Agglomeration in Green Cities?
:Emergence of Recycling Market

Kenmei Tsubota*

Graduate School of Economics, Kyoto University
May,2008
preliminary draft

Abstract

This paper examines the impact of garbage (municipal wastes) on the agglomeration economy. Waste is proportionately generated from consumption and is charged disposal cost. This paper shows the conditions for emergence of recycling market, according to the shape of disposal cost function respect to the regional population. In reality disposal costs may depend on its region's characteristics. Our analysis examines both cases under the same and the different disposal cost structures. At the transition from disposing to recycling, the determinant of recycled rate is also shown endogenously. Then this paper shows when recycling should be and how municipal waste affects the agglomeration.

1 Introduction

There are several issues related with urban problem. Most of the urban problems concern about the negative effect from increasing population. These problems are typically related with environmental aspects in cities, for example, air pollution, transportation congestion, and environmental quality. One of the topic which is dealt within this paper is waste management in city. It is crucially related with human activity; consumption. Even though people do not want to keep their waste in their home, after consuming products, they generate wastes. Especially in cities, there is little space to incinerate or to keep waste. People are nervous about the treatment when waste is disposed near their residences. Thus people want their wastes to keep away from their nearby and deal as NIMBY (Not In My Back Yard) goods. As people concentrate in cities, they accompany waste into cities. As people increase their consumptions, more waste is generated. In particular, when the facilities for proper disposal of waste are scarce, the problem is serious. Notably in developing countries, the situation is more serious because the economic rate and population grow very rapidly. Then the amount of waste increases also very rapidly.

There are several empirical studies on waste management system and waste economics. However, the relation between the population size and the waste management system is not obvious. From the section 2 we propose two observations from Japanese municipal and prefectural data. One is the positive correlation between the increase of population size and the increase of per capita garbage. The other is the positive correlation between the population increase and the increase of the disposal garbage price. Based on these observations, we construct two-region general equilibrium models.

In the theoretical literature there are several researches on waste management. There are mainly three types of approaches to this topic. (1) Dynamic models ; Smith (1972), Highfill and McAsey (1997) mainly discussing the landfill capacity as an exhaust resource. (2) Static Partial Equilibrium ; Miedema (1983), Palmer and Walls (1997) mainly discuss the combination of tax and subsidy on the recycling sector. (3) Static General Equilibrium ; Fullerton and Kinnaman (1995) Fullerton and Wu (1998) mainly discuss the optimal tax and subsidy policies on waste

*Graduate Schoool of Economics, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto-shi, Kyoto, 606-8501, Japan. E-mail: kenmei.tsubota@gmail.com Phone: +81-90-9320-3615

management. These studies prove that if the consumer behavior is highly elastic to the change of disposal price, then there may be a possibility of illegal disposal. When the possibility of illegal disposal is relatively high, it requires the additional costs, monitoring and collection of illegally disposed waste, to avoid the illegal disposal. Fullerton and Wu (1998) and Fullerton and Wolverton (2005) examined several policies to maintain this market failure. They showed the combination of tax on output and the deposit for green goods achieves the second best optimum, even the first best.

Earlier papers have examined the optimal tax and subsidy combinations in one economy with firms that have constant returns to scale technology. Our paper attempts to extend this literature based on both Fullerton and Wolverton (2005) and Fujita et al. (1999) in these two directions. We have developed a general equilibrium model that is based on the increasing returns to scale firms in the framework of Economic Geography model. It allows us to analyze the two-region model. Finally this paper consider such questions: (i) Is it necessary to recycle? (ii) When should recycling begin? (iii) How is the recycle rate determined? (iv) How does the waste influence on the agglomeration?

The rest of this paper is organized as follows. In section 2 we observe the empirical studies of municipal waste. First, earlier studies are introduced and explained. Second, using Japanese municipal data, some observations are proposed. In section 3, based on these observations, we develop two-region model. In the consequences, we discuss the impact of waste on agglomeration and the waste management system.

2 Population size and disposal cost

In this section, a simple empirical study is shown using Japanese municipal data on waste. Although the analysis is simple, this section attempt to show some insights from the data. In Japan, municipal waste is classified into two types according to the discharger. One is generated from household and the other is from not only the profit-pursuing firms such as the store, the company, factories and offices but also the school, and government and municipal offices, etc[1]. The data used for this analysis is reported by all municipalities in Japan and is published by Ministry of the Environment. The data was observed in the fiscal year 1998. There are 3,233 municipalities and 47 prefectures in Japan. Each data is aggregated annually and is normalized by logarithm. Municipal waste is composed of household garbage and firms' waste. Each amount per person per year is 269 *kg* and 139 *kg.* 65.9% of the municipal waste comes from homes. The other 34.1% comes from a variety of sources. Total amount of garbage in Japan was 51,6 million *ton.* It means the amount of municipal waste is 1,118 *g* per person per day and is 408 *kg* per person par year.

Prefectural Data

Figure 2.1 shows that the total amount of municipal waste is regressed by population. It can be interpreted that the aggregated amount of waste is determined by the population size. How about the total amount of garbage per person? In Figure 2.2, the municipal waste per person is regressed by population. This may suggest that the total amount of garbage per person and the population size is also in proportion. In these two regressions, each coefficient is strongly significant.

Observation 1 *The waste per person is strongly and positively related with the population size.*

We see two relations. Associated with the amount of waste, we have total cost of proper disposal of the collected waste. The relation between the cost of disposing garbage per person and population size is shown in Figure 2.3

In Figure 2.4, annual per person cost to dispose garbage is regressed by population size. The coefficient is strongly significant. Our analysis above induces the following observations.

Observation 2 *The cost to dispose garbage per person is strongly and positively related with the population size.*

[1]Besides municipal waste, there is a classification of industrial waste. This industrial waste is generated from the industrial sectors. 20 kinds are specified by ordinance. Those are cinder, dirt, wasted oil, abolition acid, waste alkali, waste plastics, rubber rubbish, etc. The model in the following section mainly focus on waste from consumption and not from production side.

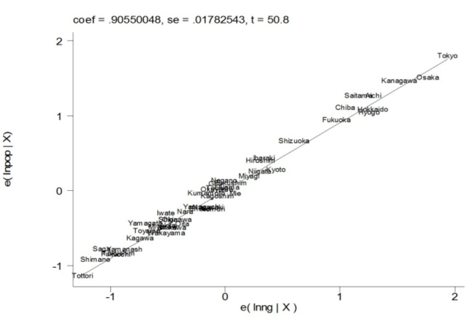


Figure 2.1: Waste amount and population size

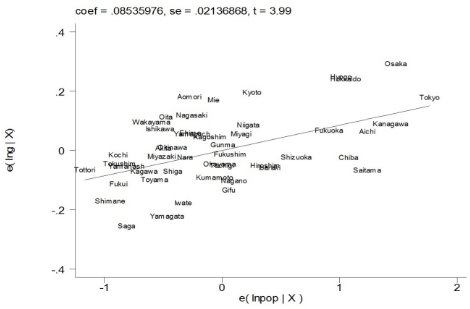


Figure 2.2: Waste amount per person and population size

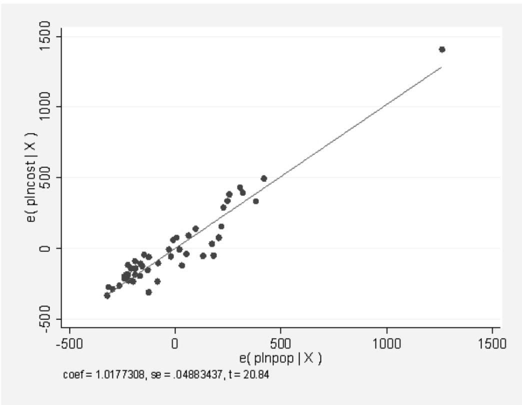


Figure 2.3: Cost and population

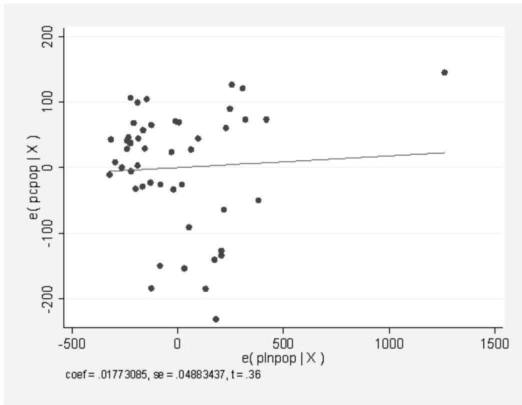


Figure 2.4: Cost per person and population

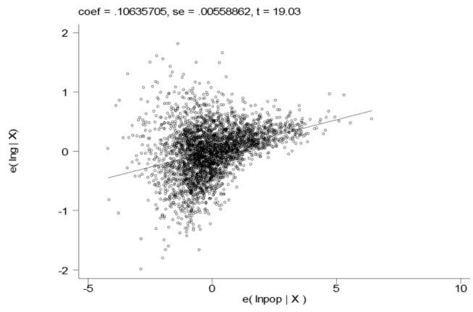
Municipal Data

Because the prefectural data is aggregated from the municipal data, as a next step, disaggregated data is utilized. Figure 2.5 shows the result of the regression of population size against per person garbage. The coefficient is significant. The result supports Observation 1. The regression of population size against annual per person cost to dispose garbage is performed in Figure 2.6. The coefficient is significant and supports Observation 2 with a note.

From the result above, these simple empirics reveals the positive relation between population size and disposal cost in both municipal and prefectural levels. As a whole, when the population size increases, the disposal cost also increases. Observation 2 gives us an assumption for our model. It is used in Assumption 2. The relation revealed in Observation 2 means that the disposal garbage price is an increasing function of population size. Then we can interpret this situation as a kind of congestion costs.

3 Model

Environmental economics has traditionally been conducted in a closed economy. In this section we examine the impact of garbage on the agglomeration and the emergence of the recycling market with two-region model.



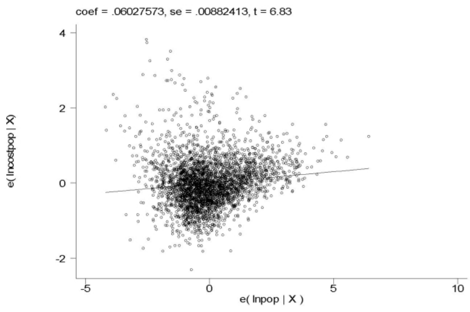


Figure 2.5: Waste amount per person and population size: municipal level

Figure 2.6: Cost per person and population size: municipal level

3.1 Assumptions and the framework

As we see in the previous section, illegal dumping is one of the critical issues in waste management. However, in this paper, our focus is the impact of waste on the agglomeration economy. So we put some assumptions.

Assumption 1 ***(No possibility of illegal dumping)***
All consumers surely pay the garbage price.

This assumption can be interpreted that private cost of illegal dumping is higher than the private cost of proper disposal. The consumers assumed in this paper have *good discretion* to dispose garbage.

From our analysis in the previous section, some evidences were observed. First, the garbage cost increases proportionately with the garbage size. Second, the amount of garbage increases with respect to the population size. Third, garbage cost increases with respect to the population size.

Assumption 2 ***(Decreasing returns technology in landfill)***
Cost for disposal garbage increases with respect to the population size.

This assumption 2 can be interpreted as follows. When regional population increase, the population density around the landfill becomes higher, then the landfill is expected to protect the health of residents. The cost for the facilities increases with respect to needs. that the impact of disposal garbage and landfill on environment is correctly estimated and charged on disposal garbage price.

In this economy,the amount of workers is N. There are two types of workers. One is high skilled, H, and the other is low skilled, L. Their wages are w^H and w^L respectively. The economy is described in Figure 3.2. There are four sectors: agriculture, manufacturing, recycling and disposing sector(landfill). Agricultural sector is perfectly competitive and produce a homogeneous agricultural good with constant return technology. Manufacturing and recycling sectors are under Dixit- Stiglitz monopolistic competition. Between manufacturing sector and recycling sector there is a difference in the production technology. Manufacturing sector only requires labor input, while recycling sector requires recycled garbage and labor input. Disposing sector is operated by public firm and dispose of waste with decreasing return technology. Individuals consume agricultural good, manufactured goods, and recycled goods. After their consumption, waste is generated inevitably.

Now we consider two-region model. Between the regions goods are transported with different transport cost with respect to the type of goods. Transportation of manufactured and recycled goods is costly, while that of agricultural good is costless and garbage is immobile.

Precisely, we assume that the agricultural good is costlessly traded and carried between two regions and is chosen as a numeraire, and thus $P_A = 1$. In contrast, the manufactured and recycled

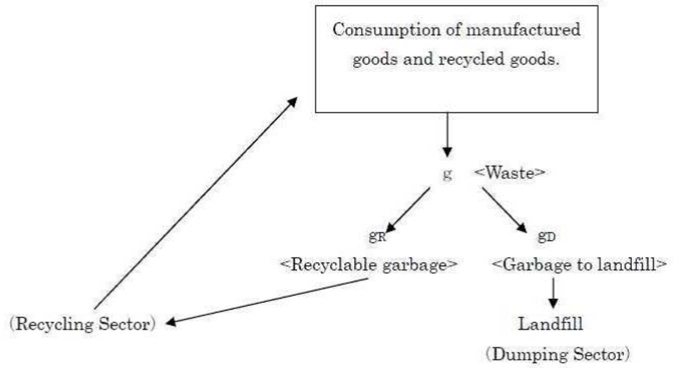


Figure 3.1: Material flow after consumption

goods are shipped at a positive cost according to the "*iceberg*" technology; when one unit of the differentiated product is carried from region s to region r, then only $1/T$ units arrive at the destination, where $T > 1$ for inter-regional transfer and $T = 1$ for intra-regional transfer. Hence, if variety i is produced and sold at the mill price $p_{r\ (i)}$ in region r, consumers in region s pay $p_{sr\ (i)}$ for the variety i including the transport cost. We set the subscription of 1 and 2 as region 1 and 2. For simple notation, we set $\phi = T^{1-\sigma}$. For simplicity, the transport cost is charged on the composite price of the price of good and the garbage price.

Nomenclatures used in this model are listed in Appendix 1.

3.2 Consumer Behavior[2]

Preferences are identical across all households and expressed by a Cobb-Douglas utility,

$$U(Q, A) = Q^{\mu} A^{1-\mu} \qquad where \quad 0 < \mu < 1, \tag{1}$$

Household utility depends on the consumption of manufactured goods and agricultural goods. The consumption of agricultural good is represented by A. The consumption of the manufacture goods is represented by $q_{(i)}$. The consumption of the recycled goods is represented by $q_{(Ri)}$. $p_{(i)}$ is the price of manufacture goods variety (i) and $p_{(Ri)}$ is the price of recycled goods variety (Ri). Now in the manufacturing sector and in recycling sector there are n, m farms which produce the differentiated goods. Q is the index of the consumption of manufactured goods and the recycled goods.

$$Q = [\int_0^n q_{(i)}^{\rho} d_i + \int_0^m q_{(Ri)}^{\rho} d_i]^{\frac{1}{\rho}} \tag{2}$$

The parameter ρ represents the intensity of preference for variety in manufactured goods. When ρ is close to 1, differentiated goods are nearly perfect substitutes for each other; as ρ decrease to 0, the desire to consume a greater variety of manufactured goods increase. If we set $\sigma = \frac{1}{1-\rho}$ then σ is the elasticity of substitution between any two varieties, which varies between 1 and ∞. [3]

After the manufactured goods and recycled goods are consumed, waste is generated according to the following function.

$$g = g(q_{(i)}, q_{(Ri)})$$

[2]This type of consumer behaviors is an extension of Fullerton and Wu (1998). Their study and also the relating studies specify that there are disutilities from the amount of disposal/hazardous garbage in the economy. For simplicity, we include this effect not in utility function directly but in the technology of disposing sector. We discuss this later.

[3]The elasticity of substitution would be different between manufacture goods and recycled goods in the real world. However, we omit this reality.

g represents the amount of the garbage generated per person. $g(...)$ is continuous and quasi-concave, with first derivatives $g_{q_{(i)}} > 0$, $g_{q_{(Ri)}} > 0$. That is, waste increases with the quantity of consumption. For simplicity, we specify the garbage generation function as below,

$$g = \beta \left(\int_0^m q_{(i)} d_i + \int_0^n q_{(Ri)} d_i \right) \tag{3}$$

This specification means that waste is generated with the constant rate from the consumption of the manufactured goods and recycled goods. Waste is segregated into two types. One is garbage carried to landfill and the other is recyclable garbage carried to recycling sector. The share of recyclable garbage is represented by r, while $(1-r)$ means the share of the garbage that would be disposed at the landfill.

Waste for recycling and for landfill per person is described as below;

$$g_R = rg, \quad g_D = (1-r)g \tag{4}$$

G represents the amount of the garbage generated in a region. Now N is given as exogenous for a mean while.

Then the amount of the garbage for recycling , G_R,and for disposing at the landfill , G_D, in one region will be shown by

There are some changes in the notations of the endogenous variables. The regional total garbage generation functions only depend on the region's population and the garbage generation function per person. Then the regional total garbage generation functions are as follows.

$$G_{s(R)} = rG_s = N_s g_R \ , \quad G_{s(D)} = (1-r)G_s = N_s g_D \tag{5}$$

The price for disposing garbage is p_D and the price for recycling garbage is p_R.

We solve the consumer problem in two steps. First we solve the minimization of the cost for Q. Secondly, we solve the whole maximization of his or her utility. Before solving the consumer problem, we set the price indices as follows.

$$\begin{aligned} P_s &= [\int_0^{n_s} \left(p_{s\,(i)} + z_s\right)^{-(\sigma-1)} d_i + \int_0^{m_s} \left(p_{s\,(Ri)} + z_s\right)^{-(\sigma-1)} d_i \\ & \quad (\int_0^{n_2} \left(p_{r\,(i)} + z_s\right)^{-(\sigma-1)} d_i + \int_0^{m_2} \left(p_{r\,(Ri)} + z_s\right)^{-(\sigma-1)} d_i) T^{1-\sigma}]^{\frac{-1}{(\sigma-1)}} \end{aligned} \tag{6}$$

$$where \quad z_s \equiv (p_{s\,D}(1-r_s) + p_R r_s)\,\beta \tag{7}$$

z represents the composite price for disposal cost. When consumers act rationaly, they dispose their waste according to the following cases.

Consumers decide the share between recycled and disposal garbage according to the difference of the disposal prices.

(a) *If* $p_D < p_R$ *Consumers only generate disposal garbage.* $(r = 0)$

(b) *If* $p_D \geq p_R$ *Consumers generate both recycled and disposal garbage.* $(r \in (0,1))$

In the case of (a), there is no garbage for recycling. So there is no recycling sector. In the case of (c) there are both sectors and $p_R = p_D$ is achieved.

Firstly, we minimize the expenditure for differentiated products including disposal cost. The F.O.C to this minimization problem gives equality of marginal rate of substitution with respect to the price ratios. Substituting the obtained equations into the original constraint, we obtain the usual form of demand for the manufacture goods for each firms. Secondly, we maximize Cobb-Douglas utility subject to the budget constraint.

$$max\ U = Q^{\mu} A^{1-\mu} \quad s.t. \quad y = p_A A + PQ \tag{8}$$

After solving the problem in two steps, we obtain regional demands for differentiated products. Regional aggregated demands in region s for the manufactured and recycled goods produced in region s are as follows,

$$q_{ss\,(i)} = \mu \left(p_{s\,(i)} + z_s\right)^{-\sigma} P_s^{\sigma-1} Y_s \tag{9}$$

$$q_{ss\,(Ri)} = \mu \left(p_{s\,(Ri)} + z_s\right)^{-\sigma} P_s^{\sigma-1} Y_s \tag{10}$$

Regional aggregated demands in region s for the manufactured and recycled goods produced in region r are as follows,

$$q_{rs\ (i)} = \mu\left(p_{r\ (i)}+z_s\right)^{-\sigma} P_s^{\sigma-1} Y_s T^{1-\sigma} \tag{11}$$

$$q_{rs\ (Ri)} = \mu\left(p_{r\ (Ri)}+z_s\right)^{-\sigma} P_s^{\sigma-1} Y_s T^{1-\sigma} \tag{12}$$

First subscript of q means the region where product is manufactured or recycled. Second subscript of q means the region where product is consumed. When we use $q_{s\ (i)}$ as the aggregated demand for differentiated product produced in region s. $q_{s\ (i)} = q_{ss\ (i)} + q_{sr\ (i)}$.

$$q_{s\ (i)} = \mu\left(p_{s\ (i)}+z_s\right)^{-\sigma} P_s^{\sigma-1} Y_s + \mu\left(p_{r\ (i)}+z_r\right)^{-\sigma} P_s^{\sigma-1} Y_s T^{1-\sigma} \tag{13}$$

The first term is the demand from region s and the second term is the demand from region r. As is shown above, different disposal price is charged in different regions. This aggregated demand is the one which producer faces. We can interpret this form as a general version of aggregated demand in the framework of New Economic Geography. The specification in , Fujita and Thisse (2002) and Baldwin et al. (2003) include some of the typical cases when the regional tax (or disposal price) is not charged and the transport cost does not violate the symmetry of goods across regions. In our specification the price elasticity of demand across regions is not constant because of the different disposal cost between regions. Thus each firm determines their product price respect to its destinations. This is similar to the specification of Ottaviano et al. (2002).

Here we note that the amount of garbage is different from a function of the aggregated demand discribed above. It is the outcome from the sum of equation (9) to (12) for all manufactured and recycled goods.

$$G_s = \beta\left(\int_0^n \left(p_{s\ (i)}+z_s\right)^{-\sigma} d_i + \int_0^m \left(p_{s\ (Ri)}+z_s\right)^{-\sigma} d_i\right) P_s^{\sigma-1} Y_s d_i \left(1+T^{1-\sigma}\right) \tag{14}$$

3.3 Producer Behavior

There are two types of labors, high skilled and unskilled. High skilled can move between regions. However, unskilled cannot move between regions. Between regions the share of the high skilled labor are denoted by λ_s and $\lambda_s + \lambda_r = 1$. In each regions, the share of the skilled labor between manufacture sector and recycling sector are denoted by h_s and $(1-h_s)$. On the other hand unskilled labors are equally distributed.

In each region there are 4 sectors in one region; Agriculture, Manufacturing, Recycling, and Dumping sector. In manufacture and recycling sector labor inputs are both high skilled $\left(H^M, H^R\right)$ and unskilled labor $\left(L^M, L^R\right)$. On the other hand in agriculture and disposing sector, labor input is only low skilled labor $\left(L^A, L^D\right)$.

The amount of the skilled labor in this economy is H, while that of the unskilled labor is L. The unskilled workers are unable to move between the regions but can move intra-regions. Thus the unskilled's wage is the same, w^L across sectors.

Agriculture Sector[4]

One unit of unskilled labor produce one unit of agricultural goods. Then the prices of agricultural good is determined as $P_A = w^L$ and is taken as numeraire. So the agricultural price and low skilled labor's wage are normalized to 1. As we assume no transportcost for agriculture, the unskilled workers' wage and price of agricultural good is the same across regions.

Disposing Sector

Landfill is operated by public firm and the production technology of this sector is assumed to be decreasing returns to scale and only uses labor input, $\left[\pi_D = p_{s\ D} G_{s\ D} - \left(d_s G_{s\ D} - D\right) w^L\right]$ [5]. D represents the fixed input of labor and the same across regions. d_s represents the marginal input of labor and varies across regions. Furthermore we assume the disposal garbage can not be shipped across regions. Landfill is operated by the public firm. Then the price is determined

[4]We assume the consumption share of agricultural goods is large enough.

[5]We can adopt usual Cobb-Douglas type production function $G_D = (L_D)^\alpha$,*where* $0 < \alpha < 1$ However, the calculation becomes too complicated to make implication. So we adopt the specification in the text.

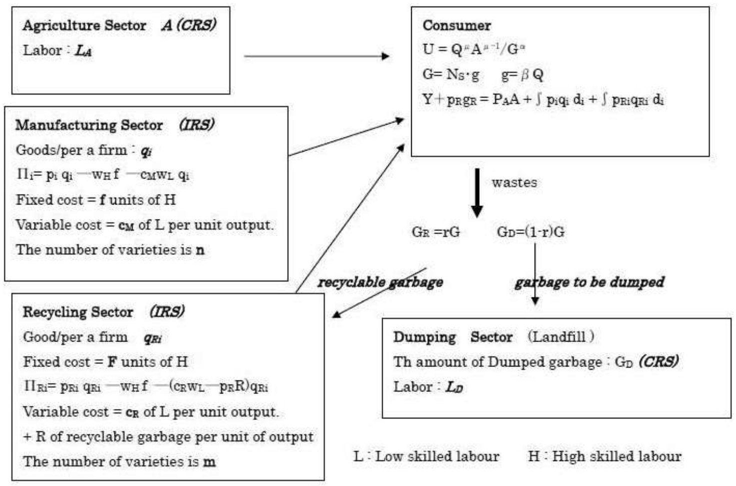


Figure 3.2: Schematic diagram of the model

as $p_{s\ D} = \left(d_s - \frac{D}{G_D}\right) w^L$ by balanced budget. When we think about the negative externalities from the waste and landfills (NIMBYs), the quantity or scale is concerned. The larger the amount of waste is, the more people are concerned with the environmental and social damage from the NIMBYs. To respond to the social reaction, the landfill company (assuming public firm) has to invest in the facilities for the environment and publicity activities. We interpret this situation as decreasing returns to scale as we assumed.

Manufacturing Sector and Recycling Sector

Since trade costs are positive and the composite garbage prices are different across regions, firms determine the price specific to the market in which its product is sold. It is observable and there are some empirical studies which show that firms succeed in determining discriminating price among spatially separated markets. The reason why the firms adopt discriminating price comes from the different price

There are n_1 manufacturing firms in region 1, while there are n_2 in region 2,In this economy there are n firms.($n = n_1 + n_2$) Each firm produces a differentiated good and the production input is only labors input. f represents the fixed amount of the labor input (high skilled labors) for production and c_M represents the marginal unit costs for production (unskilled labors). The profit function of manufacture sector in region r is supposed to be below in the equation (15).

There are m_1 recycling firms in region 1, while there are m_2 in region 2,In this economy there are m firms.($m = m_1 + m_2$) Each firm produces a differentiated recycled good. The production input requires skilled labors ,F, as fixed cost and requires unskilled labors ,c_M, and recyclable garbage ,R, as the marginal unit costs for production. The profit function of recycling sector in region r is supposed to be below in the equation (16), ($r \neq s$)

$$\Pi^s_{Mi} = \sum_{r=1}^{2} \left(p_{sr\ (i)} - w^L c_M\right) q_{sr\ (i)} - w^H_s f \tag{15}$$

$$\Pi^s_{Ri,} = \sum_{r=1}^{2} \left(p_{sr\ (Ri)} - \left(w^L c_R - p_R R\right)\right) q_{sr\ (Ri)} - w^H F \tag{16}$$

After solving the profit maximization to each region, firms determine the discriminating prices as follows. $(r \neq s)$

$$
\begin{aligned}
p_{s\ (i)} &= \frac{\sigma c_M w^L + z_s}{\sigma - 1} && (17) \\
p_{s\ (Ri)} &= \frac{\sigma\left(c_R w^L - p_R R\right) + z_s}{\sigma - 1} && (18) \\
where\ \ z_s &\equiv \left(p_{s\ D}(1 - r_s) + p_R r_s\right)\beta
\end{aligned}
$$

Under free entry, profits are zero, firms in region s pay the high skilled workers' wage as follows.

$$
\begin{aligned}
w^H_{M\ s} &= \frac{\mu}{f}\frac{(\sigma-1)^{\sigma-1}}{\sigma^\sigma}\left[(c_M + z_s)^{1-\sigma} P_s^{\sigma-1} Y_s + (c_M + z_r)^{1-\sigma}\phi P_r^{\sigma-1} Y_r\right] && (19) \\
w^H_{R\ s} &= \frac{\mu}{F}\frac{(\sigma-1)^{\sigma-1}}{\sigma^\sigma}\left[(c_R - p_R R + z_s)^{1-\sigma} P_s^{\sigma-1} Y_s + (c_R - p_R R + z_r)^{1-\sigma}\phi P_r^{\sigma-1} Y_r\right] && (20)
\end{aligned}
$$

Since skilled workers can be employed in both sector, in the equilibrium skilled wage for both sector should be equal, $w^H_{s\ M} = w^H_{s\ R}$. Then,

we assume fixed cost is the same in both sectors. This equality yields the following equation.

$$
\begin{aligned}
\frac{1}{f}(c_M + z)^{1-\sigma} &= \frac{1}{F}(c_R - p_R R + z)^{1-\sigma} \\
\theta &= \frac{f}{F} = \left(\frac{c_R - p_R R + z}{c_M + z}\right)^{1-\sigma}
\end{aligned}
$$

In our analysis, recycling sector does not necessarily exist from the begining. This expresses the production of recycling is more expensive than typical manufacturing. In this paper, we abstract this cost difference as expressing only in variable cost and do not integrate as fixed cost. This abstraction means $c_R - c_M = p_R R > 0$ and $\theta = 1$.

For simpler notation the share of the skilled labors between manufacture sector and recycling sector are denoted by h_s and $(1 - h_s)$. Then the number of firms in each sector $n_s = \frac{h_s H}{f}, m_s = \frac{(1-h_s)H}{F}$

3.4 Conditions and Equilibrium

From the distribution of skilled and unskilled labor, the regional incomes in each region are described as follows.

$$
Y_s = \lambda_s H w^H_s + \frac{L}{2} \tag{21}
$$

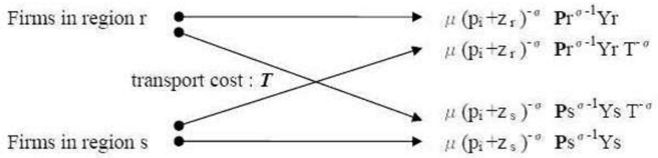


Figure 3.3: Quantity consumed in each region

After consumption, consumers generate garbage. The garbage are traded or disposed at the following markets and satisfies the following market clear conditions. These conditions determine the recycle rate and disposal garbage price. The amount of garbage generated in one region has already obtained in equation (14) and is described in Figure 3.2

Recyclable Garbage Market

For the next, we consider *the market clear condition of recyclable garbage*. This condition means that in the recyclable garbage market the demand from the firms, $mR\left(\int_0^m q_{(Ri)} d_i\right)$, and the supply from the consumers ,$G_{s(R)}$, are equal. (Calculation is in Appendix 3) The amount of recycled garbage in region s is expressed by $\mu\left(p_i\right)^{-\sigma} P_s^{\sigma-1} Y_s\left(1+T^{-\sigma}\right)$. Here we assume that recycled garbage is not transferable.

$$
\begin{aligned}
G_{s(R)} &= R \int_0^m q_{s(Ri)} = r_s \beta\left(\int_0^n q_{ss(i)} d_i+\int_0^m q_{rs(Ri)} d_i\right) \\
& (s=1,2 \qquad s \neq r)
\end{aligned} \tag{22}
$$

From this market clear condition, we obtain the recycle rate in each regions.

$$
r_s=\frac{\left(1-h_s\right) \lambda_s R}{Y_s \beta}\left(\frac{Y_s}{\lambda_s+\lambda_r \phi}+\frac{Y_r \phi}{\lambda_s \phi+\lambda_r}\left(\frac{c_M+z_s}{c_M+z_r}\right)\right) \tag{23}
$$

Recycle rate is determined in this procedure and depend on the regional demand and labor share.

Disposal Garbage Market

For the next, we consider *the market clear condition of disposal garbage*. This condition means that in the disposal garbage market the demand from the public landfill and the supply from the consumers, are equal.

$$
\begin{aligned}
G_{s(D)} &= \left(1-r_s\right) \beta\left(\int_0^n q_{ss(i)} d_i+\int_0^m q_{rs(Ri)} d_i\right) \\
& (s=1,2 \qquad s \neq r)
\end{aligned} \tag{24}
$$

In one-economy model this condition require the labor market clear condition at the same time. On the other hand, in two-region model labor market clear condition, especially unskilled labor, is very difficult to solve analytically. Though we do not explicitly solve the condition, we assume it cleared.

$$
p_{s\ D}=d_s-\frac{\left(\left(c_M-c_R\right) h+c_R\right) D}{(\beta-R(1-h))\left(\frac{\mu(\sigma-1)}{\sigma-\mu} L+D\right)} \geq 0 \tag{25}
$$

As for the labor market condition, firstly the labor requirement in each sector are listed. Then we could satisfy the condition.

Substituting the firm sizes in each sectors, then we obtain the following price indices.

$$
P_s^{1-\sigma}=\frac{H}{F}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\left[\lambda_s+\lambda_r \phi\right]\left(c_M+z_s\right)^{1-\sigma} \tag{26}
$$

Substituting the price indices above into the wage equations, we obtain the following nominal and real wage equations.[6].

$$
\omega_s^H=w_s^H P_s^{-\mu} \tag{27}
$$

Finally, we obtain all variables endogenously. Then we see the spatial equilibrium.

Before we obtain the long run equilibrium, we classify the composite garbage price into three stages. It is related with the disposal garbage price. That is landfill technology. The landfill technology is specified by the regional features.

The equilibrium is classified into three cases according to the economy size measured by amount of garbage and is discribed in Figure 3.4. It is because the economy size influences on the price of disposal garbage. A) [Free disposal] *If the amount of garbage,G, is less than* $\frac{D}{d_s}$*, disposal price is zero (free disposal).* We can interpret this case as the community that is small or keep the traditional life-style. B) [Increasing disposal price] *If the amount of garbage is more than* $\frac{D}{d_s}$ *and less than* $\frac{D}{d_s-p_R}$*, disposal garbage price increases with the increase of garbage.* This garbage increase is caused by population growth, economic growth, and the change of the expenditure share

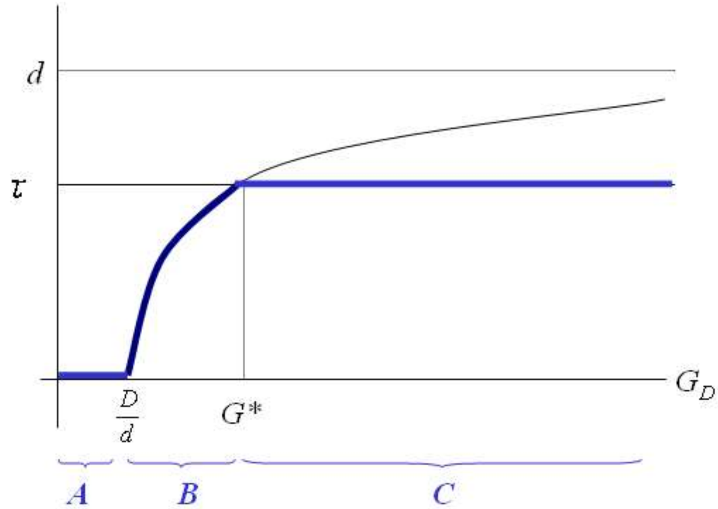


Figure 3.4: Disposal price and recycled price

of manufactured goods. *C*) [Recycling] *If the amount of garbage is more than* $\frac{D}{d_s - p_R}$, *there are both sectors and the composite garbage price is equal to the recycled garbage price.*

For example, some regions have plenty of lands or space for landfill like not beautiful sea. This is stage (A). Some regions have high population density. Then the land price is very high and also the facilities for the protection for health of nearby residents are very high. Further if there are many people who heavily concern on the environmen tal issues. People may persist in the preservation of the environment and require the facilities with high technology that doesn't burden the environment. These situation is stage (B). From the point of case (C), there exist both sectors and part of waste is recycled. Then there is no further rise of garbage price. These features are closely related with the landfill technology.

3.4 Long run equilibrium[7]

In our analysis, changing disposal cost affects the type of migration. As is shown above, there are 3 stages. (A) Free disposal (B) increasing disposal price (C) Recycling. When a region is in the phase of (A) and (C), the disposal price does not change. In the phase (C), the economy faces constant disposal price. Using the equations (19) to (21) and (26) to (27), we could analyze the long run equilibrium.

$$\begin{aligned}
w_s^H &= \frac{\mu}{\sigma H}\left(\frac{Y_s}{\lambda_s + \lambda_r \phi} + \frac{Y_r \phi}{\lambda_s \phi + \lambda_r}\right) \\
Y_s &= H\lambda_s w_s^H + \frac{L}{2} \\
P_s^{1-\sigma} &= \frac{H}{F}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\left[\lambda_s + \lambda_r \phi\right](c_M + z_s)^{1-\sigma} \\
\omega_s^H &= w_s P_s^{-\mu} \\
z_s &= \begin{cases} (A) & d_s\beta \\ (B) & \beta p_D = d_s\beta - \frac{D}{G_s} \\ (C) & \beta p_R \end{cases} \quad where \begin{cases} G_s < \frac{D}{d_s} \\ \frac{D}{d_s} < G_s < \frac{D}{d_s - p_R} \\ G_s = \frac{D}{d_s - p_R} \\ \frac{D}{d_s - p_R} < G_s \end{cases} \\
(s &\neq r)
\end{aligned} \tag{28}$$

[6]In obtaining the following equations, each of the value in (h_1, h_2) should not be fixed in advance.
[7]The analysis is limited for a few cases in the possible cases.

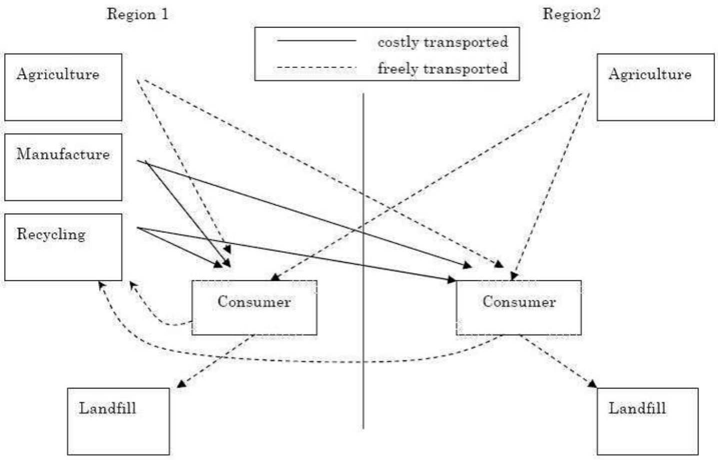


Figure 3.5: Under core-periphery structure

Pattern 1: Both regions are the same phase in (A) or (C) with the same and constant disposal cost $(z_1 = z_2)$

This pattern is the situation that each regional economy faces the same disposal price and the disposal price is constant. Thus the disposal cost does not affect as dispersion force. This situation resembles to **?**

Sustain point Under core-periphery structure

In using the equations (28) we set the parameters as $\lambda = 1$, $Y_1 = \frac{\frac{\mu}{\sigma}L}{1-\frac{\mu}{\sigma}} + \frac{L}{2}$ $Y_2 = \frac{L}{2}$. Here we analyze the sustainability of the core-periphery structure.

$$\omega^H_{M,R\ 1} = \frac{\mu}{H\sigma}\left(\frac{L}{1-\frac{\mu}{\sigma}}\right)\left(\frac{\sigma}{\sigma-1}\frac{H}{F\left(c_R - p_R R + z\right)^{\sigma-1}}\right)^{-\mu}$$

$$\omega^H_{M,R\ 2} = \frac{\mu}{H\sigma}\left(\left(\frac{\frac{\mu}{\sigma}L}{1-\frac{\mu}{\sigma}} + \frac{L}{2}\right)\phi + \frac{L}{2\phi}\right)\left(\frac{\sigma}{\sigma-1}\frac{H}{F\left(c_R - p_R R + z\right)^{\sigma-1}}\left[\phi\right]^{\frac{-1}{\sigma-1}}\right)^{-\mu}$$

$$\eta_{sustain} = \frac{\omega^H_2}{\omega^H_1} = \frac{\left(1+\frac{\mu}{\sigma}\right)}{2}T^{(1-\sigma-\mu)} + \frac{\left(1-\frac{\mu}{\sigma}\right)}{2}T^{(\sigma-1-\mu)} \tag{29}$$

If $\eta_{sustain} \leq 1$, it means the real wage of high skilled workers in region 1 is higher than that in region 2. So when the condition holds, migration of workers doesn't occur. When shipping is costless ($T = 1$), we always have $\frac{\omega^H_2}{\omega^H_1} = 1$. In the equation (29), the first term is always decreasing in T. When $\mu < \rho$, the second term goes to infinity when $T \to \infty$. And the ratio $\frac{\omega^H_2}{\omega^H_1}$ is discribed as 3.6.

Because the second term is also decreasing when $\mu \geq \rho$, the ratio $\frac{\omega^H_2}{\omega^H_1}$ always decreases with T. It means that $\omega^H_2 < \omega^H_1$ for all $T > 1$. This situation is that when $\mu \geq \rho$, the core-periphery structure is a stable equilibrium for all $T > 1$. This is called black hole condition. This condition is too strong to analyze the agglomeration phenomenon. Thus we exclude this case in our analysis.

Break point Under symmetric structure

In using the equations (28), we set the parameters as $\lambda = \frac{1}{2}, Y_1 = Y_2 = \frac{H}{2}w^H + \frac{L}{2} = \frac{\frac{\mu}{\sigma}L}{1-\frac{\mu}{\sigma}} + \frac{L}{2} = \frac{L}{2}\frac{1+\frac{\mu}{\sigma}}{1-\frac{\mu}{\sigma}} = Y$. Here we analyze the break condition of symmetric structure. Firstly, we totally differentiate all of the equations and obtain $\frac{\partial\omega}{\partial\lambda}$. This means the migration dynamics due to the real wage difference. In the long run equilibrium this parameter surely equals to zero.The equilibrium

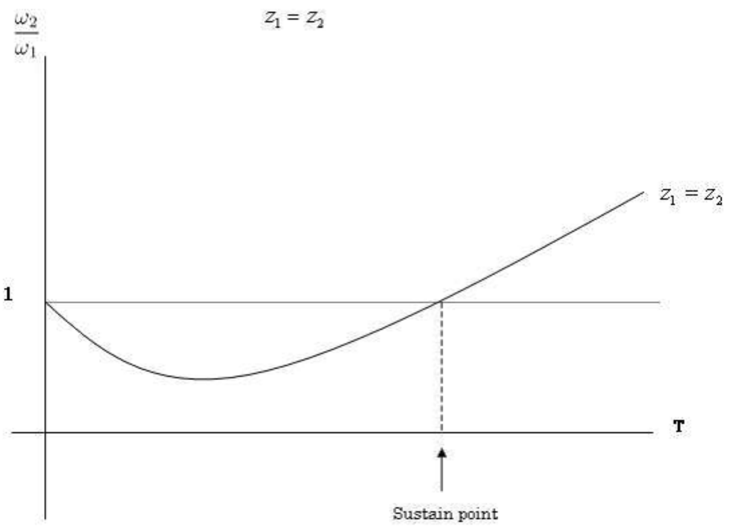


Figure 3.6: Under constant disposal cost

is stable when $\frac{\partial\omega}{\partial\lambda} = 0$. Then we get the critical point of transport cost as below. (See Appendix 4)

$$T_{break}{}^{\sigma-1} = \frac{(\sigma+\mu-1)(\sigma+\mu)}{(\sigma-\mu-1)(\sigma-\mu)} \tag{30}$$

Pattern 2: Both regions are the same phase in (A) or (C) with the different disposal cost function (z_1)

Secondly, we examine the patterns that each regional economy faces different disposal cost function. The situation is described in Figure17. In the long run analysis, the initial combination of two regions becomes ten cases. Especially, the migration of A⟹B, B⟹A, and C or D⟹B feature. In the following, we examine the agglomeration caused by the decrease of the transportation cost and the influence of decentralization according to an increase in the disposal garbage cost.

Sustain point Under core-periphery structure

$$\eta_{sustain} = \frac{\omega_2^H}{\omega_1^H} = \left(\frac{\left(1+\frac{\mu}{\sigma}\right)}{2}T^{(1-\sigma-\mu)} + \frac{\left(1-\frac{\mu}{\sigma}\right)}{2}T^{(\sigma-1-\mu)}\right)\left(\frac{c_M+z_1}{c_M+z_2}\right)^{\mu} \tag{31}$$

Core-periphery structure is stable under $\eta_{sustain} \leq 1$. (*region 1* is core-region) From the equation (31), shifts of the real wage ratio curve are observed. The direction of shift depends on the second parenthesis in equation (31). When $z_1 > z_2$ under core-periphery distribution, the shift is upward. This situation is discribed in Figure 3.7 and 3.8. When $z_1 < z_2$ under core-periphery distribution, the shift is downward. This is situation is described in Figure 3.9 and 3.10. These results shows that when disposal cost is relatively high in core region, agglomeration force is weakened and that when disposal cost is relatively low in core region, agglomeration force becomes stronger. The results goes along with our intuition high disposal cost weaken agglomeration force in core-region.

In a word, the symmetric equilibrium is a stable solution in high transportcost. This is the same across all combinations in any cases. Agglomeration happens in low transport cost. However, there is a possibility of disproportionate equilibrium that is not fully aggromerated. For example in pattern 1 that both regions are (A), when agglomeration occurs by low transport cost, the core region may shift into the phase with increasing disposal cost (B). Because of the increasing

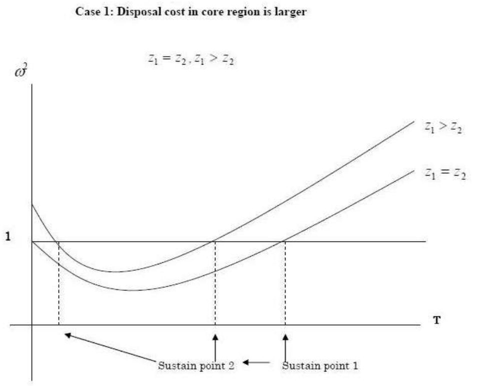


Figure 3.7: Sustain point :Case 1

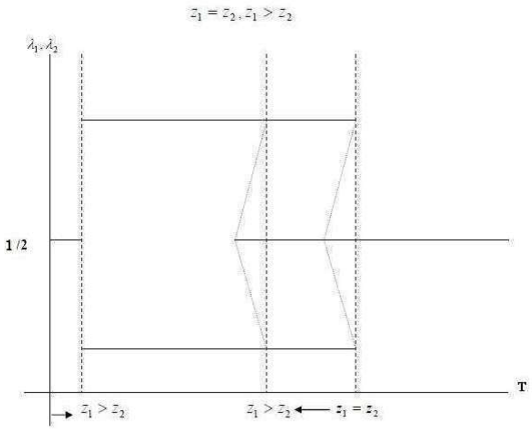


Figure 3.8: Tomahawk diagram : Case 1

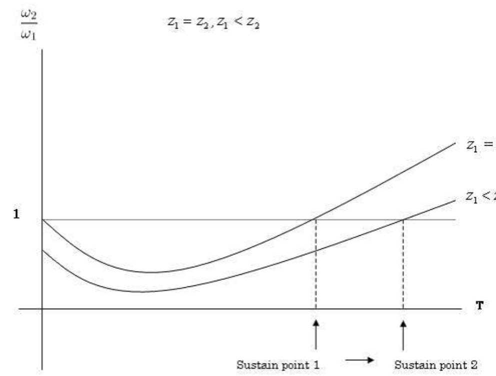


Figure 3.9: Sustain point :Case 2

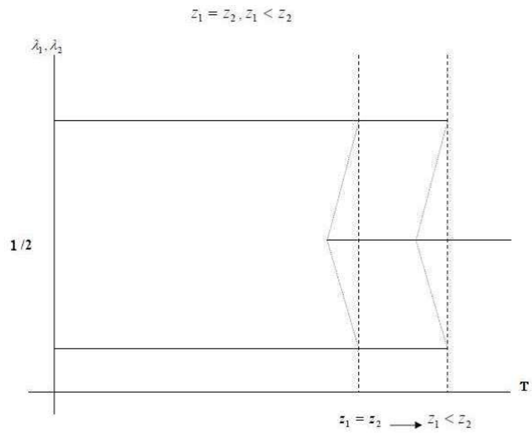


Figure 3.10: Tomahawk diagram : Case 2

disposal cost, there is a dispersion force in core region and the increasing disposal garbage price prevents the full agglomeration. Thus full agglomeration does not occur. It means some amount of skilled labor remains in pheriphery region. For another example in pattern 1 that both regions are (C), when agglomeration occurs by low transport cost, the periphery region may shift into the phase with dicreasing disposal cost (B). [8] Because of the decreaseing disposal cost, there is an agglomeration force in periphery region and full agglomeration does not occur. We call this core-periphery equilibrium as disproportionate equiibrium. At that time, the disproportionate equilibrium becomes a stable solution again. Because the core region can not absorb all skilled labor. This kind of situations also occurs in the following cases.

When both regions are in (B), both regions have been faced the disposal garbage prices which are the increasing functions of the population. While agglomeration occurs, there is a dispersion force in core-region and agglomeration force in periphery-region. It is because population increase in core induces higher disposal cost and because population decrease in periphery induces lower disposal cost. Therefore, full agglomeration similar to pattern 1 connot be achieved. Then imperfect agglomeration is temporarily caused by the decrease of the transport cost, and when the transport cost lowers enough, the symmetric equilibrium might be stable.

When two regions are different phases, the region whose disposal cost is lower has comparative advantage. These cases are the analysis for regions with asymmetric endowments.

[8]Disposal cost in (C) is the highest. When population decreases in (B), disposal price also decreases.

When one region is in (A) and the other is in (B), with the decrease of transport cost, agglomeration occurs in (A) caused by the inflow from (B). When the region of (A) shifts to the phase of (B), a disproportionate equilibrium is achieved.

When one region is in (A) and the other is in (C), agglomeration occurs in the region (A) from the region (C) like the case (A) and (B). Then a disproportionate equilibrium is achieved when both regions are in (B).

When one region is in (C) and the other is in (B), agglomeration occurs in the region (B) from the region (C) like the case (A) and (C). Then a disproportionate equilibrium is achieved.

3.5 Conclusion and Further extension

In this paper, we examine the condition of the emergence of recycling market. In this two-region model, there are several cases that the recycling market endogenously emerges. It is observed that the recycling market emerges in the regions that does not have it. These are the cases the regions which was the phase of (A) and (B) shift to the phase (C). These cases are caused by the migration from the higher price index region (C) to the lower price index region (A) and (B). This migration rises the disposal garbage price and it reaches the recycled garbage price. Then the recycling market occurs.

On the other hand, the opposite cases are also observed. That is, some regions which had the recycling market lose it. These are the cases of the regions which was the phase of (C) shift to the phase (B).

In our model, once the disposal garbage price in the region reaches and pass over the recycled garbage price, then recycle rate becomes 100%. This situation is not realistic. Even though the technology makes great progresses, 100% recycle rate is a kind of dreams. Then we may set a upper boundary of recycle rate. In the situation, landfill and recycling sector exist together. This modification allows us to examine further realistic model.

Furthermore, one of the exclusion of our analysis is the rise of consideration on environment by the residents. Because people's consideration changes make the environmental destruction as an internal cost. These changes push up the disposal garbage price function. Then the recycling market could emerge in the region where it was absent before.

Actually the phase of (A) [free disposal] does not continue long. The initial condition of regions may start from (B).

For further extension, there are some interesting directions. (1) *Mobility of recycled garbage* (*domestic*): this phenomenon is easily observed among the prefecture level. So this extension is meaningful for the policy makers in tax competing municipalities. (2) *Mobility of recycled garbage* (*international*): It is the international trade of recyclable garbage. From the difficulty of distinction among hazardous, recyclable, and non-recyclable waste is a practical problem, specific recyclables can be analyzed. For example, lots of used cars are exported from Japan to Russia and developing countries. (3) *Technological substitution in landfill*: in our analysis the agglomeration of people and firms assumed to make the land price higher. Then the production function in landfill would be shift from the land intensive to the technology intensive. This might be occur in large city. To analyze this situation, Cobb-Douglas function and the sum of exponential is less than 1 is one way. (4) *Heterogeneity of goods*: in the reality, there are vast heterogeneity in goods. Depending on the good characteristics, the propotion of waste after consumption varies. So the waste generation rate varies across each heterogeneous good. Then the modification be the introduction of heterogeneous waste generation coefficient,(3) into equation (3) and we have $g = \int_0^n \beta_{(i)} q_{(i)} d_i + \int_0^m \beta_{(Ri)} q_{(Ri)} d_i$. Since we assumed the symmetry of waste generation ratio across the manufactured and recycled goods, this modified expression is more general.

References

Baldwin, Richard, Rikard Forslid, Philippe. Martin, Gianmarco Ottaviano, and Frederic Robert-Nicoud (2003) *Economic Geography and Public Policy*: Princeton University Press.

Fujita, Masahisa and Jacques-François Thisse (2002) *Economics of Agglomeration*: Cambridge University Press.

Fujita, Masahisa, Paul Krugman, and Anthony Venables (1999) *Spatial Economy*: MIT Press.

Fullerton, Don and Thomas C. Kinnaman (1995) "Garbage, Recycling, and Illicit Burning or Dumping", *Journal of Environmental Economics and Management*, 29, 78–91.

Fullerton, Don and Ann Wolverton (2005) "The Two-Part Instrument in a Second-Best World", *Journal of Public Economics*, 89(9-10), 1961–1975.

Fullerton, Don and Wenbo Wu (1998) "Policies for Green Design", *Journal of Environmental Economics and Management*, 36, 131–148.

Highfill, Jannett and Michael McAsey (1997) "Municipal waste management; Recycling and landfill constraint", *Journal of Urban Economics*, 41, 118–136.

Miedema, Allen K. (1983) "Fundamental economic comparisons of solid waste policy options", *Resources and Energy*, 5, 21–43.

Ottaviano, Gianmarco, Takatoshi Tabuchi, and Jacques-François Thisse (2002) "Agglomeration and Trade Revisited", *International Economic Review*, 43(2), 409–436.

Palmer, Karen and Margaret Walls (1997) "Optimal policies for solid waste disposal: taxes, subsides, and standards", *Journal of Public Economics*, 65, 193–205.

Smith, Vernon L. (1972) "Dynamics of waste accumulation; Disposal versus recycling", *Quarterly Journal of Economics*, 86, 600–616.

Appendix 1 Nomenclature

Subscripts	
i or j	commodities
s	regions $(s = 1, 2)$
$_R$	*Recycling* sector or recycled goods
$_M$	*Manufacturing* sector or manufactured goods
$_D$	*Disposing* sector or household garbage to landfill
Variables	
y	per capita income
Y	Total income in the economy
Y_s	Total income in s region $(s = 1, 2)$
p_A	price of *agricultural* good
$p_{(i)}$	price of differentiated *manufactured good*
$p_{(Ri)}$	price of differentiated *recycled good*
p_R	price of *recycled* garbage
p_D	price of *disposal* garbage at the landfill
$q_{(i)}$	a differentiated *manufactured* good
$q_{(Ri)}$	a differentiated *recycled* goods
g_R	the amount of *recycled* garbage per person
g_D	the amount of *disposal* garbage in the landfill per person
G_D	total *disposal* garbage in s region
G_R	total *recycled* garbage in s region
r	recycle rate
z	composite price of garbage $\quad , where \;\; z \equiv \beta \left[p_D (1 - r) + p_R r \right]$
n	the number of firms in *manufacturing* sector
m	the number of firms in *recycling* sector
τ	tax on consumption
δ	subsidy for recycling
Parameters	
β	garbage generation ratio after consumption
f	fixed labor cost for *manufactured* goods
F	fixed labor cost for *recycled* goods
D	fixed cost for the *public landfill* firm
c_M	marginal unit labor cost for the *manufactured* goods
c_R	marginal unit labor cost for the *recycle* goods
R	marginal unit recycled garbage for *recycled* goods
d	marginal unit of labor cost for the *public landfill* firm

Appendix 2 Recycled garbage price

Skilled labor can work at both manufacturing and recycling sector across regions. Then the wage for skilled labor should be equal in the equilibrium, $w_M^H = w_R^H$.

$$
\begin{aligned}
0 \;\; = \;\; & \left((c_M + z_s)^{1-\sigma} - (c_R - p_R R + z_s)^{1-\sigma} \right) P_s^{\sigma-1} Y_s \\
& + \left((c_M + z_r)^{1-\sigma} - (c_R - p_R R + z_r)^{1-\sigma} \right) P_s^{\sigma-1} Y_s
\end{aligned}
\tag{32}
$$

To satisfy the equality in the equation above, the parenthesis in first and second term should be zero. Then we obtain the recycled garbage price, p_R, as the marginal cost difference between manufactured and recycled sector. R represents the marginal input of recycled garbage.

$$c_R - c_M = p_R R \tag{33}$$

Appendix 3 Garbage market clear condition

Regional amount of garbage is obtained in equation (14). Using the recycled garbage price obtained in Appendix 2 and the equilibrium price of manufactured and recycled sectors, equation (9)-(12), we obtain the recycle rate from this market clear condition as in the text. This recycle rates are achieved only when the disposal garbage price is more than the recycled garbage price. Unless all garbage is disposed as disposal one.

Next,using the equation (34) to (37), (47), (48) and above, we obtain the total amount of garbage.

$$G_s = \beta \frac{(\sigma - 1)}{\sigma\left(c_M + z_s\right)} \frac{\mu Y_s}{\left(\lambda_s + \lambda_r \phi\right)}(1 + \phi)$$

This is the sbstituted version of equation (#).

Substituting the equations above into the profit function of landfill, we obtain the disposal garbage price.

$$\begin{aligned} p_{D,1} &= \frac{d_1 - \frac{\left(p_{(i)} + \beta p_R r_1\right) D}{\mu\beta(1-r_1)Y_1(1+\phi)}}{1 + \frac{1}{\mu Y_{1(1+\phi)}}} \\ p_{D,2} &= \frac{d_2 - \frac{\left(p_{(i)} + \beta p_R r_2\right) D}{\mu\beta(1-r_2)Y_2(1+\phi)}}{1 + \frac{1}{\mu Y_2(1+\phi)}} \end{aligned}$$

$$G_{D,1} = \frac{\beta\mu Y_s}{c_M + z_s} - \mu\left(1 - h_s\right)\lambda\left(\frac{Y_s}{\left(\lambda_s + \lambda_r\phi\right)}\left(\frac{1}{c_M + z_s}\right) + \frac{Y_r\phi}{\left(\lambda_s\phi + \lambda_r\right)}\left(\frac{1}{c_M + z_r}\right)\right)$$

These disposal prices and the amount of garbage is determined only when the recycling market does not emerge $G_s \leq \frac{D}{d - p_R}$.

Appendix 4 Sustain point (pattern 1)

In this pattern, disposal costs in each region are equal. $z_1 = z_2$ Then we set it $z_r = z$. Totally differentiating the equations (I), we obtain the following equations and solve for $\frac{\partial\omega}{\partial\lambda}$. This ratio means the effect of migration on the real wage for high skilled. The difference between former literature and our analysis lies in the existense of parameter set in our model. In this pattern, disposal cost,z, is constant in this pattern and the same across regions. Thus it doesn't affect the migration dynamics.

$$\begin{aligned} \partial Y &= \partial\lambda H + \frac{H}{2}\partial w \\ \partial w &= K(1-\phi)((\sigma-1)\frac{\partial P}{P} + \partial Y)P^{\sigma-1} \\ (1-\sigma)\frac{\partial P}{P}P^{1-\sigma} &= K\partial\lambda(1-\phi) \\ P^{\mu}\partial\omega &= \partial w + \frac{\partial P}{P} \\ K &\equiv \left(\frac{H}{f}\right)\left(\frac{\sigma\left(c_M + z\right)}{\sigma - 1}\right)^{1-\sigma} \end{aligned}$$

where $P^{1-\sigma} = \frac{1+T^{1-\sigma}}{2}$. For simple notation and calculation, we set $Z \equiv \frac{1-T^{1-\sigma}}{1+T^{1-\sigma}} = \frac{1-T^{1-\sigma}}{2P^{1-\sigma}}K$. This means the openness of trade between the regions.