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On the Relationship between the Provision of Waste Management Service and Illegal Dumping

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Abstract

The illegal dumping of waste has been a serious environmental concern of most countries in the world. This paper examines the relationship between the provision of waste treatment facilities and the frequency of illegal dumping.
While the amount of illegal dumping has a positive correlation with the provision of landfill, our results show that a shortage of intermediate waste treatment facilities has played an important role in increasing the frequency of illegal dumping.

Keywords: illegal dumping, count data panel model, industrial waste

JEL Classification: Q53, C23, Q24

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1 Introduction

The illegal dumping of waste has been a serious environmental concern of most countries in the world. According to USEPA (1998), for example, illegal dumping is "a major problem for many communities throughout the United States". The UK Environment Agency also reports that "[i]t is estimated to cost £100-£150 million every year to investigate and clear up" illegal dumping.[1] In response to these situations, several countries are starting to reexamine their regulations for illegal dumping and introduce more stringent rules and/or penalties for waste crimes. UK's Defra has just launched tougher penalties against waste crimes like illegal dumping,[2] while the Japanese government has within the last decade repeatedly strengthened the penalties laid down in the *Waste Disposal and Public Cleansing Law*.

Although illegal dumping occurs for various reasons, one of the main factors inducing illegal dumping is thought to be a shortage of proper waste treatment facilities. In the absence of enough proper waste treatment facilities, the cost of proper waste disposal will increase. As a result, people are more likely to dispose of their waste illegally to reduce the cost of such disposal when there is a shortage of waste treatment facilities. Munton (1996), for instance, noted that "[i]ncreased demand coupled with insufficient disposal capacity 'threatens to increase illegal disposal, a result which would exact a terrible price in terms of environmental degradation and danger to human health' ".[3] This logic is quite intuitive, but there is little quantitative evidence to support the argument that the shortage of waste treatment facilities increases the frequency of illegal dumping. In this paper, then, we empirically show how the shortage of waste treatment facilities influences the frequency of illegal dumping.

We shall show how the shortage of waste treatment facilities influences the frequency of illegal dumping. For this purpose, we use prefecture-level panel data of illegal dumping in Japan. In order to measure the shortage of waste disposal facilities, as we do in the following section, we use the number of landfill sites and the number of intermediate waste treatment facilities, where waste is incinerated or reduced in weight before being disposed in landfills.

The present study is mostly related to that of Sigman (1998), to our knowledge the only study besides that of Kim et al. (2008) that empirically examines the issue of illegal dumping.[4] Sigman studied the illegal dumping of used oil in the United States and shows the relationship between the number of illegal dumping incidents and restrictions on the disposal of used oil, the salvage value of oil, and so on. She did not, however, examine the effect of a shortage of waste treatment facilities, which is what we mainly focus upon in this paper. Kim et al. (2008) also examined illegal dumping, but from a different point of view. They argued that illegal dumping has been induced by the introduction of unit pricing of municipal solid waste in Korea. They urged that authorities be careful about increasing unit prices.

The main results of our study are as follows. First, we statistically show that (1) increasing the number of intermediate waste treatment facilities decreases the number of illegal dumping incidents, yet (2) increasing the number of landfill sites leads to increased illegal dumping, and (3) there is a positive relationship between the weight of waste discharge and frequency of illegal dumping. We also find that (4) stronger penalties for illegal dumping deter illegal dumping. In the next section we describe the state of waste discharge and its illegal dumping in Japan. In Section 3 we provide economic and econometric models and the properties of the relevant data. In Section 4 we present an estimated result and its policy implications. Finally, in Section 5 we provide some concluding remarks.

2 Waste management and illegal dumping in Japan

All waste in Japan is classified as either municipal solid waste or industrial waste. Chapter 2 of the *Waste Disposal and Public Cleansing Law* lists 20 types of waste produced by business activity and defines them as industrial waste, while all the rest of the waste is defined as municipal solid waste.[5] In the following study we focus on the illegal dumping of industrial waste, since data on illegal dumping of municipal solid waste is not available. For the sake of notational convenience we refer to industrial waste as 'waste' in our analysis. Since the weight of industrial waste discharge is much larger than that of municipal solid waste,[6] we believe our analysis reflects the major features of illegal dumping in Japan.

2.1 The state of waste discharge in Japan

First, we briefy summarize the state of waste discharge and treatment in Japan. Figure 1 shows the weight of discharged waste, and how the discharged waste was treated. In 2005 about 421 million tons of waste was discharged in Japan. This weight has not changed much during the last 15 years. About 22% of the waste was directly recycled, while 75% was treated in intermediate waste management facilities where waste is incinerated or reduced in weight. Only 3% of the total waste was directly disposed of in landfills.

/// Insert Figure 1 around here. ///

After being treated in the intermediate waste management facilities, 30% of the waste was recycled and 3% was disposed of in landfills. As a result, about 52% of the waste was recycled, 6% of the waste was land?lled, and the rest was reduced in intermediate waste management facilities. From this observation we can say that, in Japan, intermediate waste management plays a large role in waste treatment, compared to that of landfill.

2.2 How often and how much illegal dumping is reported

Figure 2 shows the changes in the reported incidents and weight of illegal dumping since 1996. Although the number of cases increased until around 1999 to 2001, it has been dramatically decreasing since 2001. The number of cases in 2006 came to about half of the figures reported in 2001. The amount of illegal dumping, however, did not follow the tendency of the number of cases. The largest amount in the ten-year period (from 1997 to 2006) was reported in 2003, and it amounted to 2.3% of the total weight of landfill in that year.

This asynchrony happens because of a few exceedingly large illegal dumping incidents. In 2004, for example, about half of all the volume of illegally dumped waste was accounted for by a single incident in Numazu City. Since the reported weight of illegal dumping is greatly influenced by these few exceptional incidents, the reported amount and the reported number show a different trend.

/// Insert Figure 2 around here. ///

As we see above, we can use two types of data (the volume, and the number of incidents), as indicators of the degree of illegal dumping. However, as Sigman (1998) points out, measuring the weight of illegal dumping is technically difficult, and so its figures are not always reliable. On the other hand, the problem of using number and ignoring amount is that one pile of illegally dumped material is counted as one time of illegal dumping regardless of its size. Since massive illegal dumping is usually the result of repeated dumping on one pile, the meaning of the reported number of illegal dumpings can be ambiguous if there are many cases of such huge piles.

Still, only 0.6% of illegal dumpings were classified as huge illegal dumpings –more than 5,000 tons according to the Ministry of Environment (2007c; hereafter, MOE)– between 2000 and 2006, and many cases involved less than 50 ton.[7] For these reasons in the following analysis we follow Sigman (1998) and use the reported number of illegal dumpings, not weight, as an indicator of the degree of illegal dumping.[8]

2.3 What is dumped by whom

According to MOE (2007c), in 2005 composite waste from construction sites, including debris, was a major component of illegally dumped wastes, both in terms of weight and numbers. It made up 393 incidents out of 558 (70.4%) and 143,000 tons out of 172,000 tons (83.3%). As for the total discharge of industrial waste, the largest portion was discharged by the utility industry, which was followed by the agricultural industry, with the construction industry being the third largest with a share of just 19.0%.

/// Insert Table 1 around here. ///

MOE (2007c) also tells us by whom the reported illegal dumping was done. The information is summarized in Table 1. In these statistics, a discharging firm is defined as one that discharges any kind of waste. This thus includes not only manufacturers' factories but also intermediate waste treatment firms. In Japan, the *Waste Disposal and Public Cleansing Law* prescribes that a firm needs a license when it runs a business dealing with waste. The term 'licensed contractor' means that the firm in question has this license, while a 'non-licensed contractor' does not. Table 1 shows that the majority of specified illegal dumpings were done by discharging firms. From the point of view of the number of incidents, it amounts to two-thirds of the specified incidents. When we look at the weight of the illegal dumping, however, licensed contractors play a major role. Even though discharging firms still dump the most, the share of the licensed contractors (who are expected to deal with waste properly) is the second largest, making up about 25% of the specified weight.

2.4 Geographic Features

In order to clarify the spatial features of illegal dumping, we plot the data on illegal dumping and each prefecture's income level in Figure 3.[9] Note that the number of illegal dumpings is aggregated for a period of ten years (from 1997 to 2006). Economic levels are quite high in the prefectures between Osaka and Tokyo, the largest city in Japan.

/// Insert Figure 3 around here. ///

According to MOE (2007c), Tokyo recorded the smallest number of illegal dumpings even though huge amounts of industrial waste were generated in Tokyo for those ten years. Osaka, the second biggest prefecture in Japan, also recorded a small number of illegal dumpings. This phenomenon indicates that waste is transported from prefecture to prefecture, and waste generated in one prefecture is illegally dumped in other prefectures. We try to control this phenomenon in our explanation at the end of section 3.

3 The Model

In this section, we provide a model of illegal dumping. Initially we develop an economic model to identify the determinants of an illegal dumping incident. Then we confirm the results of the economic model by using an econometric method, showing the main results of the study.

3.1 The Economic Model

Suppose that in a market there are k number of identical firms that discharge waste and n identical firms disposing of the waste. We assume that all players are price takers. A discharging firm possesses G amount of waste to be disposed of in total. Once the waste is handed over to a disposing firm, it can be disposed of in an appropriate treatment process (denoted by L). Or the discharging firm can dump the waste illegally. The amount of illegal dumping is denoted by mI, which represents the number of illegal dumpings (m) and the fixed amount of waste dumped per number of dumpings (I). We assume that it costs c_L to dispose of the waste properly and c_I to dump mI amount of waste illegally. Although the cost for the proper waste management c_L(in other words price of a legal waste management service) is a key determinant of the number of illegal dumping incidents, there is no available data that can be used as an proxy variable for in Japan. Thus we cannot characterize c_L as an exogenous variable. To alleviate this problem, we characterize c_L as an endogenous variable, which is determined in market equilibrium. This enables us to derive a function for c_L with the variables which we can find appropriate real data.

Furthermore, illegal dumping would be punished if detected. Let $p(mI)$, with $p' > 0, p'' > 0$ be the probability of the environmental authority detecting the illegal dumping. Then the individual discharging firm i faces the following problem:

$$\min_{L_i, m_i} \; c_L L_i + c_I m_i I + p(m_i I) F, \tag{1}$$

$$\text{s.t.} \;\; L_i + m_i I = G, \tag{2}$$

where F stands for the fine for illegal dumping. By minimizing (1) with the constraint, we get the demand function of the proper treatment of waste as follows:

$$c_L - c_I - p'(G - L_i)F = 0 \tag{3}$$

Let L_i^d be the individual firm's demand for legal waste treatment; then, from (3), the individual firm's demand function can be written as $L_i^d = l(c_L, c_I, G, F)$. Since we suppose all firms are identical, total demand for legal waste treatment is

$$\sum_{i=1}^{k} L_i^d = kl(c_L, c_I, G, F). \tag{4}$$

If we now look at the disposing firms, each of them are also assumed to have the same supply function of waste treatment service. That is,

$$L_j^s = f_j(c_L), \tag{5}$$

where j is the indicator of each disposing firm. We suppose $f_j(\cdot)$ is twice differentiable and its first derivative is positive. Since all disposing firms are homogeneous, the aggregate supply function can be written as follows:

$$\sum_j^n L_{j=1}^s = nf_j(c_L). \tag{6}$$

where n is the number of imposing firms. At the equilibrium, $\sum_i L_i^d = \sum_j L_j^s$ must be satisfied. That is,

$$kl(c_L^*, c_I, G, F) - nf(c_L^*) = 0, \tag{7}$$

must be met. We are interested in how a small change in a variable affects the other variable at the above equilibrium. In particular our main concern is to examine each parameter's effect on the amount of proper treatment. To focus on the relationship between the number of facilities, n, and the number of illegal dumping, m, let us assume that $k = 1$.Then a little bit of algebra results in the following (see Appendix for details):

$$\frac{dL_i^*}{dn} = -\frac{(\partial c_L/\partial n)}{p''F} > 0 \qquad \frac{dL_i^*}{dc_I} = -\frac{(\partial c_L/\partial c_I) - 1}{p''F} > 0 \tag{8}$$

$$\frac{dL_i^*}{dG} = -\frac{(\partial c_L/\partial G) - p''F}{p''F} > 0 \qquad \frac{dL_i^*}{dF} = -\frac{(\partial c_L/\partial F) - p'}{p''F} > 0 \tag{9}$$

Note that the sign of the illegal dumping is just the opposite of that for proper treatment since G is given[10]. Let M stand for the total number of illegal dumpings, namely, $M(n, c_I, G, F) \equiv \sum_i m(n, c_I, G, F)$. The comparative static on M is as follows:

$$\frac{dM}{dn} = \sum_i \frac{dm_i^*}{dn} < 0 \tag{10}$$

$$\frac{dM}{dc_I} = \sum_i \frac{dm^*}{dc_I} < 0 \tag{11}$$

$$\frac{dM}{dG} = \sum_i \frac{dm^*}{dG} = \sum_i \left(1 - \frac{dL_i^*}{dG}\right) > 0 \tag{12}$$

$$\frac{dM}{dF} = \sum_i \frac{dm^*}{dF} < 0 \tag{13}$$

Thus, theoretically speaking, we can say from (10) that an increase in the number of waste treatment facilities decreases the number of illegal dumpings. We also have the relationship between the number of illegal dumpings and other factors: (11) indicates that a high cost of illegal dumping decreases illegal dumping, (12) indicates that a large amount of waste discharge increases illegal dumping, and (13) indicates that strict punishment decreases illegal dumping. In the following subsection we try to verify these theoretical results by using econometric inference.

3.2 The Econometric Model

The number of illegal dumping incidents, which we use as a dependent variable in our estimation, can take only non-negative integer values. This means that our data is count data. In analyzing count data, application of the conventional OLS method is inappropriate. The usual model in count data analysis is a Poisson regression model, which assumes that each dependent variable follows Poisson distribution. But since that model is based on a strict assumption that requires the equality of conditional mean and conditional variance, an assumption that is often violated in a count model, we adopt a negative binomial regression model that allows a more general relationship between conditional mean and conditional variance.[11] A panel data version of a negative binomial model was first developed by Hausman, Hall and Griliches (1984), and our estimation method basically depends upon their work.[12]

3.2.1 Reported and Actual Number of Incidents

Since we can only use the data from "reported" illegal dumping incidents, which always differ from the actual number of incidents, there may be a bias in estimation if the frequency of reporting is affected by covariates. To handle this problem, we apply the approach developed by Sigman (1998), who assumes that the observed number of illegal dumping incidents is the product of the actual number of incidents and the"reporting propensity". We specify the relationship as follows:

$$M_t^{ob} = M_{t-1}(n, c_I, e, G, F)\xi_t(r) \tag{14}$$

where t indicates year t. The LHS of (14), M_t^{ob} is the observed number of incidents. $M_{t-1}(n, c_I, e, G, F)$ is the actual number of incidents explained by variables we indicated in the theoretical model, while $\xi_t(r)$ is the probability of reporting explained by covariates vector r. As Sigman (1998) noted, this approach cannot avoid the bias perfectly, but we believe this is the best approach we can take to reduce the bias.[13]

Unlike Sigman (1998), we assume that there is a time lag of one period between the occurrence and detection (or reporting) of an illegal dumping incident. This is because, in the real world, there are quite a number of illegal dumpings that are reported some time after the dumping takes place. In Japan, extensive investigation must be carried out before authorities finally announce that something has been illegally dumped. Such investigation requires considerable time, so a time lag between occurrence and detection/reporting has to be taken into account. To reflect this fact, we assume that the reported number of illegal dumping incidents in the present period is obtained by the actual number of illegal dumpings in the last period multiplied by the probability of detection/reporting in the present.

3.2.2 Data

In the previous subsection we derived the theoretical model regarding the number of illegal dumpings. Our next step is to assign the real data for each argument in (14) in order to execute an econometric inference. We prepared the data for a ten-year period (from 1997 to 2006) for each prefecture. Since there are 47 prefectures in Japan, we have 470 observations in this data set. Table 2 gives the descriptive statistics of the data we use for the count data panel model. The correlation matrix of the data is shown later in Table Table 3.

/// Insert Table 2 around here. ///

Let us first explain the dependent variable. We adopted the number of illegal dumping incidents (`no`) as a dependent variable because of the reliability of data. The data was taken from MOE (2007a).[14] The rest of the variables in Table 2 are independent variables. First, `lwaste` denotes a one-year lag of industrial waste discharge in terms of weight. This data can be found in MOE (2007a) and is assigned to G in (14).

The number of landfill and intermediate waste treatment facilities can be found in MOE (2007b). To use them as independent variables, we divided them by unit area and adopted a one-year lag for each of them. These two are represented by `llastm` and `lmidm`, which means we have two alternatives for n in (14).

As an index of strengthened regulation, we selected years of sentence for illegal dumping and named it `ljail`. It plays the role of F in (14). This punishment is determined in chapter 25 of the *Waste Disposal and Public Cleansing Law*, and at present it stands at five years (or less) of imprisonment if arrested. The severity of the punishment varies from year to year, yet it is identical in all prefectures.[15] Note that a one-year lag is also adopted for `ljail`. In other words, we assume that there is some range of a time lag before toughening of the punishment becomes effective.

For the "cost" of the illegal dumping, c_I, we use the ratio of cultivated acreage and label it as `lcultiv`. Since we assume that the cost of illegal dumping influences the actual number of illegal dumpings, not the reported number, a one-year lag is adopted for `lcultiv`. It is reasonable to take the ratio of cultivated acreage for the cost because the level of ease in dumping illegally depends very much upon how easy it is to find a place to dump and how many people may be nearby when waste is dumped. So we assume that the cost of illegal dumping decreases as the ratio of cultivated acreage increases. We also use population density, denoted by `ldense`, as an index of the cost of illegal dumping. This is the ratio of the population divided by the area in each prefecture, with a one-year lag adopted. This was taken from National Census of 2005. As in the case of `lcultiv`, if population density is high, then it is difficult to find a place to dump waste, and so the cost of illegal dumping will increase as population density increases.

For r_{it} in (14), `pclaim` is adopted. This is the per capita number of complaints about pollution grievances in each prefecture. To avoid the endogeneity problem, we exclude grievances about illegal dumping from the total number of grievances. The statistics regarding the complaints are available from the Environmental Dispute Coordination Commission (2007). This survey reports the number of grievances accepted at a pollution grievances inquiry counter established in each local public agency. Since more complaints means people are aware of their environment and watching for environmental crime more attentively, we can assume that if `pclaim` is high, then the probability of reporting is high.

As was mentioned in the last part of Section 2, there is evidence that waste moves beyond a prefecture's borders, and that waste generated in one prefecture is illegally dumped in another prefecture. So we have to consider the interprefectural transportation aspect of waste to provide unbiased estimation.

Although there is no available data that can directly measure trends in waste transportation, we can use the cost of illegal dumping, c_I, as a proxy indicator. It is said that waste tends to go to places where it is easy to dump the waste. In other words, we can assume that waste moves from a prefecture where the cost of dumping is high to a prefecture where the cost of dumping is relatively low. Thus we can use the cost of illegal dumping as a transport-related variable. Although it does not enable us to avoid the bias perfectly, we believe it is the best way to reduce the bias.

4 Estimated results

Tables 4 and 5 present the coefficient estimates and standard errors for the model explained above. As shown in the tables, we considered five types of negative binomial models. Each of them is estimated by the fixed effect model and random effect model.

/// Insert Table 4 around here. ///

Our main finding is that the coeffcient of `lmidm` is negative and statistically significant, at least at the 5% level in all models that include `lmidm` as an explanatory variable. In other words, the number of illegal dumping incidents decreases (increases) as the number of intermediate waste treatment facilities per unit area increases (decreases). This estimation result empirically confirms the common belief that the proper provision of waste treatment facilities deters illegal dumping. It is also consistent with the result of our economic model.

On the other hand, `llastm` is not always significant and the sign is different from the theoretical result. Our empirical result indicates that the number of illegal dumpings increases as the number of landfill sites increases. This result is quite different from the result of our economic model, and also different from the popular belief that provision of waste treatment facilities decreases illegal dumping. One reason for this contradiction may stem from the fact that landfill sites are always located at a place convenient for those who intend to dump waste illegally. Since a landfill site may cause environmental pollution, such as land or water pollution, it is usually built away from populated areas. This is why a location that is appropriate for a landfill will be also suitable for illegal dumping. Another reason is that illegal dumping takes place even at legal landfill sites. There are two types of illegal dumping at a landfill. One involves extending the landfill illegally. Most landfills suffer from exhaustion of their capacity. Not a few landfill sites extend their boundaries without official permission, and this is deemed to be illegal dumping (MOE, 2007c). Therefore the more landfill sites there are, the more illegal dumping there will be. The other type involves dumping waste that is prohibited from being dumped. Each landfill is assigned to receive a specific type of waste. For example, most landfills prohibit the dumping of toxic waste. If a toxic substance is found at a landfill, it is recorded as an illegal dumping. Again, this leads to more illegal dumping, the more landfill sites there are, something that has not been considered in the theoretical part.

We also find other interesting results from the estimation. First, the weight of industrial waste discharge (`lwaste`) has a positive effect on the number of illegal dumping incidents, and it is statistically significant at the 1% level in almost all models that include`lwaste` as an explanatory variable. This result tells us that the number of illegal dumpings increases as waste discharge increases. Second, we found that the penalty for illegal dumping, denoted by `ljail`, does deter illegal dumping. In particular, the number of illegal dumpings decreases as the length of jail terms increases. Yet these results are not always statistically significant.

Finally, the results indicate that the cost of illegal dumping is negatively correlated with the number of illegal dumpings. The positive signs for the coefficient of `lcultive` show that if the cultivated acreage is large, where the cost for illegal dumping is relatively low, then the number of illegal dumpings increases. On the other hand, the negative signs for the coefficient of `ldense` indicate that if the population density is relatively high, where the cost for illegal dumping is also relatively high, then the number of illegal dumpings decreases. As in the case of `ljail`, however, these results are not always statistically significant.

/// Insert Table 6 around here. ///

Table 6 is a summary of estimated results in comparison with theoretical results. The 'number of significant models' in Table 6 shows in how many models each variable is statistically significant at least at the 10% level. It is apparent that only `llastm` behaves improperly, since the signs of the two columns differ (for the reasons we discussed above), while all the other variables seem to fit well.

5 Policy implication for waste management

Our results support the common belief that the proper provision of waste treatment facilities decreases illegal dumping. Specifically, we show that the number of illegal dumpings decreases as the number of intermediate waste management facilities increases. Each estimated result consistently showed that the number of intermediate waste treatment facilities has played an important role in the frequency of illegal dumping. This result suggests the probability that not only strict punishment but also the provision of waste management facilities, especially intermediate waste management facilities, may deter illegal dumping. If there are sufficient numbers of legal intermediate waste management facilities, the cost of legal dumping will decrease, and the incentive to dump illegally will be dampened.

In comparison, the analysis shows that the number of landfill sites has a positive effect on the number of illegal dumpings. This result contradicts the common belief. There is, however, an estimation result that `llastm` is statistically insignificant. This means we cannot draw conclusions about how the provision of landfill sites affects the number of illegal dumpings. To explain the relationship between landfills and illegal dumping is something we aim to look at in further research.

/// Insert Figure 4 around here. ///

Another robust conclusion is that the volume of industrial waste discharge has a positive effect on the number of illegal dumping incidents. The straightforward implication from this is that we should introduce a policy that encourages firms to reduce their industrial waste discharge. In order to do more to promote a resource circulation society, Japan 's Ministry of Environment has implemented a variety of measures, especially since the enactment of the *Circulated Social System Promotion Standard Law* in June 2000. One of the aims of this law is to reduce the amount of waste emitted. Nevertheless, emission has not decreased, neither in industrial waste nor in municipal solid waste.

Figure 4 shows the change in emission, landfill, and recycling of waste from 1997 to 2005. Each set of data is normalized by setting the data in 1997 as 100. It is apparent from Figure 4 that waste discharge has not changed, while the other two indexes are successful. Since this phenomenon is observed not only in Japan but also in many other countries,[16] we are skeptical about a policy targeted at emission reduction in order to reduce illegal dumping. In such circumstances, therefore, along with a penalty for illegal dumping, the proper provision of waste management facilities can be an effective policy to deter illegal dumping.

Appendix

The results of comparative statics can be derived by using the following equations. Initially the comparative statics of discharging firm's demand function becomes as follows:

$$\frac{\partial L_i^d}{\partial c_L} = -\frac{1}{p''F} < 0 \tag{15}$$

$$\frac{\partial L_i^d}{\partial c_I} = -\frac{-1}{p''F} > 0 \tag{16}$$

$$\frac{\partial L_i^d}{\partial F} = -\frac{-p'}{p''F} > 0 \tag{17}$$

$$\frac{\partial L_i^d}{\partial G} = -\frac{-p''F}{p''F} = 1 > 0 \tag{18}$$

Since all firms are price takers, c_L is constant for discharging firms. Then, comparative statics of equilibrium price of legal waste management is as follows:

$$\frac{\partial c_L^*}{\partial n} = -\frac{-f}{kL_{c_L} - nf'} < 0 \tag{19}$$

$$\frac{\partial c_L^*}{\partial c_I} = -\frac{L_{c_I}}{kl_{c_L} - nf'} = -\frac{\frac{1}{p''F}}{-\frac{k}{p''F} - nf'} = \frac{1}{1 + nf'p''F} \in (0, 1) \tag{20}$$

$$\frac{\partial c_L^*}{\partial F} = -\frac{kL_F}{kL_{c_L} - nf'} = \frac{p'}{1 + nf'p''F} > 0 \tag{21}$$

$$\frac{\partial c_L^*}{\partial G} = -\frac{kL_G}{kL_{c_L} - nf'} = -\frac{1}{l_{c_L} - nf'} = \frac{p''F}{1 + nf'p''F} > 0 \tag{22}$$

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Tables

Table 1: The number and amount of illegal dumping by whom

	number of cases	amount of dumping(tons)
discharging firm	271	47,810
non-licensed contractor	63	10,499
licensed contractor	58	34,869
combination of above	14	26,109
not specified	148	11,947
total	554	131,234

Source: Ministry of Environment (2007c)

Table 2: Summary statistics

Variable	Description of Data	Mean	(Std. Dev.)
`no`	number of illegal dumping incidents	18.5880	28.0385
`lwaste`	discharge of industrial waste (million tons)	8.6038	7.3429
`llastm`	number of landfill sites per 1000 km^2 in each prefecture	8.7837	7.5722
`lmidm`	number of intermediate waste treatment facilities per 1000 km^2	64.1901	61.9313
`ldense`	density of population	639.2518	1098.329
`ljail`	year of sentence for illegal dumping	2.6563	2.0302
`lcultiv`	ratio of cultivated acreage	12.8041	5.7766
`pclaim`	per capita number of complaints about environmental problems	0.6806	0.3000
the number of observations		470	

Table 3: Correlation Matrix

	lmidm	llastm	lwaste	lcultiv	ljail	ldense	claim
lmidm	1.0000						
llastm	0.4395	1.0000					
lwaste	0.4711	0.1234	1.0000				
lcultiv	0.0705	0.3213	0.1666	1.0000			
ljail	0.1337	-0.0413	0.0029	-0.0505	1.0000		
ldense	0.7550	0.0738	0.5323	-0.1076	0.0046	1.0000	
pclaim	0.1690	0.1286	-0.0629	0.1364	0.2312	0.1042	1.0000

Table 4: Estimation results (1)

	Model 1				Model 2				Model 3			
	Fixed Effect		Random Effect		Fixed Effect		Random Effect		Fixed Effect		Random Effect	
Variable	**Coef.**	**(S.E.)**	**Coef.**	**(S. E.)**	**Coef.**	**(S.E.)**	**Coef.**	**(S.E.)**	**Coef.**	**(S.E.)**	**Coef.**	**(S.E.)**
`lmidm`	-0.0102^{**}	(0.0023)	-0.0066^{**}	(0.0019)	-0.0081^{**}	(0.0023)	-0.0041^{*}	(0.0017)	-	-	-	-
`llastm`	0.0467^{**}	(0.0125)	0.0299^{**}	(0.0106)	-	-	-	-	0.0323^{*}	(0.0131)	0.0126	(0.0097)
`lwaste`	0.0494^{**}	(0.0131)	0.0430^{**}	(0.0104)	0.0449^{**}	(0.0129)	0.0413^{**}	(0.0101)	0.0462^{**}	(0.0132)	0.0410^{**}	(0.0103)
`lcultiv`	0.0058	(0.0173)	0.0313^{*}	(0.0135)	0.0248	(0.0161)	0.0418^{**}	(0.0124)	0.0016	(0.0171)	0.0287^{*}	(0.0133)
`ljail`	-0.0176	(0.0233)	-0.0314	(0.0221)	-0.0304	(0.0228)	-0.0450^{*}	(0.0216)	-0.0657^{**}	(0.0212)	-0.0631^{**}	(0.0205)
`ldense`	0.0823	(0.1808)	-0.2496^{*}	(0.1180)	0.0702	(0.1869)	-0.3259^{**}	(0.1126)	-0.4743^{**}	(0.1265)	-0.5211^{**}	(0.0867)
`pclaim`	0.4813	(0.3075)	$0.4890^{\dagger}$	(0.2738)	0.4933	(0.3052)	$0.4933^{\dagger}$	(0.2691)	0.3717	(0.3101)	0.4203	(0.2733)
`Intercept`	$0.5151^{\dagger}$	(0.2774)	0.3603	(0.2381)	0.6066^{*}	(0.2725)	$0.4043^{\dagger}$	(0.2333)	0.5804^{*}	(0.2737)	$0.4114^{\dagger}$	(0.2346)
N	470		470		470		470		470		470	
Log-likelihood	-1343.106		-1625.3678		-1629.3313		-1349.5113		-1353.0763		-1631.5253	
χ^2	58.4558		75.9040		43.4384		70.7426		37.0885		65.4864	

Significance level: **: 1%, *: 5%, †: 10%

Table 5: Estimation results (2)

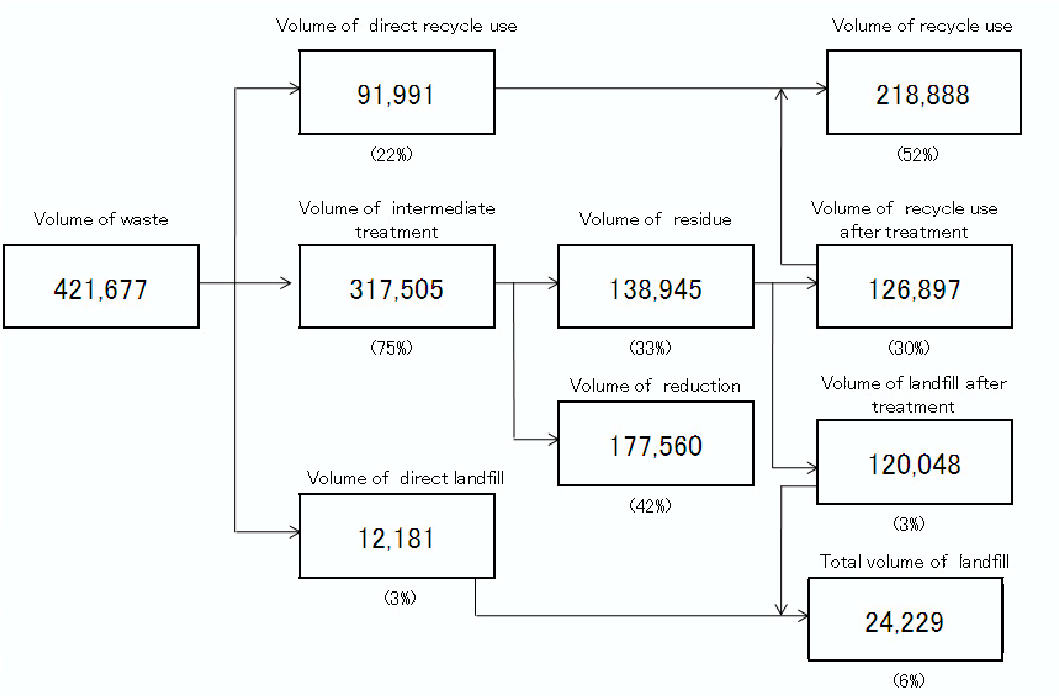
	Model 4				**Model 5**			
	Fixed Effect		Random Effect		Fixed Effect		Random Effect	
Variable	**Coef.**	**(S.E.)**	**Coef.**	**(S.E.)**	**Coef.**	**(S.E.)**	**Coef.**	**(S.E.)**
`lmidm`	-0.0073**	(0.0016)	-0.0072**	(0.0013)	-	-	-	-
`llastm`	-	-	-	-	0.0245*	(0.0122)	0.0192†	(0.0101)
`lwaste`	0.0531**	(0.0116)	0.0449**	(0.0103)	0.0327**	(0.0120)	0.0202†	(0.0111)
`lcultiv`	-	-	-	-	-	-	-	-
`ljail`	-0.0409*	(0.0207)	-0.0403*	(0.0203)	-0.0612**	(0.0210)	-0.0616**	(0.0208)
`ldense`	-	-	-	-	-	-	-	-
`pclaim`	0.5263†	(0.3027)	0.5219†	(0.2786)	0.2300	(0.3169)	0.2051	(0.2942)
`Intercept`	0.8678**	(0.2129)	0.9482**	(0.1953)	0.6111**	(0.2329)	0.7852**	(0.2106)
N	470		470		470		470	
Log-likelihood	-1350.7161		-1639.2859		-1359.0219		-1651.7361	
χ^2	39.3757		43.0759		23.7535		218.5305	

Significance level: **: 1%, *: 5%, †: 10%

Table 6: Summary of Empirical Results in Comparison with Theoretical Results

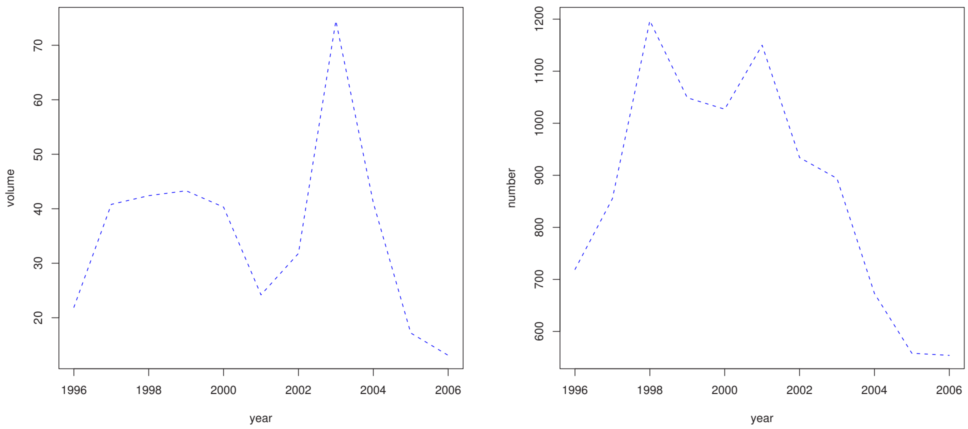
variable	sign (empirical)	sign (theoretical)	number of signif. models
`lmidm`	−	−	2/2
`llastm`	+	−	1/2
`lwaste`	+	+	3/3
`ljail`	−	−	2/3
`lcultiv`	+	+	2/3
`ldense`	−	−	2/3
`pclaim`	+	+	1/3

Figure Titles



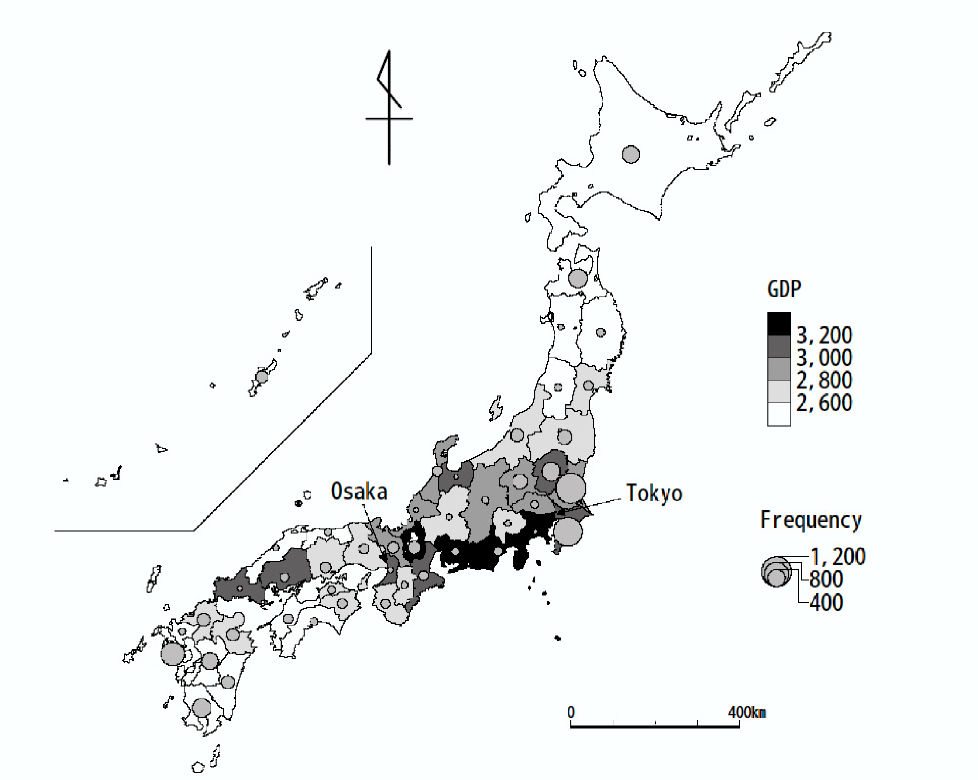
Source: Ministry of Environment (2007a)

Figure 1: Discharge and Treatment of Industrial Waste in Japan (FY2005, per thousand tons)



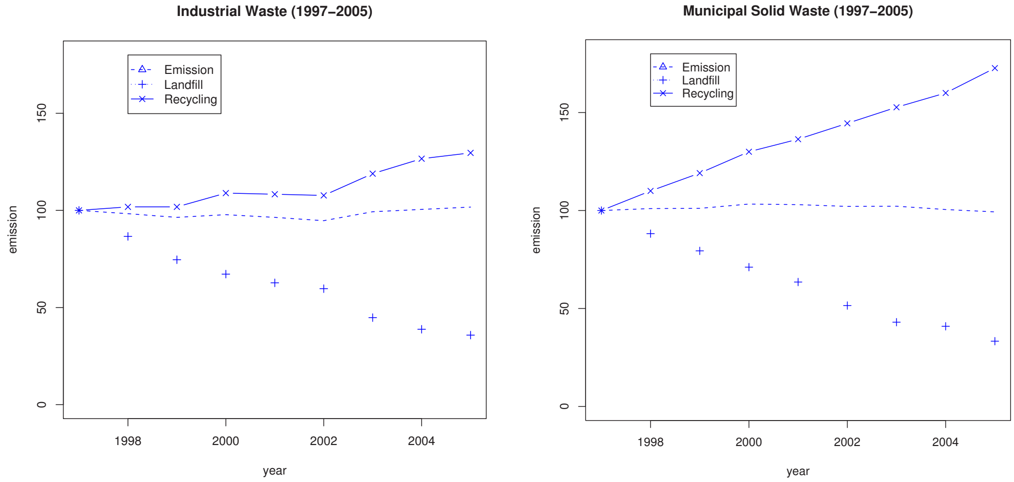
Source: Ministry of Environment (2007c)

Figure 2: Weight and Numbers of Illegal Dumping in Japan



GDP: per capita gross regional income in 2005 (unit: thousand yen)
Frequency: total number of illegal dumpings from 1997 to 2006

Figure 3: Geographic pattern of illegal dumping in Japan



Source: Ministry of Environment(2007a)

Figure 4: Change in weight of emission, landfill, and recycling

Notes

[1] http://www.environment-agency.gov.uk/subjects/waste/1029679/1032559/?lang=_e

[2] See the news release (http://www.defra.gov.uk/news/2008/080613a.htm) on July 13, 2008 for details.

[3] Munton (1996), p.7.

[4] Contrary to the empirical study, there are several theoretical studies focusing on illegal dumping, such as Fullerton and Kinnaman (1995).

[5] Broadly speaking, waste is defined as industrial waste if it is emitted from a firm. It would be called municipal solid waste if it is emitted from a household.

[6] In 2005, for example, the volume of industrial waste discharge was about 421 million tons, while the volume of municipal solid waste was about 50 million tons.

[7] According to the Ministry of Environment (2007c), about 60% of illegal dumping incidents involve less than 50 tons.

[8] Note that illegal dumping must be reported only when the weight of waste is over ten tons altogether.

[9] The indicator is cited from Japan's SNA.

[10] The only exception is when we consider the change against G, where both L and mI have the same sign as G.

[11] See, for example, Cameron and Trivedi (1998) for details

[12] The estimation was done by STATA. For the actual procedure of the estimation, see the manual of STATA. For further theoretical issues, see Hausman, Hall, and Griliches (1984).

[13] See Sigman (1998) for details.

[14] Regarding the source of data, we only mention the latest issue of the publication. Some of the data we used were taken from the older editions.

[15] Even though the fine's data is available, we do not use it because the data made little change relative to the prison time between 1997 and 2006.

[16] See, for example, Johnstone and Labonne (2004).