THE POTENTIAL FOR REDUCING FINAL WASTES THROUGH RECYCLING: 
THE CASE OF PAPER IN TOKYO, JAPAN

by
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ABSTRACT

One of the most serious problems in the Tokyo area is the shortage of final waste disposal sites. Even though recycling is recognized as a solution to this problem, promoting recycling is difficult mainly for economic reasons. Hence, the objective of this research is 1) to summarize the current situation around recycling; and 2) to find out the optimal recycling rate for waste management and figure out the potential reduction of final waste through recycling. Waste management is defined as a total system, which consists of both waste recycling and disposal.

In the paper industry, recycling is well practiced. Since this industry is considered mature enough to discuss the optimality of recycling, the paper industry in the Tokyo area is focused as an example.

To derive the optimal recycling rate for the waste management system, a function describing the net benefits of wastepaper management is developed and solved. In this research, the product of recycling paper is assumed to be pulp, not paper.

From the simulation, the following results are obtained. Under the current situation, the net benefit of waste paper management is negative. The optimal recycling rate for the waste management system is 77.8% of the wastepaper generated. Under
current condition s, if this rate is achieved, 106,408 tons of final waste per year would be reduced, that is 6.6% of total final waste. The benefit of this reduction in final waste would be avoiding what otherwise is a loss of 34 billion yen.

Considering that the current recycling rate is 57.7%, this optimal rate of 77.8% is fairly high. The main reasons for this gap are the following:

(1) For the private sector, the current recycling rate is optimal.

(2) As a consequence of user demand for whiteness, the demand for recovered pulp is not high enough to achieve the estimated optimum.

As for the first reason, the problem is that private paper recyclers are not responsible for disposal and its social problems. Hence, to solve this problem, paper recycling should be considered as a part of the total wastepaper management system.

As for the second reason, even though the preference for high whiteness is not necessarily a bad idea, it is worth reconsidering. Since recovered pulp cannot have enough whiteness to be used in the production of paper with high whiteness, which is preferred by Japanese customers in some types of paper products, this preference is a constraint on the demand for recovered pulp. If this preference for high whiteness could be reduced, demand for recovered pulp would rise and the recycling rate would be higher.
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Chapter 1

INTRODUCTION

The shortage of final wastes disposal site is a serious problem in Tokyo. According to the Tokyo-Seisou Kenkyu-jo, the research arm of Tokyo Metropolitan Government, if the recently opened landfill disposal site located in Tokyo Bay continues to be filled at its current rate, its life span will be only 15 years. It is the only landfill site in the whole Tokyo metropolitan area.

The focus in Tokyo is now turning to source reduction, programs to reduce the amount of waste generated.

Two concrete ways of source reduction exist. The first is to replace current materials with substitutes that generate less waste. However, this depends on developing or identifying substitutes. An alternative is to consider recycling. This process uses wastes as an input of production of new material.

However, recycling has its problems. First and most significant is the high cost. In some materials, the cost of recycling is much higher than that of producing virgin material. In addition, since recycling is not well practiced in some industries, the cost is not clear and this makes producers hesitate to recycle.
In this sense, some public incentives are considered necessary to promote recycling. In the case of paper in Japan, a new container packaging recycling law has been established and is gradually being carried out. In addition, in some areas, provincial governments promote recycling. To promote recycling, making clear the associated costs is meaningful. Figuring out the optimal rate of the recycling from the view point of society is also useful for social planners. If there is a benefit from more recycling to recyclers, they will recycle more.

Hence, the main purpose of this research is 1) to summarize the current situation of paper recycling in Japan, in both the amount and its cost; and 2) to find out the optimal recycling rate for the industry from the perspective of waste management. For this purpose, the net benefit of waste management, not only of recycling but also of disposal, is calculated and maximized.

As for second purpose, in some industries, recycling has not matured enough to discuss its optimality. However, currently the recycling rate of paper in Japan is high (52%). It can be said to have matured enough to argue the optimality of the recycling rate. However, maturity is not always a good thing. Paper recycling is so mature that it has created an excess stock problem. To try to solve it, thermal recycling is being promoted. This problem will be discussed in detail later. The optimal rate is hypothesized to be higher than the current recycling rate. Part of this reason is the
difference of the viewpoint in society and the private sector. Considering this difference is part of the objective of this research.

In Chapter 2, the current situation in wastepaper management is discussed, followed by the introduction of previous work. Not much previous work exists, but among the few, some are quite useful. Then, the model of net benefit of waste paper management and data used in the model are introduced. After the introduction of model, its results are discussed, followed by the conclusion of this research.
WASTEPAPER MANAGEMENT IN TOKYO

In this chapter, the current situation of wastepaper management in Tokyo is presented. This can be divided into two parts, the first is disposal, and the second is recycling, as shown in Figure 2.1. Paper is made from two types of pulps, virgin pulp and old pulp. Old pulp is made of fibre recovered from old paper. In this research, this process is called recycling. As for waste disposal systems, a significant change is happening. The flow from “municipalities” to “waste paper to be recycled,” expressed in the dotted arrow in Figure 2.1, is being generated as a result of container packaging recycling law. This will be discussed later in this chapter. The word “paper” includes both paper and paperboard, unless otherwise specified.

Waste Disposal Systems

As mentioned, wastepaper management system is divided into two parts, disposal and recycling. In this section, waste management system is discussed. Wastepaper is primary focused here, however other wastes are also discussed. In this section, cost of each process is introduced. For your convenience, 1 dollar is roughly
Figure 2.1 Material Flow
equal to 100 yen. (One dollar is equal to 102.14 yen on the Tokyo market, December 6, 1999)

General Issues

For government regulation purposes, wastes are classified into two categories, industrial wastes and general wastes. Wastes from households, categorized as general wastes, are directly collected without charge by municipalities. Households can drop off their wastes at the designated area.

General wastes from businesses are not free. Businesses have to pay for the service by buying stickers and attaching them to their garbage bags. This system started in 1997, and there are no real statistics showing how it works. However, considering that 54% of general wastes are from businesses, this income may be huge. In addition, this cost encourages business firms to recycle.

Nineteen types of wastes from businesses, which are all of wastes from businesses not included in general wastes, are classified as industrial wastes. In the case of paper, only wastepaper from industries defined by law, such as publishing or paper producers, which are supposed to generate a lot of wastepaper, are categorized as industrial wastes. Industrial wastes are not collected by municipalities. Companies have to transport their wastes to disposal facilities by themselves and pay a fee. Many
companies that generate large amounts of industrial wastes consign collection and transportation to waste disposal firms. The composition of both general and industrial wastes is as shown in Tables 2.1. and 2.2.

In 1992, industrial waste from the Tokyo Metropolitan area was 24.8 million tons, which included 90,000 tons of wastepaper. General wastes totaled some 4 million tons, which included 1.2 million tons of paper wastes (Bureau of Waste Management, Tokyo Metropolitan Government, 1999). This may sound ridiculous. The reason why the amount of wastepaper in industrial wastes is so small is that recyclable wastepaper in industries is collected as recyclable material prior to the collection of wastes. Since industrial waste does not contain much wastepaper, this chapter will focus on the disposal of general wastes.

Basically, the Tokyo Metropolitan Government is responsible for general waste disposal. Beginning in 1998 the responsibility has been gradually shifting to the metropolitan units of cities and wards. Collection of general wastes is fully transferred, incineration is partially transferred. Basically, the Tokyo Metropolitan Government’s responsibility will be only for final landfill disposal. Some wards and cities cannot handle incineration because of lack of the facilities of it.

Now the Metropolitan Government and its municipalities are trying to promote recycling. General wastes – combustible, incombustible, and large-sized wastes - were
Table 2.1 Composition of General Waste [%]

<table>
<thead>
<tr>
<th>Types of wastes</th>
<th>Combustible wastes</th>
<th>Incombustible wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste paper</td>
<td>50.0</td>
<td>7.2</td>
</tr>
<tr>
<td>Kitchen Garbage</td>
<td>29.9</td>
<td>5.4</td>
</tr>
<tr>
<td>Textiles</td>
<td>3.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Wood and glass</td>
<td>8.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Plastic</td>
<td>7.0</td>
<td>41.9</td>
</tr>
<tr>
<td>Rubber, leather</td>
<td>0.2</td>
<td>4.0</td>
</tr>
<tr>
<td>Metal</td>
<td>0.5</td>
<td>17.2</td>
</tr>
<tr>
<td>Glass only</td>
<td>0.2</td>
<td>14.1</td>
</tr>
<tr>
<td>Ceramics, sand and others</td>
<td>0.2</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Note: In this table, Combustible wastes denotes the waste collected as combustible wastes. And same in Incombustible wastes.


Table 2.2 Composition of Industrial Waste in 1992 [1000 tons/year, %]

<table>
<thead>
<tr>
<th>Types of wastes</th>
<th>weight</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>5</td>
<td>0.02</td>
</tr>
<tr>
<td>Sludge</td>
<td>18,206</td>
<td>73.45</td>
</tr>
<tr>
<td>Waste oil</td>
<td>55</td>
<td>0.22</td>
</tr>
<tr>
<td>Waste acid</td>
<td>89</td>
<td>0.36</td>
</tr>
<tr>
<td>Waste alkali</td>
<td>36</td>
<td>0.15</td>
</tr>
<tr>
<td>Plastic</td>
<td>301</td>
<td>1.21</td>
</tr>
<tr>
<td>Wood</td>
<td>363</td>
<td>1.46</td>
</tr>
<tr>
<td>Paper</td>
<td>90</td>
<td>0.36</td>
</tr>
<tr>
<td>Metal</td>
<td>248</td>
<td>1.00</td>
</tr>
<tr>
<td>Glass, ceramic</td>
<td>442</td>
<td>1.78</td>
</tr>
<tr>
<td>Waste from construction</td>
<td>4,708</td>
<td>18.99</td>
</tr>
<tr>
<td>Others</td>
<td>245</td>
<td>1.00</td>
</tr>
<tr>
<td>total</td>
<td>24,788</td>
<td>100</td>
</tr>
</tbody>
</table>

collected separately, and have had no chance to be recycled for a long time. And now, citizens must separate their wastes into four categories: unrecyclable-combustible, unrecyclable-incombustible, large size wastes and recyclables, which includes paper. All this is part of container packaging recycle law. The detail will be discussed later in this chapter.

**Each Process of General Waste Disposal**

Voluntary prior separation plays a significant role in the current waste disposal system (Figure 2.2). Large size wastes includes such items as refrigerators or furniture. Although some of these are combustible, currently these wastes are processed as incombustible wastes. And all wastes are incinerated or crushed in order to reduce their volume. This is one of the solutions to the final disposal site problem.

**Collection and Transportation.** There is no data on collection and transportation from cities and wards. The data is primarily from the Metropolitan Government in 1997. Basically, municipalities received collection tools, trucks, and methods from the Metropolitan Government. Hence the cost is considered not dramatically changed by this transfer of responsibility from the Metropolitan Government to cites and wards.

Costs include collection, transportation to processing facilities, such as
users

Voluntary separation

Recyclable wastes

Combustible wastes

Incineration

Large-size wastes

Crushing

Regular-size incombustible wastes

Crushing

Final disposal sites

Note: all arrows denote the transportation by trucks or ships

Figure 2.2 Flow of General Wastes Disposal
incineration, and transportation to the final disposal site. According to the Bureau of Waste Management, the average cost of collection and transportation is 39,964 yen per ton. Of those costs, collection is 23,964 yen per ton on average and transportation is 16,000 yen per ton. Roughly speaking, collection is the most expensive among all operating costs.

**Incineration.** There are a couple of reasons why combustible wastes are incinerated. Two of them are quite significant. First, incineration reduces the mass and volume. This is an answer to the problem of final disposal site shortages. According to the Bureau of the Waste Management, combustible wastes after incineration are reduced to 15% of their former mass, and 5% of their former volume.

The other reason is sanitation. Nearly 30% of combustible general wastes are kitchen garbage. According to the Bureau, average cost of incineration is 13,788 yen per ton.

**Landfill.** Basically there is only one final waste disposal site, the Tokyo Bay site. Originally, Tokyo was under water and landfilled it, and there is not much space left. According to the Bureau of Port and Harbor of the Metropolitan Government, the current final disposal site may be the only place left for a landfill. The site, which has
just started receiving wastes, has the capacity of 120.37 million tons. Its life estimate varies between 15 to 50 years, depending on usage. Currently, the site accepts not only the general wastes from the Tokyo Metropolitan Government but wastes carried in by private waste management firms. However, the site is expected to be closed to private firms in near future. This will make the life longer.

Operating the landfill does not cost a lot. Its cost is 8,767 yen per ton. Building the landfill site in the sea, however, has been significant, 744 billion yen. If we assume a life of 15 years, discounted by 5%, the annual cost for this is about 71,68 billion yen, almost six times as much as the annual cost of the landfill operation in 1996, 12.27 billion yen.

Recycling Process and Paper Industry

As for paper recycling, the data specific to the Tokyo area cannot be collected. Hence, in this section, data for all of Japan is primarily presented. According to Bureau of Waste Management, Tokyo Metropolitan Government, the recycling rate has been a little over 50% in the latter half of 90’s. This value may be slightly different in the Tokyo area.
Recycling Process

Wastepaper is used as an input in pulp production, and pulp is used as the input in paper production. Hence, once recovered as pulp, wastepaper is not different from timber the inputs of virgin pulp production. In many cases, pulp production occurs in the paper production plant. This industry is so vertically integrated that some companies cultivate their own forests.

Pulp production incurs the following costs: purchase of inputs (old paper, or timber chips), purchase of chemicals, electricity, and fixed costs such as, labor and depreciation. Since life-long contracts are still common in Japan, the labor cost is a fixed cost. According to the Office Neighborhood Association (1995), the total cost to produce low quality pulp for newspapers is 34,000 yen per ton, and for high quality paper 53,000 yen per ton. On the other hand, the cost for virgin pulp is 50,000 yen per ton. The high cost for high quality recycled pulp is one of the main factors discouraging recycling.

Wastepaper Collection

Among the costs of pulp production, the purchase cost of wastepaper seems to vary most depending on the recycling rate, that is the collection rate. Clean Japan Center tried to estimate the price of old newspaper as a function of the recycling rate. This research is old, from 1978, and the situation around old paper collection has been
changed. In addition, the center did not seem to have enough data to estimate the curve itself. However, the most important thing from this research is that the results from surveying paper companies and organizations showed that the function is expressed in the shape of the curve, Figure 2.3. Even though many things have changed since 1978, the changes are basically the increases in voluntary separation and collection. Hence, even though the value for a specific point must be changed, this curve is supposed to have same shape.

This shape of the curve is determined as follows. From a zero recycling rate to a point, that is, the optimal point, the cost of collection per unit must be decreased, because there is scale economy and also some advantages from the viewpoint of geographical distribution of waste paper. Nonetheless, beyond the optimal point, because of both for geographical and technical reasons, the collection cost per unit must increase.

The price of wastepaper contains collection costs. According to Adachi (1998), one paper collection company responded that its collection cost was roughly 7,000 yen per ton. Considering that even the most expensive wastepaper costs only around 15,000 yen per ton, at least half of the price was collection cost.

Collection cost is supposed to be determined by the recycling rate. Collection is a labor-intensive process. There must be one optimal point of collection rate, that is, equal to the recycling rate, where collection cost per unit of wastepaper is minimized.
Figure 2.3 Old Paper Price and Recycling Rates

Note: Based on the Clean Japan Center (1978)
From the geographical viewpoint, from low rate to the optimal rate, the density of wastepaper is getting higher. This decreases the unit collection cost. However, past the optimal point, for both technical and geographical reasons, collection will be getting more difficult and the unit cost is supposed to become higher.

Market Situation

There is no data for the consumption of paper in the Tokyo area. The total production of paper in Japan in 1997 was 31 million tons. Annual growth of consumption from 1993 to 1997 averaged 2.5%. As shown in Figure 2.4, the price of paper is unstable. Considering there has been no significant technological advances in these five years, the instability is caused by the price of inputs. As mentioned before, paper consumption has been constantly growing. Hence demand is not the significant reason either.

The prices of inputs are shown in Figure 2.5, and these are unstable, too. As mentioned, in order to promote recycling, it is important that the collection costs be lowered.

There is a slight problem of excess supply of wastepaper. According to the Ministry of International Trade and Industry, 787,329 tons of wastepaper sat unrecycled in the warehouses in 1997. Considering that the annual consumption of old paper was 16
million tons in 1997, this number was slightly high.

**Thermal Recycling**

Wastepaper is currently excess-stocked. As one of the solutions to this excess-stock problem, thermal recycling is suggested. According to Fujino et al. (1999), from 1 ton of wastepaper, 16.3 giga joule of energy can be acquired from thermal recycling. However, with current technology this energy can not be used effectively, because this energy is in the form of heat and is difficult to be transported.

**Recycling Rate and Society**

The recycling rate is determined not only by the technological or economic issues, but also by social systems or peoples ideas about paper. Even if the quality is enough high, people sometimes demand higher quality. In the case of paper, people demand high whiteness. This issue is discussed in this section. Also public policy is considered to affect the current recycling rate. As one of those policies, new container packaging recycling law is discussed in this section.
Figure 2.4 Paper Prices

Figure 2.5 Input Prices

Recycling Rate and Whiteness

The recycling rate of paper has been little more than 50%. Because of the limit of current technology, the recovered pulp is inferior to virgin pulp in terms of quality. The low quality pulp leads to low whiteness level paper. Besides the economical reasons, the requirement for whiteness deters the increase of the recycling rate. If paper products did not require high whiteness, technically the recycling rate could be much higher.

However, high whiteness is considered a symbol of high quality. Some products, such as packaging or containers, require a very high whiteness to reflect luxuriousness. It is doubtful whether office paper requires a high whiteness rating. In Japan, currently most office use papers with whiteness of 80. According to the Office Neighborhood Association (1995), the production of paper with whiteness of 80 requires high quality recycled pulp and virgin pulp. On the other hand, the production of paper with whiteness of 70 requires virgin pulp and low quality recycled pulp. This low quality pulp can be same as is used for newspaper. As already mentioned, the costs for these two different quality pulps are 34,000 and 53,000 yen. This difference is significant. Currently, Office Neighborhood Association is promoting the use of office paper with a whiteness of 70, as is Japan’s Environmental Agency.

Preference for high whiteness is not necessarily a bad idea. However, considering the huge effect of this issue on the demand for papers with recovered pulp,
this is worth to reconsider.

**Container Packaging Recycling Law**

Some containers or packaging are difficult to recycle. As for paper products, milk cartons and other coated containers are difficult to recycle. Container packaging recycling law\(^1\) seeks to promote the recycling of these products. In addition, the law has a secondary expected effect of reduction of wastes. The law obliges each municipality to establish a system for the separate collection of recyclable wastes. Citizens must separate their wastes prior to throwing them into dumpsters. Industries will be most significantly affected by this law. They must recycle a specified amount of wastes, depending on their amount of wastes.

There is however, one concern about the law, a slight overstock of wastepaper. If more wastepaper flows into warehouse, the problem will be significant one. Prior and more detailed separation is obviously required to avoid this problem. Prior and more detailed separation will lower collection costs, lead to a reduction of the recycling cost, and may lead to more old paper use as inputs of pulp production. The promotion of

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1. The official name of the Container Packaging Recycling Law is “容器包装に関わる分別収集及び再商品化の促進に関する法律” (Yohki Hohsoh ni kakawaru hunbetsu shuushuu oyobi sai-shouhin ka no sokushin ni kansuru houritsu: Law for Promotion of Sorted Collection and Recyclable of Containers and Packaging)
collection of wastepaper must come along with the promotion of prior and more detailed voluntary separation by users.
The shortage of final disposal sites and recycling as a solution for waste reduction are serious problems in Japan. Not much research has been done to solve the problem.

**Input-Output Analysis**

There are couple of studies of recycling and waste management using input-output matrix. These studies analyze total waste management, not just the paper. One recent study, Adachi (1998) introduced the input-output matrix to find out the optimum allocation of general waste recycling among industries. Adachi set a 60% reduction of general wastes as the goal of the amount of general waste recycled. He tried to find out the optimum allocation of these wastes additionally recycled among industries. In his calculation, he used the following two criteria: first, minimize Gross Domestic Product decrease per unit of reduced final waste; second, maximize the reduction of the final waste. To satisfy the first criterion, he calculated the effect on each industry of an additional one unit of recycling on GDP with the input-output matrix repeatedly. He
used the data of Japan, and concluded that recycling should first be promoted for wastes with a high ash content ratio, such as metal or glass, and then move to wastes with a low ash content ratio, such as paper and textile.

Cost-Benefit Analysis

Turner (1978) introduced one criterion for the waste management. He defined the recycling project as a part of total waste management system. Then he introduced the criteria for the system. According to him, the net benefit equation is as follows:

\[
NB = \text{saved disposal cost (SDC)} - \text{increased collection cost in order to recycle (ICC)} + \text{revenue of the recycled material (R)} + \text{environmental impact}
\]

However, the environmental impact is unlikely to be quantifiable. Then, deleting the last term and converting the equation to present value terms,

\[
NB = \sum_{t=0}^{T} (SDC - ICC + R)e^{-rt}
\]

His criterion is as follows:

i) NB is positive and the environmental impact is also supposed to be positive, then the recycling project is worthwhile;

ii) NB is negative and the environmental impact is also supposed to be negative,
then the project should be rejected;

Other two cases are difficult to decide. Because the relative size of environmental impact to other factors determine the worth of recycling.

Pearce and Nash (1981) analyzed paper recycling using cost-benefit analysis. They defined two methods of collection, namely, integrated collection and prior separate collection and three methods of disposal, namely landfill, landfill after shredding, and direct incineration. Then they devise scenarios by combinations of methods of collection and disposal.

The authors introduced one equation of marginal net benefit of paper recycling as follows:

\[ \text{NEBR} = (\text{cost of virgin fibre}) + (\text{cost of disposal}) - (\text{cost of secondary fibre}) \]

\[ = (V_c + V_p + V_f) + (S_k + S_d) - (S_k + S_s + S_t) \]

\[ = (V_c - S_s - S_t) + (V_p + V_f - S_p) + S_d \]

where \( V_c \) = the cost of a unit of virgin fibre

\( V_p \) = the pollution impact of processing one tonne of virgin fiber

\( V_f \) = the loss of amenity by having to fell the requisite amount of timber to supply one tonne of virgin fibre

\( S_k \) = the cost of collection

\( S_s \) = the cost of separation of used paper
St = the cost of transportation of used paper

Sp = the pollution from the use of 1 tonne of secondary fibre

Sd = the cost of disposal

The first two terms in the equation represent the benefits of recycling, since these costs are avoided by recycling.

There is a big difference between this research and Turner’s. According to Turner, the collection cost of waste is significantly different if the waste will be recycled, but in this research, it is not. What causes this difference is the definition of the collection cost. Turner’s collection cost includes the separation cost, but this equation’s does not.

Because of the significance of separation costs, Pearce and Nash concluded their research that voluntary prior separation is strongly recommended. As mentioned before, prior separation plays a really significant role in the waste management in Tokyo. The result from Pearce and Nash is main reason why the collection cost is exaggerated in my model. This will be discussed in the chapter 4.

These two cost-benefit analyses are fundamental to my net social benefit function.
Optimal Recycling Rate for Society

Huhtala (1997) introduced the dynamic model for determining optimal levels of recycling and landfilling.

\[
\max_{L,R} J = \int_{0}^{\infty} e^{-\delta t} \left[ B_i(R_i) - C_i^L(L_i) - C_i^R(R_i) \right] dt - F_i(S_i(0)) \\
+ \int_{0}^{\infty} e^{-\delta t} \left[ B_i(R_i) - C_i^L(L_i) - C_i^R(R_i) \right] dt - F_i(S_i(t)) e^{-\delta t} - D_1(S_i(0) - S_i(t)) e^{-\delta t}
\]

\[\begin{align*}
\dot{S}_i &= -L_i, i = 1,2 \\
\dot{S}_i &= -L_i, t \geq t_i, i = 1,2 \\
\text{s.t.} & \quad S_i(0) = S_i^0, S_i(t_i) \geq 0 \\
& \quad S_2(t_i) = \text{free}, S_2(t_2) \geq 0 \\
& \quad G_i = L_i + R_i, i = 1,2
\end{align*}\]

where \( J \) = present value of social net benefits from waste disposal services;

\( \delta \) = discount rate;

\( B \) = benefits (external benefits, this doesn’t denote the revenue)

\( C \) = net cost (in the case of recycle, this \( C \) = total costs – revenue)

\( F \) = fixed costs for opening landfill

\( S \) = space available for landfill

\( D \) = future damage caused by current landfill

The goal of this model is designed to maximize the present value of the social net benefits from waste disposal services (\( J \)). Whole municipal solid waste is treated in this
research. The space available for landfill (S) is the state variable in this model. The amount of waste going to disposal (L) is a control variable. Since the total amount of waste G is exogenous, the amount of waste, which is going to be recycled (R), is just a function of L. B and C in this equation mean benefit and cost in both recycling and landfill, and D denotes the future damage caused by the completed current disposal site.

The important thing in this model is that this model is the two-stage dynamic optimization model. "Two stage" means the current disposal site and a new disposal site. With this, this model can include both the opening and closing cost of disposal site F[S(t)]. In this research, the landfill site is the land area, not the sea. This is the huge difference between Huhtala's research and mine.

There is another important point. The B_r includes the demand effect measured by household willingness to pay for recycling. Since a large-scale recycling program depends heavily on households sorting efforts, this is meaningful. This willingness to pay represents the value of environment saved by recycling for household, who are consumers of the recycled products. In this sense, this point should not be ignored.

According to Huhtala, recycling significantly prolongs the life span of landfills. However, in the case of Tokyo, since its disposal site is in the sea, the capacity is strictly fixed. If someone applies this model to the case of Tokyo, two stages are not necessary. Even considering this point, Huhtala's research has a significant effect on my model. In
addition to the previous two cost-benefit analyses, the model in this research is fundamental to my model.

Current Situation of Paper Recycling in Japan

The Office Neighborhood Association (1995) introduced results from a survey of costs associated with paper recycling. In Japan, private companies commonly withhold their cost of operation. However, since this association is a non-governmental Organization, which includes paper companies as their members, they could make a cost comparison between recycled paper and new paper. According to the association, the copy paper made of virgin pulp (whiteness 80) costs only 143 yen per kg. On the other hand, the copy paper made of both recovered and virgin pulps (whiteness 70) costs 131.80 yen per kg. However, production of the same quality recycled paper as virgin paper (whiteness 80) costs 145.10 yen per kg. The objective of this research is to promote the use of recycled paper with a whiteness of 70. Hence this difference in costs may promote the use of it. With this result and the price of virgin pulp and old paper, the price of old pulp and cost for the recovery of old pulp will be estimated.

Both Fujino et al. (1999) and Morisawa et al. (1995) introduce the life cycle analysis of paper recycling from the view point of energy, not money. Thermal recycling is supposed to be one of the solutions of this excess stock problem. But Morisawa
concludes that thermal recycling has no practical role due to the current low waste heat recovery level. According to Fujino, with the current technology of thermal recycling, we can get 16.3 giga joule of energy from one ton of wastepaper.

The problem with thermal recycling is that the energy recovered is heat. Heat is difficult to be stocked or even transferred. Hence, even though this method of recycling is recognized as useful one, it is not yet practical.

In both studies, the authors make the same significant point. Among virgin pulps, there are two types - one is kraft pulp and the other is mechanical pulp. Kraft pulp is made through a chemical process. That eliminates impurities, which heat can be recovered from. Hence, from the viewpoint of energy balance, making kraft pulp is superior to material recycling. In this case, since the heat recovered can be used in the production of pulp, recovered heat can be used efficiently.
Chapter 4
MODEL AND DATA

General Form of Model

The primary objective of the static model presented here is to calculate the optimal recycling rate by maximizing net benefit (NB) of paper waste management, which consists of both recycling and disposal. In this simulation, recycling means only material recycling, and does not include thermal recycling. Because thermal recycling is not well practiced in the Tokyo area yet.

This net benefit function ignores the user cost for use of landfill space. Hence, in the strict sense this is not social. In order to avoid misunderstanding, this function is called just the net benefit function of wastepaper management. The word "private" means only recyclers in this research.

The general form of model is as follows;

$$\max_r NB(r) = \left[\pi_r (rW) - C_r (rW) + E_r (rW)\right] + \left[\pi_L ((1 - r)W) - C_L ((1 - r)W)\right]$$

s.t. \( 0 \leq r \leq 1 \)

where \( NB = \) net benefit of wastepaper management
\[ r = \text{recycling rate} \]

(the amount of paper recycled/ total amount of waste paper)

\[ W = \text{total amounts of wastepaper (ton)} \]

\[ \pi = \text{revenue (yen per ton)} \]

\[ E = \text{net benefits of external effects} \]

(except for revenue from the sales) (yen per ton)

\[ C = \text{costs of operation (yen per ton)} \]

R and L: recycle and landfill (disposal)

In this simulation, the following assumption exists. Since pulp is the intermediate input of paper production, the product for recycling paper is pulp, not paper. Usually recovered pulp is used as a substitute of the combination of pulps, 20% of high quality pulp and 80% of middle quality pulp (Clean Japan Center 1978). Hence, in this research, recovered pulp is assumed to be a perfect substitute for this combination of virgin pulps.

\[ \pi_r \text{ and } C_r \] denote the revenue and cost of the recycling material. \( E_r \) denotes the net external effect of recycling. This could include the net environmental effect of recycling, for example the amenity from saved timbers. These three should be the function of the recycling rate “\( r \)” and amount of wastes “\( W \).”

Since the landfill space is a scarce resource, the user cost for the use of landfill
space saved by recycling should be considered as a part of external effects from recycling. However, in this case, user cost is difficult to estimate in monetary units. Then, the user cost is ignored this time. If this is included in the model, the derived optimal "r" should increase.

\( C_t \) denotes the cost of the disposal. As for the effects other than costs of landfill, only revenue from landfill \( \pi_t \) is considered. In the Tokyo area, the price of land is too high to be ignored. As a negative effect, the environmental damage from the wastepaper landfill could be included here.

Tokyo Bay has no other use than the landfill site. Of course, it has some ports, but they are not affected by landfill, and there is little fishing in the bay. Thus, opportunity cost for landfill is expected to be small enough to be ignored.

The net benefit function can be used for other kinds of wastes. And in the case of any waste, the external effects is difficult to estimate in monetary terms. The form of each function is discussed in the following section.

**Each Term and Data**

In this section, each function is set with the data used in the basic simulation. Basically data used here are in 1997, otherwise mentioned.
**Current Recycling Rate**

In deriving each terms, the current recycling rate is sometimes used. 52% of the recycling rate is calculated by dividing “the amount of wastepaper recycled” by “production.” Since “r” in my model is defined as dividing “the amount of wastepaper recycled” by “the amount of wastepaper total”, current “r” is supposed to be different from 52%.

Here, by assuming the amount of wastepaper total is 90% of production, current “r” is set as 57.7%. The reason of this is 10% of total consumption of paper is high quality paper, which is supposed to have longer life.

The problem with this assumption is discussed in chapter 5.

**Revenue from Recycling**

Revenue from the sale of the old pulp can be estimated as follows:

\[ \pi = \text{Price of old pulp} \times \text{ArW} \]

where

\[ A = \frac{\text{pulp generated[ton]}}{\text{old paper used[ton]}} \]

There is, however no market for old pulp. Paper companies usually recycle wastepaper into old pulp as one process of paper production. Then, there’s no market for old pulp and of course, no price for the old pulp. Then, we estimate the price of old pulp
from the price of the virgin pulp.

In 1997, the price of the virgin pulp, whose quality is considered almost same as that of the recycled pulp, is 60,000 yen per ton. We can use this price as the price of old pulp. In this simulation, recovered pulp is assumed to be a perfect substitute for virgin pulp. And since the recovered pulp producers are only a portion of the producers in the perfect competitive pulp market, they are mere price-takers. Then price can be exogenous, and determined by the total amount of pulp; that is, the sum of virgin and recovered pulps. This is the reason why the price is constant in this model.

In addition, A is roughly estimated as 85%. This data estimated by Oji Paper Company. Then this term is set as follows:

\[ \pi_r = 51,000 \times r \times W \]

**Recycling Cost**

According to the Office Neighborhood Association (1995), the cost of recycling paper into pulp is around 39,000 yen per ton. No more detailed data is available except for the price of the old paper, 16,000 yen per ton. We can define the cost as follows;

\[ C_{\text{recycle}} = \{ P_{\text{oldpaper}}(r)[\text{yen/ton}] + \text{other costs[yen/ton]}\} \times r \cdot W \]

Here, "other costs" are defined as constant. Only the price of old paper is defined as a function of recycle rate "r." From the data above, other costs are defined as 23,000 yen.
per ton. A large part of this is operating and fixed costs. Since this industry is so large and mature, it is difficult to expect that there is significant scale economy. Hence, this value is assumed to be constant in this model.

The price of old paper depends significantly on the collection costs, partly because collection is labor-intensive and wages in Tokyo area are really high. I assume that this function must have the shape of graph in Figure 4.1.

The meaning of this shape is as follows. The diminishing part of the curve expresses the scale merit in collection. According to my phone survey, this cost could be reduced a little more. Considering that the current recycling rate is 57.7%, the cheapest price will appear around the recycling rate of 60% to 70%. Once $r$ is over that rate, the cost will increase dramatically. This portion of wastepaper must not locate concentratedly. Hence, it is difficult to collect and some of them are almost impossible to collect. This was already discussed in Chapter 2, current situation.

Of course there are other factors that effect the price of old papers. However, according to Pearce and Nash (1981), collection and separation have a significant effect on the total cost of recycling. Here the relationship between the recycling rate and price of wastepaper is focused on most.

Besides costs, demand can be a factor. However, demand for old paper largely depends on price of inputs for virgin pulp. Since putting demand in this model makes
Figure 4.1 Old Paper Price and Recycling Rate
the model too complicated, demand is ignored at this time.

In order to express this shape in Figure 4.1 mathematically, the following function is introduced here:

\[ P = \frac{a}{r - 1} + b \cdot (r - 1) + c \]

where \( a, b, \) and \( c = \) constant

\( P = \) price of old paper, yen per ton

\( R = \) recycling rate

All constant value should be estimated with sufficient data. However, there is little.
Hence, we use the data for current situation of (57.7%, 14,500 yen per ton) and the assumption that the minimum collection cost occurs around the recycling rate of 65%.

From these data and assumption, I assume these constant as follows:

\( a = 7150, \) \( b = 65000, \) \( c = 36400 \)

This is just a rough estimation, and these constants could be changed in sensitivity analysis. Especially the point where the collection cost is minimum changes by social systems. For example, if voluntary separation is practiced more, this rate must increase.

Now we have the following cost function:

\[ C_R = \left\{ \frac{7150}{r - 1} + 65000(r - 1) + 36400 + 23000 \right\} \times rW \]
External Effect from Recycling

As for external effects of recycling, the following can be considered: the value of timbers not cut, the loss of the virgin pulp producers, and amenity of forests saved. By recycling, timber will be saved. This timber has economic value as a commodity, and this value is saved. Then this effect must be positive. Increasing recycling means that the demand for virgin pulp producers decreases. Then they lost their profit. This effect must be negative. At last, the timbers saved has some value of amenity. Then saving timbers has another positive effect other than its value as a commodity.

However, each of these factors considered is difficult to estimate in monetary values, and are ignored at this time. As mentioned before, the user cost for use of landfill space is ignored, too. Hence, $E_R = 0$.

Landfill Revenue

This landfill means waste disposal. As a starting point, the value of land generated by landfill is considered. Then,

$$\pi_L = P_{\text{land}} \left[ \frac{\text{yen}}{\text{m}^2} \right] \times B \left[ \frac{\text{m}^2}{\text{ton}} \right] \times (1 - r) \times W \left[ \text{ton} \right]$$

where \( B = \frac{\text{area of surface of the site} [\text{m}^2]}{\text{capacity of the site} [\text{ton}]} \)

Both \( P_{\text{land}} \) and \( B \) is constant. And from the current data, \( P_{\text{land}} \cdot B = 8772 \) yen per
ton. As for the price of land, the price set by the National Tax Administration for area in similar condition is used. Then, this term is set as:

\[ \pi_L = 8,772 \times (1 - r) \times W \]

In this term, the revenue from the sale of stickers for general wastes from business can be included. However, since currently no exact data is available, this is ignored in the basic simulation. This issue is analyzed as part of the sensitivity analysis.

**Disposal Cost**

Disposal cost is divided into two parts. First is the operation cost, which includes transportation, incineration, preprocessing, and landfill (landfill means just dumping wastes into the site). The other is the annual payment for building the landfill site.

The former cost is \( C_{op} \times (1-r)W \). According to Tokyo Metropolitan Government, \( C_{op} = 52,807 \) yen per ton. Since wastepaper is just a part of total wastes, the amount of wastepaper should not have a significant effect on the cost. Hence, this value is assumed to be constant.

Annual payment for building the landfill site is estimated as follows. First of all, assuming the life of current disposal is 15 years and discount rate is 5%, the annual payment of the building cost is 71,678,661,981 yen per year. According to the Tokyo
Metropolitan Government, in 1997, final waste from the paper waste is 15.241% of the total amount of final wastes landfilled. Hence, we can estimate this cost is 10,924,544,872 yen, by multiplying 71,678,661,981 by 0.15241. Then, this term is set as:

\[ C_L = 52,807 \times (1 - r) \times W + 10,924,544,872 \]

**Wastepaper**

The last variable left is the amount of waste, W. Unfortunately, there are no exact statistics on this from the Tokyo area. However, we have statistics of the amount of paper not recycled. And also we know the current recycle rate of 52%, that is 57.7% in my definition of “r”.

Considering the recycling rate of 57.7%, and data of the amount of waste paper not recycled (Bureau of Waste Management and Japan Paper Association), it is estimated as 3,529,267 tons per year. This value could be slightly different because of the recycling rate. However, this value is used in basic simulation, and changed in sensitivity analysis later.
Chapter 5

SIMULATION RESULTS

Basic Simulation Results

Rearranging the function with the data used in the basic simulation, we get the following objective function.

\[ NB(r) = \frac{166335817217 - 2.94395 \times 10^{11} r - 7.61086 \times 10^{10} r^2 + 229402355000 r^3}{r - 1} \]

(0 < r < 0.8)

The reason why the upper limit of "r" is 0.8 is with current technology paper can be recycled only about 4 or 5 times. Then, if calculated "r" is more than 0.8, the optimal recycling rate is 0.8.

Now taking the first order derivative of this function, we can get the first order condition for the optimal recycling rate for wastepaper management as follows:

\[ \frac{\partial NB}{\partial r} = 0 \]

We get the second order condition as follows:

\[ \frac{\partial^2 NB}{\partial r^2} < 0 \]

From the first order condition, we get \( r = 0.777572 \). Since this value is the only value
that satisfies both first and second order conditions, it represents the optimal rate of recycling under current conditions. The net benefit is shown as part of Figure 5.1.

According to these results, the net benefit of waste paper management is negative. This may sound ridiculous. However, since disposal and recycling are the only two alternatives for wastepaper management, even if the net benefit is negative, the society has to recycle or dispose of wastes. The loss should be covered by taxes, since general waste disposal is free for households and even though businesses are charged, the amount of charge is not enough. Anyway, the purpose of recycling paper should be to minimize the net loss of waste paper management rather than to maximize the net benefit.

The optimal recycling rate of 77.8% is much higher than the current rate of 57.7%. Possible reasons are as follows:

1. The model itself is wrong.
2. The data is not correct or appropriate.
3. Current recycling rate in Tokyo is much higher (57.7% is for whole Japan).
4. Both current and optimal rates are correct, but our society cannot achieve the optimal rate right now.
5. From the viewpoint of private section, this is not optimal.

The first reason does not seems to be appropriate here. Only the external effects
Figure 5.1 Basic Results and Sensitivity Analysis of Price of Old Pulp
can be changed. However, this is caused by the difference of definition of social benefit and does not mean the model is wrong.

The third reason seems plausible, at least technically. However, it does not explain everything. Even if the current recycling rate is much higher, 77.8% is still high. Considering that consumption of paper in the Tokyo area is more than 10% of total consumption in Japan, if current recycling rate is 77.8% in Tokyo, the recycling rate in other areas must be below 50%. This gap between the areas is too huge to be explained.

The fifth reason is not appropriate here, either. There are virgin pulp producers as competitors for private old pulp producers. If the cost of production of old pulp is higher than that of virgin pulp and old pulp is a perfect substitute for virgin pulp, the producers will not produce old pulp. In this sense, this reason is appropriate enough. However, knowing this difference of optimums for recyclers and for whole wastepaper management systems is the objective of this research. Then, every other reason should be considered. And the fifth reason should be considered last.

Thus, the second and fourth reasons seem possible.

As for fourth reason, there is one problem. This problem is mentioned in chapter 4. The current recycling rate is usually calculated as follows: the amount of waste paper recycled divided by the production of paper in the same year. This definition is different from the definition of “T” in my model. The production in one year may be
larger than the amount of waste paper in the year. There are couple of reasons for that. Firstly, the consumption is growing each year. Secondly, paper products have a life span. Not much papers has a life span of more than one year. But some paper products do. For example, usually books must have a life of more than one year.

But there is no data for the difference of wastes and consumption. Then if the amount of paper wastes are equal to 90% of consumption, the current recycling rate is 57.7% in my definition. If this is 80%, the current recycling rate is 65 %. Since about 10% of total paper production is high quality paper, which is supposed to have longer life than other kinds of paper, in this analysis, the current recycling rate is assumed to be 57.7 % in my definition. However, this value is just an estimation, and it may be higher or lower. But at least, it is higher than 52%. This may explain some of the difference between the current and the optimal recycling rate, but can not explain it all.

Only the second reason remains. In order to verify it, the results of sensitivity analysis are presented in the following section. If there is no difficulty with data, sensitivity analysis shows which factor has a large effect on the social net benefit and optimal recycling rate.
Sensitivity Analysis

In this section, the result from sensitivity analysis is presented. In each part, each variable, which may vary or not be sure, is tested.

Price of Old Pulp

In basic model, according to the assumption that old pulp is a perfect substitute for a specific type of the virgin pulp, the price of old pulp is set as 60,000 yen per ton, estimated from the average price of virgin pulps. The assumption that the price of old pulp is the same as that of virgin pulp of the same quality is supported by the assumption of the existence of many competitive producers in the market of pulp, which makes every producer a price-taker.

Considering that the price of virgin pulp may vary, the price of old pulp may also vary. The price of virgin pulp has been between 55,000 and 95,000 yen per ton. Here the price varies from 30,000 to 100,000 yen per ton.

The change in net benefit is shown in Figure 5.1. The important thing here is, even though the net benefit itself is largely changed and even becomes positive with a high price, the optimal rate of recycling does not change much. With a low price, the optimal recycling rate is 75.1%, and with a high price, 80.1%. Since “r” must be less than 80%, this means that the optimal rate is 80%.
Recycling Cost

The cost function of recycling consists of two parts, the purchase of old paper and other costs. As for the old paper price, one small model was assumed to present the curve in Figure 2.3 mathematically. In this model, the only factor that is supposed to vary is the minimum cost point. Here, three additional models are used. Each model has a price function as shown in Figure 5.2. In the basic model, the minimum point is assumed to be at 66% of the recycling rate. In additional ones that is assumed to be 60%, 70%, 80%.

The result is in Table 5.1. In this case, the change in net benefit is not so large. However, the optimal recycling rate changes greatly, especially in the case of the model with the highest peak (minimum cost at 80%). With this case, the optimal recycling rate is 86.8%. However, since r must be less than 0.8, the optimal rate is 0.8.

This must be considered well. Since this function of price of old paper is just an assumption and supporting data is not enough, this is not sure. However, even though this sensitivity analysis shows the possibility of failure, this sensitivity analysis tells us the following. The minimum cost point can vary by the social situation. For example, if voluntary prior separation is practiced more, the recycling rate at the minimum cost point goes up. Hence, if we can make this, the optimal recycling rate dramatically goes up. Other than voluntary prior separation, voluntary collection system should be
Figure 5.2 Old Paper Price

Table 5.1 Sensitivity Analysis: Price of Old Paper

<table>
<thead>
<tr>
<th>Minimum cost</th>
<th>Optimal r</th>
<th>Price</th>
<th>$C_R$</th>
<th>Social NB</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ 66%</td>
<td>0.778</td>
<td>16262.987</td>
<td>107000000000</td>
<td>-14400000000</td>
</tr>
<tr>
<td>@ 80%</td>
<td>0.868</td>
<td>8800.904</td>
<td>97000000000</td>
<td>27200000000</td>
</tr>
<tr>
<td>@ 70%</td>
<td>0.797</td>
<td>14698.736</td>
<td>106000000000</td>
<td>-5000000000</td>
</tr>
<tr>
<td>@ 60%</td>
<td>0.717</td>
<td>18607.387</td>
<td>105000000000</td>
<td>-31200000000</td>
</tr>
</tbody>
</table>
Other costs are assumed to be constant at 23,000 yen per ton. This is not supposed to vary a lot. In this analysis, it varies from 11,500 to 46,000 yen per ton. The result is shown in Figure 5.3. With low cost, the optimal recycling rate is 78.7%, and with high cost, 75.4%. This does not seem to be significant.

**Land Price**

In the basic model, the price of land in the cheapest area around Tokyo Bay is used. The newly landfilled land is without any urban development. Considering the scarcity of land in the Tokyo area, urban development will no doubt occur after the landfill is closed. The price itself may vary, but not a lot. In the Tokyo Bay area, the price of some land is five times higher than the cheapest. The price depends on the extent of development and the most expensive area is well developed. Hence, the price of land without development cannot be higher than the highest.

In the basic simulation, $P_{\text{land}} \cdot B$ is equal to 8,772. Then in this analysis, this value vary from 8,772 to 43,860.

The result is shown in Figure 5.4. With the highest estimated price of land, the optimal recycling rate is 73.8%. This does not seem significant. With this case, the higher the recycling rate becomes, the smaller the effect on social net benefit becomes.
Figure 5.3 Sensitivity Analysis: Fixed Part of Recycling Cost
Figure 5.4 Sensitivity Analysis: Land Price
Disposal Cost

The cost of disposal consists of the operation cost and the building cost of the landfill site. Since the constant value is vanished in the first derivative, the building cost of the landfill site does not matter with optimal rate. Then in this section, only the operation cost may vary.

Thus, the cost data is exact. Considering that wastepaper is only a part of total waste, even if the amount of wastepaper changes, the operation cost per unit should not change dramatically.

In the basic simulation, the disposal cost is set as 52,807 yen per ton. It varies from 26,000 to 105,600 yen per ton. The result is shown in Figure 5.5. With the high cost, the optimal recycling rate is 80.5%, and with the low cost, 73.1%. Since \( r \) must be less than 0.8, at high cost, the optimal recycling rate is 80%.

The Effect of Charging Business Firms for General Waste Management

In my model, the revenue from charging businesses is ignored. The reason is mainly the shortage of data. Firms are charged 5 yen for 1,000 cubic centimeter. According to the Bureau of Waste Management, this amount of waste weighs 0.19 kg on average. This means that the Metropolitan Government would receive 26,315 yen for each ton of waste from firms.
Figure 5.5 Sensitivity Analysis: Operation Costs of Disposal
However, currently no punishment for this violation. No one checks. Hence, to make this system work properly, all business firms must be too honest to ignore this system. No one knows whether this system is working as expected. This is the reason why this term is cut in the original simulation. There is no data for how many firms pay honestly.

Assuming if all firms pay honestly, considering that 48.4% of wastepaper from business firms, this can be expressed by adding

\[ 26315 \times 0.484 \times (1 - r)W = 12736.46 \times (1 - r)W \]

to \( \pi_L \). Then \( \pi_L \) is as follows:

\[ \pi_L = (8772 + 12736.46) \times (1 - r)W = 21508.46(1 - r)W \]

In this case, the optimal rate is 76.6%. However, this sounds ridiculous, because this policy should lower the recycling rate first, then raise it.

There is one complicated issue here. The Bureau of Waste Management expects a 10% reduction of general waste from business firms by using this system, not that the amount of waste would decrease but that firms would separate their recyclable wastes prior to dumping them. Then, this system is not expected to reduce \( W \) a lot, but \( C_R \) is expected to decrease by the effort of prior separation. There is no data to calculate this effect. But in reality, \( r \) must go up.
Summary of Sensitivity Analysis

As a result of the sensitivity analysis, the second reason for the huge difference between current and optimal recycling rate seems to be denied. At least, it is clear that data problem does not explain everything.

Except for the price of old paper, every term is a linear function of “r.” The effect on both the recycling rate and the net benefit is determined by the size of the value. Because of this, the price of land has little effect. Neither does the fixed part of the recycling cost.

The effect of the change in the function of the price of old paper seems slightly different. The change in the optimal recycling rate for wastepaper management is significantly large. This has two meanings. The first is that this function must be considered carefully. And the second and more important one is as follows; if we can make the minimum cost point (the recycling rate where the price of old paper is minimum) go up, the optimal recycling rate goes up significantly.

The effect of charging business firms for general waste disposal is difficult to know right now. Because this system has an effect on the collecting cost of old paper and since this system is new, this effect is difficult to evaluate.
Constraint by Whiteness

Another issue ignored in this simulation is the whiteness issue. If customers did not care about the whiteness of the paper products, the recycling rate could reach 80%. However, most customers do. They care not only about whiteness but also about the strength of the paper products. Low quality printing paper sometimes can contain 100% of old pulp. Higher quality printing paper can contain only 20%, and sometimes not any. The relationship between old pulp content of various papers is shown in Table 5.2. Assuming the two “N/A”s add up to 50%, old pulp can be contained in only 67% of paper produced.

This 67% is not the recycling rate, at least different from my definition of “r”. As before, assuming that wastepaper accounts for 90% of the paper production, 67% is converted to 74%. This is fairly rough estimate, but unfortunately no better information is available.

The above explains part of the difference between the current and the optimal recycling rate. A point to remember in this discussion is that the rate can be changed not only by technology but also by customer preferences concerning whiteness. If demand for whiteness decreases, this value becomes more than 74%. Of course this preference itself is not necessarily a bad idea. However, to increase the demand for paper with recovered pulp, this issue is worth reconsidering.
Table 5.2 Content of Old Pulp in Various Papers

<table>
<thead>
<tr>
<th>Type of Paper</th>
<th>Production [1000 tons] in 1997</th>
<th>Contain ratio [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Total</td>
<td>18268</td>
<td></td>
</tr>
<tr>
<td>Newspaper</td>
<td>3192</td>
<td>40</td>
</tr>
<tr>
<td>Printing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High quality</td>
<td>3529</td>
<td>0-20</td>
</tr>
<tr>
<td>Low quality</td>
<td>5722</td>
<td>40-100</td>
</tr>
<tr>
<td>Copy</td>
<td>1841</td>
<td>70-80</td>
</tr>
<tr>
<td>Sanitary</td>
<td>1715</td>
<td>100</td>
</tr>
<tr>
<td>Others</td>
<td>1160</td>
<td>N/A</td>
</tr>
<tr>
<td>Paperboard total</td>
<td>12747</td>
<td></td>
</tr>
<tr>
<td>Paperboard containers</td>
<td>9425</td>
<td>80</td>
</tr>
<tr>
<td>Paper articles</td>
<td>2236</td>
<td>60-70</td>
</tr>
<tr>
<td>Others</td>
<td>1086</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Source: Production: Ministry of International Trade and Industry the government of Japan, YEARBOOK OF PAPER AND PULP STATISTICS 1997

Optimality for Private Firms

One complicated issue has been left untouched. In this simulation, the optimal recycling rate for wastepaper management is derived as 77.8%. However, the current recycling rate is determined by private paper companies, not by social planners.

For paper companies, of course, there is the alternative of virgin pulps for paper production, when virgin pulps are cheaper than old pulps, virgin pulps are used. This issue is too complicated to be included in this analysis. The price of virgin pulps is unstable, not only by market conditions, but also largely by other factors, such as weather.

Paper companies think the current recycling rate is almost optimal for them. (Information gathered through a phone survey.) The implications are too important to ignore. If social planners try to achieve this optimal recycling rate, they will have to consider policies for promoting recycling to paper companies. This private optimality issue must be the most significant reason for the difference between current and optimal recycling rates.

Currently, only the container packaging recycling law obliges producers to do some recycling. But this law is concerned only with containers and packaging, which are difficult to recycle. Further policies are needed. There are couple of things done in order to promote the collection of recyclable wastes - collection of recyclable wastes by
municipalities and charging fees to business firms for general waste disposal. Government policies to consider might include, an obligation to recycle according to the amount of production, or charging virgin product producers for waste disposal.

Potential for Reducing Wastes and Net Benefit through Recycling

From the previous discussion, the current recycling rate is 57.7 %, and the optimal rate is derived as 77.8 %. If this optimal rate is achieved,

\[ W \times (0.778 - 0.577) = 3,529,267 \times 0.201 = 709,383 \]

709,383 tons of wastepaper are saved from disposal. Almost all of this reduction is from general wastes. Considering that the total amount of general waste was 4,004,247 tons in 1997, the reduction amounts to 17.7% of total general waste.

As for final disposal, paper is combustible and loses 85% of its weight after incineration, this reduction is still 106,408 tons after incineration. Considering the total amount of wastes disposed in the final disposal site is 1,620,276 tons, this is a 6.6% reduction in final wastes.

Also if the 77.8% of the recycling rate is achieved, the net loss is reduced by 34,667,352,390 yen.
Chapter 6

CONCLUSION

Conclusions

The current recycling rate in Tokyo is not optimal from the waste management point of view. The current recycling rate is 57.7% in my definition, and the optimal rate for the whole waste management system is 77.8%.

By achieving this optimal recycling rate, under current condition final wastes can be reduced by 106,408 tons per year, that is 6.6% of total final wastes. By achieving this rate, we can also reduce net losses to the waste management system by 34 billion yen.

In order to achieve this waste reduction and reduction in net loss, the reasons for the current recycling rate being so much less than optimal should be known. There are two main reasons:

1. For private paper producing companies, the current rate is almost optimal.
2. Because of customer desire for whiteness, the 77.8% can not be achieved.

Considering the first reason, the result of 77.8% is optimal for whole waste management system. Then, some policies or incentives, which make recyclers concerned
about whole waste management system, not only recycling but also disposal, are recommended.

As for the second, the most important issue is that the problem can be solved by changing people's ideas without technological changes or economic incentives. The Office Neighborhood Association tries to promote paper with less whiteness. The Japanese have a tendency to appreciate high whiteness as a symbol of luxury and cleanliness. This is not necessarily a bad idea; however, there are many possibilities to expand the use of paper that is a little less white.

The excess supply problem in the old paper market, in the short run, should lead to price reductions and make recycling cost less. However, in the long run, paper collection companies hesitate to expand or even shrink their business, because their profit decreases. Hence, this excess supply leads to a smaller supply of old paper in the long run.

Since one of the motivations of this research is the shortage of final disposal sites, the optimal recycling rate for the whole waste management system is derived. Of course, the result is different from the optimal rate for private paper companies. One of the reasons for this is that private companies are not concerned with the waste disposal system of the whole society.

From these, the followings are recommended to social planners.
1. In order to avoid the shortage of old paper supply, promote old paper collection to both collecting companies and those who generate wastes. The container packaging recycling law is one good solution, for promoting recycling of material that is difficult to recycle. Charging business firms for the general waste management is also a solution. Further policies promoting prior voluntary separation are required. The voluntary separation by waste producers reduces collection costs. Hence, profit for the waste paper collection companies, and they will expand their business.

2. The end users' preference for high whiteness is the constraint in the demand for paper made with recovered pulp. This is not necessarily a bad idea, but still worth reconsidering, because this can be changed without any technological advance but with the change of consumer preferences.

3. Paper producing companies should be encouraged to recycle. In addition, discouraging them from using virgin materials is a good idea. In this case, the container packaging recycling law is a solution, too, but not enough. Much stronger policies are required.

4. As mentioned before, this research ignores thermal recycling, since it is not well practiced now in the Tokyo area. For this, more research and development for effective use of heat is required. Since almost all of the wastepaper not recycled is incinerated before landfill, 100% recycling can be achieved with the combination of material and
thermal recycling.

Since the media is shifting to digital, the demand for paper may decrease. However, there is now no such tendency. About half of the combustible general waste in Tokyo is paper. Since the shortage of final disposal sites is a huge problem, social planners should try harder to achieve the optimal recycling rate of 77.8%.

Future Work

In the research here, the current situation of wastepaper management is made clear. First of all, the term of external effect of recycling should be reconsidered, especially environmental issues and the user cost for use of landfill space.

The optimal recycling rate from waste management’s point of view is derived, and unfortunately the current recycling rate is far from it. Since the current recycling rate is optimal for private paper companies, some policies for promoting recycling are required. For this purpose, policy analysis should occur as the next stage of research. Whether the current recycling rate is strictly optimal for private companies should be confirmed.

In order to avoid the uncertainty from the lack of data, the analysis here is a static one. However, the results can be compared with results from dynamic analysis. Basically, my model can be easily expanded to a dynamic one.
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