An Economic Analysis of Shredder Residue

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Abstract

The present paper analyzes empirically quantity aspects as well as cost-price aspects of shredder residue, particularly auto-shredder residue of end-of-life vehicles (ELV). Based on recent theories which regard landfill as one of the exhaustible resources for waste disposal, we have shown, by means of multiple regression, that landfill fees increase almost exponentially. We have also shown that the price of a body-shell of ELV is almost explained by the price of iron scrap and the disposal cost of auto-shredder residue (ASR). Facing the difficulty of disposing of auto shredder residue, the Japanese government is trying to enact legislation which facilitates recycling of end-of-life vehicles. According to a recent official document, automobile manufacturers may possibly be obliged to take back ASR without charge in the legislation. Hence, we have examined the effect of free-take-back of ASR on the price formation of a body-shell of ELV.

Keywords: Shredder residue, body-shell, landfill, exhaustible resource, recycling

1 Introduction

One of the most serious environmental problems in Japan is the problem of waste treatment and recycling. Waste treatment costs are increasing whether the waste comes from industrial activities or household' consumption. However, recycling of waste has not proceeded smoothly so far. Consequently, landfill is being exhausted in almost all regions of Japan. The landfill capacity is estimated to be less than two years for industrial waste and less than nine years for municipal solid waste. Particularly in inland regions, exhaustion of landfill is serious.

To cope with these difficulties, the Japanese government has recently enacted several laws to facilitate recycling of waste such as food residue, end-of-life electrical appliances, construction waste and so on. Although these items are natural targets for reduction of waste and proper recycling, there is one more important item which needs proper disposal and recycling: that is the end-of-life vehicle.

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Auto shredder residue (ASR for short), the final dust which comes from the treatment of end-of-life vehicles (ELV for short) and is disposed of at landfill, amounts to 800,000 tons annually, and is only 1 per cent of the industrial waste which is disposed of at landfill. Although the amount of ASR is small, careful treatment is required, since it may contain harmful substances such as lead, mercury, PCB and so on. Actually, illegally dumped ASR has contaminated soil on Teshima Island.[1] The so-called Teshima case triggered off a long discussion about legislating proper treatment and recycling of ELVs.

The conventional treatment of ELVs is as follows: At the first stage, ELVs are handed over from users to car dealers or garages, from whom dismantlers receive these ELVs. After the dismantlers treat oil, coolant, or other liquids properly, they dismantle the ELVs and take auto parts to resell the recycled material or rebuild parts. Body-shells, which are left after the resale of secondary materials or rebuild parts, are handed over to shredding operators for further recycling of metals or nonferrous metals and ELV treatment. Finally, most of the shredder residue is disposed of at landfill.[2]

The conventional transaction of ELVs, body-shells and shredder residue was done completely according to the market mechanism. The prices of ELVs and body-shells were competitively determined and priced positive in the respective markets. Supply-demand balance of those materials were coordinated by flexible adjustment of prices, and the transaction had been smooth until recently.

As landfill has become gradually exhausted and, hence, the disposal cost of shredder residue has increased rapidly, reverse pricing has been realized in the upstream of the transaction.[3] Considering this, we may say that the reverse pricing of a body-shell seems unavoidable from now on. Although dismantlers are trying to shift the cost-increase due to the reverse pricing of body-shells, they cannot shift the cost-increase to car dealers or garages.

This means that dismantlers have been burdened the cost-increase and have incentives to treat ELVs improperly or dispose of them illegally to reduce the cost burden. Since car users do not have sufficient information to discern good dismantlers whose treatment cost is relatively high from bad ones who treat ELVs in an improper way at low cost, apparently the circumstances are disadvantageous to the former dismantlers. Hence, so-called adverse selection of dismantlers is to some extent prevailing. This is the background against which the Japanese government is trying to introduce a new law which facilitates proper treatment and recycling of ELVs.

Although the motivation of the government for proper treatment and recycling of ELVs seems correct, it is worth remarking that satisfactory analysis of quantity aspects as well as cost-price aspects of treatment of ELVs has not yet been made. Without a precise analysis, the discussion concerning the legislation of ELV recycling might possibly

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[1] Teshima Island located in Kagawa Prefecture of Shikoku Island.

[2] Although part of the shredder residue is inputted into revolving furnaces or nonferrous refinery processes, most of it is disposed of at landfill.

[3] Reverse pricing means the switch of a price of a certain material from a positive price to a negative price.

not be to the point. The purpose of the present paper is to analyze empirically the economic nature of the treatment and recycling of ELVs, based on the recent theoretical contribution in the field of environmental economics, and to examine the part of policy which is presented in the official document on ELV recycling.

The construction of this paper is as follows: In the second section, the fundamental feature of the conventional treatment and recycling of ELVs is surveyed. In the third section, we present multiple regression analysis which shows how the number of shredder machines, treatment cost of shredder residue, the price of a body-shell, and so on, are determined. In the fourth section, we examine the effect of free-take-back of shredder residue by car manufacturers on the price formation of a body-shell. The theoretical base of this paper is Highfill and McAsey (1997) [1], Hosoda (2001) [3], and Ready and Ready (1995) [6]. The common aspect of these papers is to deal with landfill as input of an exhaustible resource into a waste disposal process.

2 A Brief Survey on the Present Situation

2.1 Quantity Aspects

Let us first refer to quantity aspects of ELV treatment and shredder residue. The annual number of ELVs depends mainly upon the accumulated number of automobiles which are used at present, namely, the number of stock of automobiles, and upon the composition of the life of vehicles. The greater the number of the stock, the greater the number of ELVs which are disposed of. Concerning the composition of the life of vehicles, if there are a relatively large number of older cars and, hence, the average age of cars is rather long, the number of the present disposal of ELVs is greater than the number in a stationary state. Yet, if the circumstances get close to a stationary state, the composition of the ELVs becomes stable, and the stock of automobiles mainly determines the number of ELVs.

The number of automobiles has increased at the average rate of 4.1 per cent annually for twenty years from 1977.[4] As a consequence, 70 million automobiles are registered at present as stock. At the same time, the number of ELVs has also increased at an annual average rate of 3.6 per cent. As the number of registered automobiles reaches saturation point, however, the increase in the number of the stock of ELVs will stop. Even when the number of automobiles reaches saturation, the ELV emission will increase for a while, since it will take some time for ELVs to be a constant number after saturation. Thus, at some time in the future, the rate of increase in ELVs will surpass that of the number of the automobile stock.

The volume of equipment such as shredder machines to treat ELVs has increased as the number of ELVs has increased. Let us look at the number of shredder machine here, since the data set is maintained relatively well. It is quite interesting to point out that the number has increased at the average rate of 9.5 per cent annually. Hence, the growth

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[4] The data referred to in this subsection are based on Table 1.

rate in the number of shredder machines is much higher than that of ELVs. We have to be a little careful, because shredder residue consists of not only ASR but also dust residue which is emitted from the treatment of other products. Shredder machines treat all the residue. This fact may partly explain the gap between the two growth rates.

Yet, even considering this point, the gap still seems too big. As we explain later, the high growth of the shredder machine cannot be explained by sound economic reasoning. That is to say, there seems to be irrational investment behavior of shredder operators.

The increase in ELV emission means an increase in shredder residue. The growth rate of shredder residue is on average 9.2 per cent, which is roughly the same as the growth rate of shredder machines. It is important to know that the growth rate of ELV emission is much smaller than that of shredder residue, since this suggests that shredder residue per vehicle has increased.[5]

2.2 Price Aspects

One characteristic nature of price aspects is that the disposal cost of shredder residue has increased continuously over time, although it was constant for a few years. The disposal cost of shredder residue means the tipping fee for landfill use. Since landfill capacity is getting smaller and smaller, the disposal cost or the tipping fee must rise rapidly. Particularly after the Teshima case, disposal of shredder residue became restricted to a specific type of landfill whose control is rather tight. It is said that this requirement has made the cost increase steeper than before and the cost burden on shredding operators heavier.

Another financial problem from which shredding operators have suffered severely is the decrease in the price of iron scrap. Even when disposal cost of shredder residue increased, shredder operators could cope with the circumstances if the iron scrap market were brisk. The cost pressure due to the increase in disposal cost of shredder residue could be partially offset by the sales of iron scrap.

As the stock of iron has been accumulating steadily in Japan, the amount of supply of iron scrap has also increased at the same pace. On the other hand, demand for iron scrap has remained relatively stagnant due to the recent economic slump in Japan. Hence, the market price of iron scrap obtained from ELV shredding processes has been low as well.

In short, cost has increased but sales have decreased for shredding operators. The only way in which they can get out from this difficulty is to decrease the price of a body-shell and, in extreme circumstances, reverse pricing a body-shell from positive to negative value. Actually, this reverse pricing did happen around 1999, and the price of a body-shell has remained negative since then.

The reverse pricing of a body-shell, once implemented, makes the cost burden on dismantlers bigger, since they cannot sell a body-shell to shredding operators, but have to pay shredding operators for treatment of a body-shell. Thus, a body-shell is no more

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[5] As we have already referred to, shredder residue per vehicle is not the same as ASR per vehicle. However, the former may be regarded as the surrogate index for the latter, as we show later.

goods, but bads. Clearly, if dismantlers can shift this cost increase to car dealers or garages when they receive ELVs, it is at least financially satisfactory for dismantlers.

It is said that the bargaining power of dismantlers is relatively small compared to car dealers or garages. Consequently, they have to absorb the cost increase by various means, including improper dismantling or illegal dumping.

3 The Model Analysis

We have briefly surveyed the recent circumstances of ELV recycling and treatment of ASRs in the previous section.[6] Keeping this in mind, let us proceed to the model analysis, mainly the empirical analysis. The fundamental theory upon which the empirical analysis depends is a theoretical model of environmental economics which has been developed recently. Particularly, the following analysis is based on Hosoda (2001) [3]. We present the minimum requirement to explain the basic economic theory in the following.

3.1 The Basic Model

According to Hosoda (2001) [3], landfill can be regarded as one of the resources which is inputted into a costly disposal process for waste treatment. Furthermore, the landfill which has reached its capacity can no longer be used as landfill. Hence, landfill is an exhaustible resource or non-reproducible resource. Considering this, we can describe the recycling and treatment processes of ELVs as follows:

$$\begin{gathered} \mathit{ELV} \oplus \mathit{Other\ Resources} \longrightarrow \mathit{Body\text{-}Shell} \oplus \mathit{Recycled\ Material} \\ \mathit{Body\text{-}Shell} \oplus \mathit{Other\ Resources} \longrightarrow \mathit{ASR} \oplus \mathit{Iron\ Scrap} \\ \mathit{landfill} \longrightarrow \mathit{landfill} \end{gathered} \tag{1}$$

The first process is a dismantling process, which uses ELVs and other resources as inputs and produces body-shells and secondary materials (recycled materials).[7] The second process is a shredding process. This process uses body-shells and other resources as inputs, and produces ASR and iron scrap. ASR is treated by the third process; it is disposed of at landfill which is an exhaustible resource.

At this stage, we have to be careful as to how cost-price formation is coordinated for a body-shell, ASR, iron scrap and so on. The price of iron scrap is determined in the domestic market in Japan. Since the amount of iron scrap which is obtained from ELV is relatively small compared to the total amount of iron scrap traded in Japan, the price of iron scrap can be regarded as given in the ELVs recycling and ASR treatment processes.

As for the disposal cost of ASR, we have to remember that the cost is nothing but the tipping fee at landfill. Thus we may regard it as the price of landfill as an exhaustible

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[6] For more detailed reference on ELV recycling and treatment of ASRs, see Togawa (1998) [8] and Togawa (2001) [9].

[7] Secondary materials in this context mean used parts, raw materials and so on.

resource. Then it must follow the Hotelling Rule: Namely, it must increase at the long-run interest rate. Denoting $p(t)$ as the price of landfill at t period and r as the long-run interest rate respectively, we have the following equation due to the Hotelling Rule:

$$\frac{\dot{p}(t)}{p(t)} = r \quad \equiv \text{the long-run interest rate,} \tag{2}$$

where $\dot{p}(t)$ is $dp(t)/dt$, namely price increase at t period.

Expressing (2) in a form of discrete time, we can obtain the following:

$$\frac{\Delta p(t)}{p(t)} = \frac{\{p(t+1) - p(t)\}}{p(t)} = \frac{p(t+1)}{p(t)} - 1. \tag{3}$$

From this equation, we can deduce the following important equation:

$$p(t+1) = (1+r)p(t) = (1+r)^{t+1}p_0,$$

where p_0 is the initial price which is given in the present model. Therefore, once the initial price of landfill and the long-run interest rate is given, the price of landfill at t period is determined by the above equation, i.e. $p(t) = (1+r)^t p_0$. Then, if the value of other resources is given in (1), the body-shell price is determined by the cost-price balance of the second process of (1), since the price of ASR is determined by (3), namely the Hotelling Rule, and that of iron scrap is given exogeneously.

Once the body-shell price is determined, the price of ELVs is determined by the first expression of (1). As we mentioned before, however, dismantlers do not seem to be able to shift the cost of body-shell treatment to the upstream. In other words, the price determination of ELVs is very ambiguous in a real economy.

To make the following empirical analysis easier, let us transform the above equation into the logarithm form as follows:

$$\ln p(t) = \ln p_0 + t \ln(1+r). \tag{4}$$

By further transformation, we can deduce the following equation:

$$P(t) = b_0 + b_1 t, \tag{5}$$

where $P_t \equiv \ln p_t$, $b_0 \equiv \ln p_0$ and $b_1 \equiv \ln(1+r)$ hold.

Thus, at least insofar as pure theory isconcerned, the landfill price increases constantly at the long-run interest rate, starting from the initial price. The price does not, however, increase infinitely and converges to a certain value in a finite period. This is because a recycling process works as backstop technology to replace the process which uses landfill as a resource for waste disposal.

The landfill price increases until the recycling process as a backstop technology comes in to utilization. Thus the price increase stops when the landfill price becomes equal to the so-called backstop price at which the recycling process is equi-profitable to the process with landfill use. Denote the backstop price and the lifetime of landfill capacity as P_b and T respectively. Then the landfill use technology switches to the backstop technology at the price of $p(t) = P_b$ such that $t = T$, and the landfill is exhausted at the period T.

In the case of ELV recycling, the recycling process as a backstop technology can be expressed as follows:

$$\textit{ASR} \oplus \textit{Other Resources} \longrightarrow \textit{Secondary Materials.} \tag{6}$$

One of the recycling technologies which is considered as a candidate for proper backstop technology is a gasification furnace. The technology is under development although pilot plants have already been constructed and operated. Coupling (1) with (6), we can specify a dynamic path of price movement as well as quantity movement. Hosoda (2001) [3] examined the path in terms of pure economic theory.

Incidentally, let us refer to the possibility that body-shells may be recycled without using a shredding process. One of the examples is utilization of body-shells as A-press to produce iron. In this case, the process may be expressed as

$$\textit{Body-Shell} \oplus \textit{Other Resources} \longrightarrow \textit{Secondary Materials.}$$

Both types of recycling process can be considered as backstop technology.

This is a rough sketch of the theoretical model, on which the following empirical analysis is constructed. We have to make two remarks at this time. Firstly, the disposal cost of shredder residue may not be the general index of disposal cost of industrial waste at landfill, since there are various types of industrial waste which is disposed of at landfill. Hence, there might be some reservation for applying the above basic model to the following empirical analysis of shredder residue. Yet, to the best of our knowledge, there is no reliable data of disposal cost at landfill other than that of shredder residue. Upon this consideration, we use disposal cost of shredder residue as an index of the landfill price.

Secondly, there is the question of whether the amount of ASR could be a stable index which represents the whole shredder residue. We will answer this question in the next section, although we would like to say, in advance, that the answer is positive with certain restrictions. Thus, we will identify the amount of shredder residue as that of ASR for most of the present paper.

3.2 The Empirical Analysis of Qautity Aspects

3.2.1

Let us start this subsection by answering the last question which we presented in the previous subsection: The question is whether the number of ELVs explains the amount of shredder residue. This question cannot be ignored, since ASR and the other shredder residue cannot be distinguished as far as data are concerned. If the number of ELVs successfully explains the total amount of shredder residue, we do not have to care about the distinction so much.

Thus we have regressed the total amount of shredder residue on ELVs and the disposal cost of the residue. We have included the disposal cost among the explanatory variables, since the rise of the cost may induce switching of the stream of body-shells from a shredding process to other processes such as A-press operation. The result is as follows:[8]

$$\begin{array}{ccccccc} DUST & = & -674.004 & + & 0.388ELV & - & 0.016DUSTPR \\ & & (-10.13) & & (18.422) & & (-3.080) \end{array} \quad (7)$$

Case 24 Adjusted $R^2 = 0.957$ $DW = 1.192$.

Here, *DUST*, *ELV* and *DUSTPR* denote the total amount of shredder residue, the number of ELVs and the disposal cost of shredder residue, respectively. Since the adjusted coefficient of determination is about 0.96, the total amount of shredder residue can be explained by the number of ELVs and the disposal cost of shredder residue. Thus, it is not amiss to identify ASR with shredder residue in this paper.[9]

In Equation (7), an intercept is minus, i.e. −674.004. This means that the amount of shredder residue per ELV increases as the number of ELVs increases, *if the disposal cost of the residue is constant or does not rise rapidly.* Since shredder residue includes residue other than ASR, however, we cannot necessarily conclude that the amount of ASR per ELV increases as ELVs increase. To know the relationship between the amount of ASR per ELV, we have to collect precise data on the contents of shredder residue.

In this context we have to remark that Equation (7) includes the term of disposal cost of shredder residue. Though it was relatively stable in the past, it has increased rapidly, particularly in the 1990s. As we show later, the cost has increased in geometric progression recently. Moreover, various types of recycling process may possibly be activated in the near future. Hence, it is anticipated that the amount of shredder residue per ELV will not grow as much as in the past.

3.2.2

Before proceeding to an analysis of cost-price aspects, we would like to examine one important matter on a quantity aspect, namely how the number of shredder machines is determined. Shredder residue cannot be an explanatory variable for this, since the residue is a result of the shredding operation. Since there is a strong relationship between the number of ELVs and that of body-shells, it is quite natural to include the number of ELVs among explanatory variables, since ASR (and so shredder residue) seems to be rather inelastically connected to the number of body-shells which are supplied by dismantlers.

Another point is that installation of shredder machines is nothing but a big investment for shredding operators. Therefore the number of machines would be considered to have

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[8] In the following regression equations, the number in parentheses under a regression coefficient represents t statistic.

[9] According to a rough estimate, more than 80 per cent of total shredder residue is attributed to ELVs.

a close connection to the profitability of the operation. Considering the second equation of (1), we see that the price of iron scrap and the disposal cost of shredder residue affect the profitability if we are allowed to ignore other resources.

Clearly, the body-shell price also affects the profitability of a shredding process. Yet we have excluded it from the explanatory variables to avoid a multicolinearity problem, since the body-shell price is explained by the price of iron scrap and the disposal cost of shredder residue, as we show later. Thus, first, we have regressed the number of shredder machines on the number of ELVs, the disposal cost of shredder residue and the price of iron scrap. The interesting fact is that the t statistic of the coefficient of $DUSTPR$ is insignificant, and so the disposal cost of shredder residue is not a reliable variable to explain the number of shredder machines.

Thus we get rid of the disposal cost of the residue from the explanatory variables, regressing the number of machines on the number of ELVs and the price of iron scrap. The result is as follows:

$$\begin{array}{cccccccc} MACH & = & -29.714 & + & 0.048ELV & - & 0.002SCPR \\ & & (-1.101) & & (11.500) & & (-3.637) \end{array} \tag{8}$$

$$\text{Case 24} \quad \text{Adjusted} R^2 = 0.956 \quad DW = 0.789$$

Here, $MACH$ and $SCPR$ denote the number of shredder machines and the price of iron scrap respectively. Incidentally, the adjusted coefficient of determination of (8) is 0.956, which is a little higher than that of the regression in which the disposal cost of shredder residue is included as an explanatory variable.

Another interesting point is that the sign of the coefficient of $SCPR$ is the opposite of what we would expect, since (8) tells that a decrease in the iron scrap price contributes to an increase in the number of shredder machines. This is contrary to our common sense. The regression result (8) might be doubted, particularly if we consider the significant serial correlation. Yet addition of other variables or transformation of variables does not change the sign of the variable $SCPR$.

Our opinion is that the regression result is correct as far as the coefficient of $SCPR$ is concerned. If so, the result implies irrational behavior of shredding operators. This is what we have observed in the past. As the economic situation has become adverse to shredding operators, they have competed to get more body-shells, making investments in more modern shredder machines.

In other words, shredding operators have increased the number of shredder machines keeping pace with the increase in the number and volume of body-shells, since they considered that mass-treatment of body-shells could benefit their profitability.[10] Apparently, this behavior backfired. The regression result seems to reveal this well-known but unverified fact (See Fig. 1).

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[10] An increase in ELVs or body-shells has been smaller than an increase in shredder machines. Volume or weight of ELVs is, however, considered to grow faster than the number of ELVs, since the volume or weight per vehicle has increased constantly.

3.3 The Empirical Analysis of Cost-Price Aspects

In this section we analyze cost-price aspects related to treatment of body-shells and ASR. The first thing which we are interested in is movement of the disposal cost of shredder residue or disposal cost at landfill.

3.3.1

According to Hosoda (2001) [3], disposal cost of shredder residue increases following (3). Thus we analyze this relationship utilizing the transformed natural logarithm equation (5). The following regression analysis is based on the data set represented in Table 2.

Strictly speaking, disposal of shredder residue became more restricted from 1966. Shredder residue was required to be disposedof at a specific type of landfill whose control is much tighter than the normal landfill where plastic waste and other safe waste are disposed of. It is suspected that this requirement made the increase in the cost of disposal different from the conventional pattern. It is, however, very difficult to deal with this circumstance statistically. Moreover, the exhaustion of landfill is real, whatever type of landfill we may consider. Thus we regressed the landfill price (the disposal cost of shredder residue at landfill) on time, according to (5).

$$\begin{array}{rclcl} \ln DUSTPR & = & 8.470 & + & 0.049TIME \\ & & (0.071) & & (12.602) \end{array} \tag{9}$$

$$\text{Case 31} \quad \text{adjusted}R^2 = 0.840 \quad DW = 0.463.$$

The increase in the landfill price is explained by the Hotelling Rule with more than 80 per cent. Yet the low DW statistic shows that there is a significant serial correlation, and that the regression result is doubtful. There are several reasons for such a significant serial correlation.

In particular, we are concerned with the problem raised when we directly apply the theoretical result (Hosoda 2001 [3]) to an empirical analysis. In Hosoda, there is no consideration of the possibility that new landfill is developed. In a real economy, however, this is quite possible, since a marginal piece of land may be developed as a landfill site if the landfill tipping fee increases sufficiently.

If new landfill is developed, stock of capacity for waste disposal changes, and this should affect the increase in the price of landfill. More specifically, it is expected that new development of landfill gives downward pressure on the price movement of landfill. Thus we take this into account and regress the landfill price on time element *and* landfill capacity. We obtain the following:

$$\begin{array}{rclclcl} \ln DUSTPR & = & 9.179 & + & 0.047TIME & - & 0.000022LANDFILL \\ & & (130.60) & & (8.918) & & (-3.256) \end{array} \tag{10}$$

$$\text{Case 17} \quad \text{Adjusted}R^2 = 0.880 \quad DW = 1.319,$$

where $LANDFILL$ denotes landfill capacity for waste disposal.

According to DW statistics, we reject serial correlation, since $d_U = 1.25 < 1.319$. But we have to note that the regression equation (10) is based on the data sets represented in Tables 1 and 2. We cannot compare the results of the two regression equations, since the number of cases is different. Thus, we have also regressed the landfill cost on time only, being based on Tables 1 and 2, to make comparison meaningful.

$$\begin{array}{rclcl} \ln DUSTPR & = & 9.020 & + & 0.034TIME \\ & & (139.32) & & (8.160) \end{array} \tag{11}$$

$$\text{Case 17} \quad \text{Adjusted}R^2 = 0.804 \quad DW = 0.680$$

First of all, the coefficient of determination in (11) is smaller than that in (10) ($0.804 < 0.880$). Moreover, the DW statistic in (11) is also smaller than the corresponding statistic in (10). Actually, in the regression (11), there is a significant serial correlation ($0.680 < d_L = 0.87$). Consequently, we can see that the effect of new development of landfill on the increase in landfill price should not be ignored, as far as past experience is concerned. (See also Fig. 2.)

Considered this, there is one question raised about the basic theory, namely the theoretical explanation for the increase in landfill price, since landfill capacity has some significant effect on the increase in landfill price as shown empirically. However, this is not the case.

If there is no new development of landfill, the third term ($LANDFILL$) in (10) does not mean anything, because the effect of reduction of landfill is completely absorbed in the second term ($TIME$). This can be understood by the fact that the third term only decreases although the second term only increases in a geometric expansion manner. Notice that the landfill price elasticity to landfill capacity is inthe form of $\partial \ln DUSTPR/\partial \ln LANDFILL = \theta \cdot LANDFILL$ where θ is constant. As landfill capacity decreases, its effect on landfill price becomes smaller and may be ignored.

3.3.2

Next let us examine how the body-shell price is determined. According to the theoretical explanation given in 3.1, the body-shell price is determined by the price of iron scrap and the disposal cost of ASR. Although we have to take into account the other resources used up in the shredding operation, as well as the other secondary material produced in the process, such as non-ferrous metal, we do not have any reliable data. Thus we have regressed the price of body-shells on the price of iron scrap and the disposal cost of ASR (the landfill price). The result is as follows:

$$\begin{array}{rclclcl} GARAPR & = & 6859.890 & + & 0.947SCPR & - & 0.304DUSTPR \\ & & (-2.431) & & (10.975) & & (-2.448) \end{array} \tag{12}$$

$$\text{Case 31} \quad \text{Adjusted}R^2 = 0.881 \quad DW = 1.099.$$

The body-shell price is explained by the price of iron scrap and the disposal cost of ASR with nearly 90 per cent. As for serial correlation, we cannot say anything from DW statistics, since $1.08 = d_L < 1.099 < d_U = 1.34$. Yet the sign conditions are satisfied. Increase in the price of iron scrap significantly increases the price of a body-shell. On the other hand, the increase in the disposal cost of ASR (the landfill price) significantly decreases the price of a body-shell. Under recent circumstances, the price of iron scrap has been stagnant while landfill price has increased rapidly. This has given great pressure to reduce the body-shell price, and even reverse pricing (negative price) has occured.

3.3.3

As we see in 3.2, the amount of shredder residue is explained by the number of ELVs and the landfill price or the disposal cost of ASR. Thus one of the most important factors in determining the amount of shredder residue is how ELVs and body-shells are treated in a dismantling process and a shredding process, since reduction of weight or volume of shredder residue is possible in these processes. It is also true that the cost-price aspects are important factors as well, since the proper treatment of ELVs and body-shells to reduce weight or volume costs much more than conventional treatment. These costs must be covered by the recycling fee represented by the price of iron scrap and so on.

We have shown that the price increase of disposal may possibly be alleviated if landfill capacity is increased. Indeed, this is what happened in the mid-1990s. Yet such new development of landfill is no longer plausible, since the restriction on development of landfill is much stricter than before and, in addition, new construction of landfill is much more expensive than before. Hence, it is expected that the price of landfill will increase rapidly, in possibl accordance with the Hotelling Rule. If the cost increase is not shifted in an appropriate way to the upstream of the transaction of ELVs and body-shells, there should be some sort of distortion in the transaction, such as improper treatment, illegal dumping and so on.

Taking these circumstances into account, let us consider that new development of landfill is extremely difficult, and that the landfill price will be determined by the type of Equation (9) rather than (10). Then we can calculate the growth rate of the landfill price from Equation (9). Converting the second term in Equation (9) into the form of a power, we can obtain $\ln(1+r) = 0.0049$. Solving this, we have $r = 5\%$, which corresponds to the long-run rate of interest. This means that the Hotelling Rule is almost applicable to the determination of landfill price.

Finally, let us consider the reliable interval of the interest rate, which is obtained from Equation (9). Since the t statistic is 2.045 in this case, the 95% confidence interval is given by $0.049 \pm 2.045 \cdot \text{standard error} = 0.049 \pm 0.008 = 0.041, 0.057$. Converting this value to the rate of interest, we have the interval $4\% \leq r \leq 6\%$. This seems quite realistic as the interval of the long-run rate of interest.

4 Implication of the Empirical Analysis: Policy Issues

The price mechanism does not work, so that the increase in the cost of ELVs and shredder residue treatment cannot be shifted to the upstream of the transaction. Considering this background, it is necessary to implement a policy to proceed with proper recycling of ELVs and efficient treatment of ASR. The Japanese government is now trying to enact a new law for ELV recycling, according to which automobile manufacturers will be obliged to take back ASR without charge from shredding operators. We discuss the effect of this policy on the price formation concerning ELV recycling, particularly on body-shell price.

4.1 The Effect of Manufacturers' Free-Take-Back of ASR

Let us make a simulation on how the body-shell price reacts to free-take-back of ASR by automobile manufacturers. As an equation for such a simulation, we utilize the regression equation (12). We might obtain a misleading result if we extrapolate some values which are out of the range of the original data. But we cannot find any reasonable formulation to simulate the price of body-shells other than (12), and so we use it, knowing the limitations.

First we have to confirm that the variance of the prediction errors is given as follows (See Maddala 1998 [4], pp. 115):

$$\sigma^2\left(1+\frac{1}{n}\right)+\sum_{i=1}^{k}\sum_{j=1}^{k}(x_{i0}-\bar{x_i})(x_{20}-\bar{x_j})cov(\hat{\beta}_1,\hat{\beta}_2),$$

where σ, n, and k are the variance, the sample number and the number of the explanatory variables, and (x_{i0}, x_{20}) denotes the points on which we are trying to estimate the confidence interval.

Before examining the policy effect, we extrapolate the average values of the prices of iron scrap and landfill. The former price is about $19,900 yen$ and the latter is about $8,480 yen$. Since the terms other than the first term in the above equation are zero, we have the following result:

$$8530 \leq GARAPR \leq 10280$$

This means that the body-shell price remains positive, namely around $9,000$ *yen* per ton, which corresponds to about $4,500$ *yen* per body-shell. This has indeed been the past experience. Thus if the past average prices prevail, the market situation should be adequate for dismantlers as well as shredding operators. Yet the reality is different at present.

To complete the simulation in which ASR is taken back by automobile manufacturers, we have to define the point of simulation: Namely, we have to define the prices of iron scrap and landfill. The latter price is zero due to the free-take-back of ASR by automobile manufacturers. Since the market for ironscrapis fluctuating, it is hard to define the proper price of iron scrap for simulation. Thus we have set three scenarios, i.e. the low-price ($6,000 yen$), middle-price ($12,000 yen$) and high-price ($18,000 yen$) scenarios.

The result of the simulation is as follows:

	Lower limit	Middle estimate	Upper limit
Low-price scenario	$-4,803 yen$	$-1,177 yen$	$2,449 yen$
Middle-price scenario	$1,136 yen$	$4,506 yen$	$7,876 yen$
High-price scenario	$7,011 yen$	$10,189 yen$	$13,367 yen$

In the above simulation results, the middle estimate means the value which is obtained by substituting the prices of iron scrap, namely $6,000 yen$, $12,000 yen$ and $18,000 yen$ respectively, as well as zero price of ASRs into (12).

In the low-price scenario, reverse pricing is unavoidable even if car manufacturers take back ASR free of charge. Since the 95% confidence interval is rather wide range, the upper limit of the price does not seem to be plausible. Thus, as far as the price of iron scrap is stagnant, the price of a body-shell will remain negative as bads under the recycling policy which the present government is considering. Incidentally, a body-shell weighs about 0.5 ton, the negative price is $2,500 yen$ at minimum.

When the price of iron scrap is higher than in the present situation, and higher than $12,000 yen$, the price of a body-shell will surely be positive as goods. The high-price scenario is almost impossible at present. Thus the result of high-price simulation is just for reference, and does not seem to have practical implications.

4.2 The Effect of Free-Take-Back of Body-Shell

As an alternative option to free-take-back of ASR, it is quite possible to consider the situation where automobile manufacturers take back body-shells without charge, namely free-take-back of body-shells by automobile manufacturers. In this case, there are two options for dismantlers to deal with body-shells according to the price of shredder scrap and/or the treatment cost of shredder residue. When the price of shredder scrap is relatively high to the extent that the price of a body-shell is positive, dismantlers will sell body-shells to shredding operators. On the other hand, when the price of shredder scrap is sufficiently low so that body-shell price is non-negative, dismantlers will choose the option that body-shells be taken back by automobile manufacturers without charge. This way, dismantlers can avoid the circumstance of reverse pricing of body-shells.

It is, however, worth noting that free-take-back of body-shells will not affect other variables such as the price of shredder scrap and the treatment cost of ASR. This is because the former price is determined by the market for iron scrap and the latter is determined according to the Hotelling Rule. This aspect is a conspicuous feature for free-take-back of body-shells, since the effect is quite different from that of the alternative policy option in which ASR is taken back free of charge by automobile manufacturers. Although free-take-back of ASR affects the price of a body-shell, free-take-back of body-shells does not affect the treatment cost of ASR.

Automobile manufacturers will be obliged to take back body-shells free of charge only if the body-shells are priced negative in a market transaction. Yet it seems that, in most cases, automobile manufacturers will have to hand over body-shells to shredding operators, since they cannot treat body-shells on their own. Then the body-shell price in this transaction should be different from that which is determined when body-shells are traded between dismantlers and shredding operators. This is because automobile manufactures are much stronger than dismantlers in terms of market control power. Consequently, automobile manufacturers can trade body-shells in a rather more advantageous way than in a conventional transaction. Although automobile manufacturers can select shredding operators for body-shell trade, dismantlers, who are much smaller in scale than shredding operators, cannot do that.

The consequence of this policy option is summarized as follows: There is the possibility that the price of body-shells would be higher than in a conventional transaction.[11] Free-take-back of body-shells will work advantageously for dismantlers and disadvantageously for shredding operators. Yet it is hard to predict how the price of a body-shell will change.

4.3 Switch to Backstop Technology

Finally, let us consider how soon landfill technology is switched to a backstop technology, i.e. a recycling technology, when the treatment cost of shredder residue will increase according to the Hotelling Rule. Presenting Equation (10), we have referred to the fact that new construction of landfill may give downward pressure on the treatment cost. This means that the simple version of the Hotelling Rule may not hold. The present circumstances are, however, that it is quite hard to construct new landfill, so that we consider only the simple version of the Hotelling Rule, which is represented by (9) or (11). According to Hosoda (2001)[3], switch between landfill technology and the backstop technology occurs and the former is completely replaced by the latter, when the treatment cost of shredder residue equals the backstop price.

At present, it is not so easy to specify the real cost of the treatment of realistic backstop technology (the backstop price), since there are several types of alternative technology, such as a gasfication furnace, a revolving furnace, a furnace of nonferrous metal refinery, and so on. The gasification furnace is supposed to be one of the most promising technologies, and the treatment cost of the furnace is around 30,000*yen/t*.

Yet it is not possible to treat all the shredder residue with the existing gasification furnaces. Treating shredder residue with another technology may be more expensive. Thus, in the following, we make simulation of the timing of the switch in the two cases where the backstop price is 30,000*yen/t* and 40,000*yen/t* respectively. The result of the regression (9) implies that the long-run interest rate is about 5 per cent. The 95% reliance interval of the rate is between 4 per cent and 6 per cent. Considering that the price rise

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[11] Since we are considering the case where the price of body-shells is negative, "higher" means that the absolute value of the price is smaller.

at 4 per cent seems unrealistic at present, we make simulation in two cases where the increase rate is 5 per cent and 6 per cent respectively.

The following result is based on the assumption that the treatment cost of shredder residue is 24,000yen/t in fiscal year 2000.

	$r = 5\%$	$r = 6\%$
$P_b = 30,000 yen$	$4.6 years$	$3.8 years$
$P_b = 40,000 yen$	$10.5 years$	$8.8 years.$

Here, P_b denotes the backstop price. Due to this simulation result, landfill technology will switch to the backstop technology, roughly speaking, in five years at the earliest, and in ten years at the latest. Thus, as far as shredder residue is concerned, landfill disposal of the dust will cease within the above periods. It must, however, be noted that this simulation result is dependent upon the increase rate of the treatment cost of shredder residue and the backstop price. The increase rate may possibly be beyond 6 per cent, and then the timing of the switch will be much earlier.

The result might seem queer, since it is quite different from the estimated lifetime of landfill.[12] It is important to remember that the estimation is not a firm one, since, in the first place, it is very hard to investigate the existing landfill capacity. Moreover, the estimation is based on the "business-as-usual" assumption, which ignores the effect of acceleration of recycling activities.

Yet it is quite true that new construction of landfill has been a rare case, so that the existing capacity of landfill is very small. Hence, let us consider the case where the lifetime of landfill capacity is shorter than the above simulation result, that is two, three and four years, and make a simulation according to these numbers. We assume that the treatment cost of shredder residue is 24,000yen/t in fiscal year 2000 as above, and consider the two cases where the backstop price is 30,000yen/t and 40,000yen/t respectively. The result is as follows:

	Landfill Capacity 2 years	L.C. 3$years$	L.C. 4 years
$P_b = 30,000 yen$	11.8%	7.8%	5.8%
$P_b = 40,000 yen$	29.2%	18.6%	13.7%.

The above result tells us that the increase rate of the landfill treatment cost of shredder residue is smaller as the lifetime of landfill is longer and/or as the backstop price is smaller. While the increase rate is about 6 per cent in the case of the lowest estimation, it is nearly 30 per cent in the case of the highest estimation. Obviously the result is quite different depending upon how we assume the lifetime of landfill capacity and the backstop price. Anyhow, this result suggests the possibility that the treatment cost of shredder residue at landfill will increase at more than 10 per cent as long as we assume the lifetime of the capacity is less than two years.

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[12] The lifetime of landfill is estimated to be 1.6 years for industrial waste.

The result might seem contradictory to the finding that the treatment cost of shredder residue at landfill has increased, so far, at the rate which corresponds to the long-term interest rate. Even the rate 10 per cent is possibly much higher than the long-term interest rate andthe increase rate of the landfill treatment cost which we have experienced for such a long time. Presumably, this difference is due to the following two factors: Firstly, as we have already mentioned, the estimation of the landfill capacity is not certain. It is based on a rough estimate of the amount which owners of landfill reported to the authorities. The assumption of the lifetime of landfill capacity affects simulation results svery much. As a matter of fact, the increase rate goes down to 5.8 per cent if we assume that the lifetime capacity is four years instead of two years, and 5.8 per cent is not so unreasonable as a long-run interest rate.

Another concernis withthe assumption of the backstop technology. There are varieties of backstop technology. Some are already active, and others are just at the stage of a pilot plant. For example, a nonferrous metal furnace is treating ASR in Fukushima Prefecture, although its capacity is not sufficient to absorb all the shredder residue which is generated in the surrounding regions.[13] Another example is the so-called "A-press" processing, whose secondary product is used as an input to revolving furnaces. Some body-shells are processed as A-pressed, although the amount is not known. Thus the activation of various backstop technologies is gradual, and the substitution between the landfill technology and the non-landfill technology (the backstop technology) will not come suddenly in the real world. All these things surely affect the regional increase rate of the treatment cost of shredder residue at landfill.

5 Conclusion

We have analyzed empirically quantity sides as well as cost-price sides concerning ELVs disposal and shredder residue. Firstly, we have confirmed that the total amount of shredder residue is determined by the number of ELVs and the landfill price. We have also shown that the number of shredder machines is explained mainly by the number of ELVs, while it is not reasonably explained by the price of shredder scrap. It is worth remarking that the treatment cost of shredder residue at landfill does not significantly affect the number of shredder machines. This result suggests that shredding operators have paid less attention to their profitability, since the price of shredder scrap and the treatment cost of shredder residue are important factors of profitability. Insofar as such an attitude is maintained, shredding operators' profitability will remain depressed.

Next, based on Hosoda (2001)[3] and Highfill/McAsey (1997)[1], we have considered landfill as an exhaustible resource, and analyzed how the disposal cost of shredder residue at landfill is determined. The disposal cost of shredder residue is a representative index of the price of landfill use. From our empirical analysis, we can conclude that the price of

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[13] It is said that there is a nonferrous metal furnace which treat a maximum of 100,000 $t/year$ of ASR in Onahama in Fukushima Prefecture.

landfill has increased at 5 per cent annually, which corresponds to the long-term interest rate. This implies that the Hotelling Rule can be applied to the price formation of landfill use, as the theory has suggested.

The price of a body-shell is determined by the price of iron scrap and the landfill price (the disposal cost of shredder residue at landfill). As the price of shredder scrap per ton increases by 10,000*yen*, the price of a body-shell per ton increases by 9,500*yen*. On the other hand, as the disposal cost of shredder residue at landfill increases by 10,000 *yen*, the price of a body-shell per ton decreases by 3,000*yen*. Since the disposal cost of shredder residue increases according to the Hotelling Rule, the price of a body-shell will be negative, and reverse pricing is unavoidable.

Utilizing the regression analysis, we have simulated the effect of automobile manufacturers' free-take-back of ASR on the price of a body-shell. If the price of shredder scrap is around 6,000*yen* per ton as it is now, there is a great possibility that the body-shell price will remain negative. If the price of shredder scrap goes up beyond 10,000*yen*, the body-shell price will possibly be positive.

We have also simulated for how long shredder residue will be disposed of at landfill, considering that there is reasonable backstop technology. The result is as follows: Depending upon the assumption that the backstop price is 30,000*yen* per ton and 40,000*yen* per ton, the lifetime of landfill utilization is four to six years and nine to 13 years respectively. Furthermore, assuming that the lifetime of landfill capacity is only two to four years as is often stated, we have simulated the increase rate of the landfill disposal cost of shredder residue. The simulation result is quite sensitive to the backstop price (P_b); corresponding to the cases of P_b = 30,000*yen* per *ton* and P_b = 40,000*yen* per ton, the increase rate is six per cent to 12 per cent and 14 per cent to 29 per cent respectively.

From the above results, it can be understood that the price of body-shells will become negative sooner or later, if we proceed with the present scheme of ELV recycling. Particularly, insofar as the price of shredder residue remains relatively low as it is now, even a free-take-back of ASR scheme by automobile manufacturers will not help the body-shell price be positive. In order to facilitate proper recycling of ELVs, negative pricing of body-shells should be avoided, since it induces improper treatment of ELVs in the process of dismantling. Thus, in the near future, we may have to consider the option of automobile manufacturers being obliged to take back body-shells free of charge.

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