowest when f is located almost in the middle of the city. This implies that the decrease of C_T is larger than the increase of C_Z at this location. However, if f closes the urban boundary x_f, where area 4 does not exist, the residents near x_f move to the area 1, and the population density in this area increases. This leads to the shrinking in x_f and the further increase in $R(x)$. The trade-off between the two effects by C_T and C_Z is reversed. The management cost T_m, therefore, increases.



<Fig. 2> The Waste management cost

Consequently, T_m is minimized when f is located at the middle of the city, and the utility level is maximized at this location. Fig. 3 represents the relationship between u and T_m. As we mentioned before, the utility level decreases rapidly in the case that area 4 does not exist. This is the reason why the utility curve is kinked near an urban boundary. Fig. 3 shows that the utility level is maximized where the waste management cost, T_m is the lowest. It means that the optimal location of the facility is almost in the middle of the city.



<Fig. 3> Relationship between u and T_m/N

Ⅴ. The Case of the Unit Pricing System

In Japan, a lot of municipal governments adopt the unit pricing system in which residents share part of the waste management cost by purchasing prepaid garbage bags for disposing waste. In this section, we introduce this system to the model instead of a lump sum charge. Since each household only pays the charge according to the amount it disposes, it is not enough for the total management cost. It is assumed that the remaining deficit is covered from a lump sum charge, T_p.

Then, the budget constraint, Eq. (3), can be rewritten as follows,

$$\begin{aligned} Y &= z + R(x)h(x) + t_c x + E(x) + \frac{T_P}{N} + t_e Z \\ &= (1+t_e)z + R(x)h(x) + t_c x + E(x) + \frac{T_p}{N} \end{aligned} \tag{15}$$

where t_e represents the charge per unit waste.

Using the similar procedures of section 3, we can obtain the followings.

$$\begin{aligned} Z(x) &= \frac{\alpha}{1+t_e}\left(Y - \frac{T_p}{N} - t_c x - E(x)\right), \\ h(x) &= \left(\frac{\alpha}{1+t_e}\right)^{\frac{-\alpha}{\beta}} e^{\frac{u}{\beta}}\left(Y - \frac{T_p}{N} - t_c x - E(x)\right)^{\frac{-\alpha}{\beta}}, \\ R(x) &= \left(\frac{\alpha}{1+t_e}\right)^{\frac{\alpha}{\beta}} \beta e^{\frac{-u}{\beta}}\left(Y - \frac{T_p}{N} - t_c x - E(x)\right)^{\frac{1}{\beta}}. \end{aligned} \tag{16}$$

From the opportunity cost of the land R_a and land rent function $R(x)$, we can obtain the urban boundary x_f is obtained as follows.

$$x_f^3 = \frac{Y - \frac{T_p}{N} - e_1 - e_2 f - \left(\frac{\alpha}{1+t_e}\right)^{-\alpha} \beta^{-\beta} e^u R_a^\beta}{t_e - e_2}, \quad x_f^4 = \frac{Y - \frac{T_p}{N} - \left(\frac{\alpha}{1+t_e}\right)^{-\alpha} \beta^{-\beta} e^u R_a^\beta}{t_c}. \tag{17}$$

The lump sum charge, T_p,can be defined as,

$$T_p = T_m - t_e\left(\int_0^{f_1} \frac{Z_1(x)L}{h_1(x)}dx + \int_{f_1}^{f} \frac{Z_2(x)L}{h_2(x)}dx + \int_{f}^{f_2} \frac{Z_3(x)L}{h_3(x)}dx + \int_{f_2}^{x_f} \frac{Z_4(x)L}{h_4(x)}dx\right) \tag{18}$$

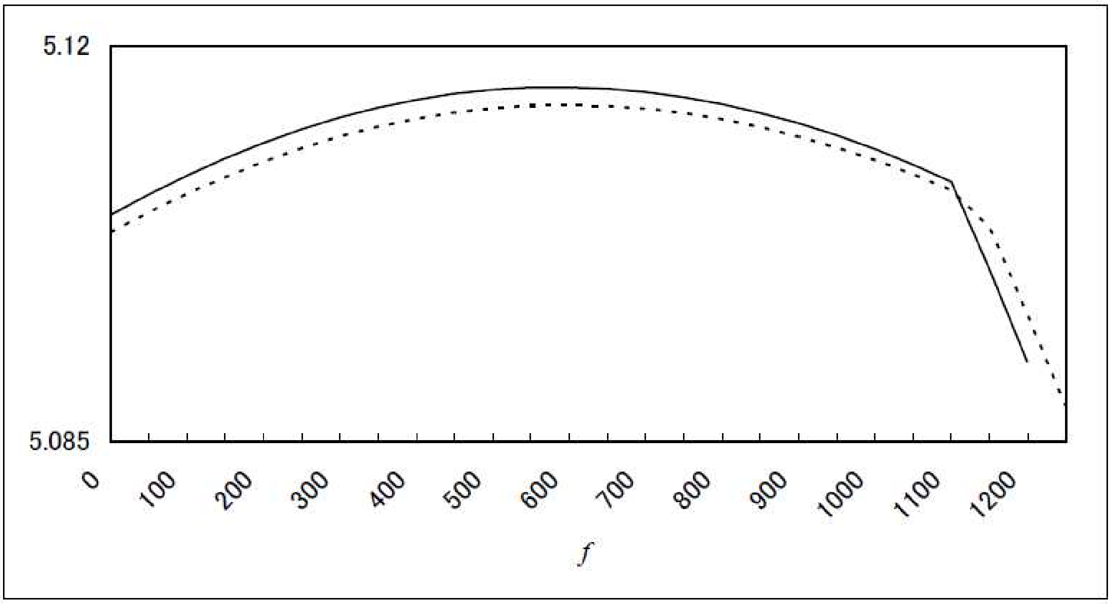
From Eqs. (16), (17), (18) and (8), we have the equilibrium utility level u under the arbitrary f is obtained. A detailed calculation is omitted because the solutions in this section basically are consistent with the solutions in section 3 where the price of composite good is (1+t_e).

A numerical analysis is attempted with all the values of parameters being the same as the previous analysis except for $t_e = 0.05$. Under this system, the most important factor for deciding the facility location is the lump sum charge, T_p, in which the result is the same as the previous case, T_m. The utility level becomes the highest where the burden of T_p becomes the lowest. This result does not depend on the size of the charge, t_e. For example, though the weight of the charge in the total management cost is higher than that of T_p, the optimal location is where the T_p becomes the lowest, and the same result could be obtained when t_e is low. It can be considered as follows: t_e has price effect to the consumption of Z, while T_p has income effect to the residents. This means that the burden of the charge, t_e, does not affect to the utility level along with the location, f, even though it influences $Z(x)$, $n(x)$ directly,

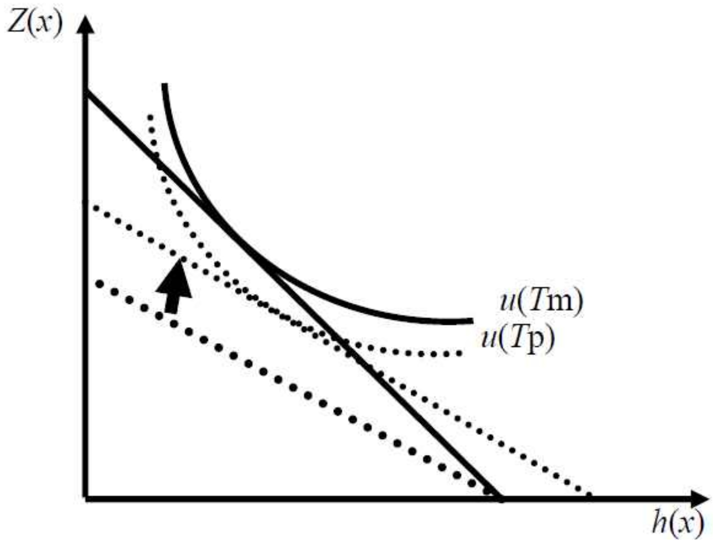
Fig. 4 shows the utility level under the two systems. The solid line represents the case of lump sum charge, and the dotted line represents the case of unit pricing system. The optimal location is the middle of the city regardless of either of the cost burden systems, and the utility level is higher under the system of lump sum charge than that of unit pricing system. This means that the price effect by t_e is larger than the income effect by T_p. The price of Z in which the residents are faced is (1+t_e), so the increase of t_e has the effect that the price rises.

On the other hand, it has the effect that the disposal income increases through the cost burden, so T_p, decreases. The former is negative effect and the latter has a positive effect to the utility, and the negative effect is larger than the positive effect except near the urban boundary. If the income effect is sufficiently high so that it offset the price effect, the utility level becomes higher than that of lump sum charge system, but it is restrictive because it can not exceed T_m. Nonetheless, if f is located near urban boundary and the area 4 does not exist, this relation is reversed. Fig. 5 shows this relation.

Furthermore, in the case of unit pricing system, the urban size becomes larger than the case of lump



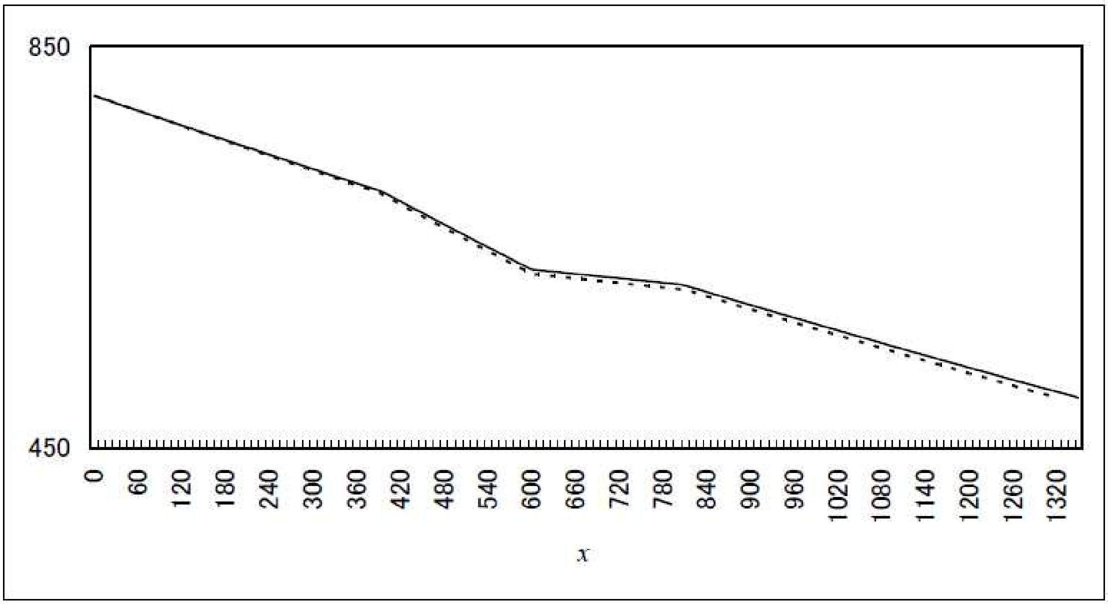
<Fig. 4> Utility levels of both systems



<Fig. 5> Comparison the utility levels

sum charge, T_m. As mentioned before, because t_e has a price effect to Z, the residents increase the size of housing lot, h, instead of decreasing consumption goods, Z. Therefore, the population density in all the location decreases and the urban boundary is expanded.

On the other hand, a substantial change is not found in the land rent, $R(x)$, as seen from Fig. 6. Two effects can be considered for the rent under the unit pricing system: the rising effects of rent by lower cost burden and higher level of lot size, h, and the falling effect of rent by lower population density by the expansion of urban boundary. This trade-off relation does not change intensely the land rent. Fig. 6 shows this.



<Fig. 6> Land rents under both systems

Ⅵ. Concluding Remarks

In this paper, we investigated the location problem of the waste treatment facility in the context of spatial economics. It is usual that the economic behaviors of the households in the city are influenced by the location of such facility because of the negative externality and the burden of management cost, including transportation cost and treatment cost of the waste. Thus, it is important to note that their behaviors are influenced by the facility location through the land rent or population density in the city. As for the waste management cost, the two cost burden systems are considered in this paper. The one is that all the households evenly bear the cost through a type of lump sum charge, and the other is that a charge is paid by each household against the amount of waste it generates. The latter is often called the "unit pricing system," and it is adopted in most of the municipalities in Japan.

The main results are as follows: There are two factors that affect household's utility level through the facility location: i.e., the negative externality and the management cost. The results show that the effect of the latter is more significant than that of the former. Therefore, the optimal location is in the middle of the city where the management cost is minimized. This result is the same in both cost burden systems. On the other hand, the social welfare under lump sum charge system is higher than that under unit pricing system except the case that the facility is located near urban boundary. Thus, it could be said that the former system is better than the latter system on the context of welfare maximization. However, the amount of waste in the city under latter system is less than that under former system. The main reasons why the unit pricing system is accepted in Japan, even though the lump sum charge system is more effective, are the increasing of management cost and the shortage of landfill space. Especially, the shortage of landfill might be a significant factor for the countries which are troubled with lack of the space like

Korea or Japan. If we introduce this factor into the model, we should take the possibility that the result changes into consideration. On the contrary, for the countries with enough space like U.S. or China, it can be disregarded.

In this paper, the situation is simplified as much as possible in order to obtain the results based on a theoretical analysis. However, it is more complicated in the real world. A lot of people may have negative images of such facilities itself besides the issue of externality. It might be one crucial reason why they do not want the construction of such facilities near their residence. It is difficult, however, to treat such complex factors through the economic analysis. The government should eliminate such complex factors through disclosing information, risk management or resident participation, etc.

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<국문초록>

도시의 일반폐기물 처리시설 입지문제에 관한 분석

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현대 사회에 있어서 폐기물 처리는 중요한 문제로 대두되고 있으며, 그것을 처리하기 위한 시설은 필요불가결한 것이 되었음에도, 소음, 악취 등을 이유로 사람들로부터 경원시 되고 있다.

본 논문의 목적은, 이론 분석을 통해 도시에서 발생하는 일반폐기물의 처리시설의 입지에 관한 도시 정부의 결정에 영향을 미치는 변수의 분석, 사회후생 최대화의 관점에서 본 최적 입지점, 그리고, 폐기물 처리 비용에 관한 두 가지의 비용 부담 구조, 즉 정액 요금제와 단위 가격제를 비교 분석하는 데 있다.

분석을 통해 얻어진 주요 결과는 다음과 같다. 닫힌 도시 (closed city)를 가정할 경우, 도시에 있어서 일반폐기물 처리시설의 최적 입지점은 도시의 거의 중간 지점이 되며, 사회 후생 최대화의 관점에서 볼 때, 정액 요금제가 단위 가격제보다 더 효율적일 수 있다.

주제어 : 폐기물 관리, 시설 입지, 단위 가격제

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