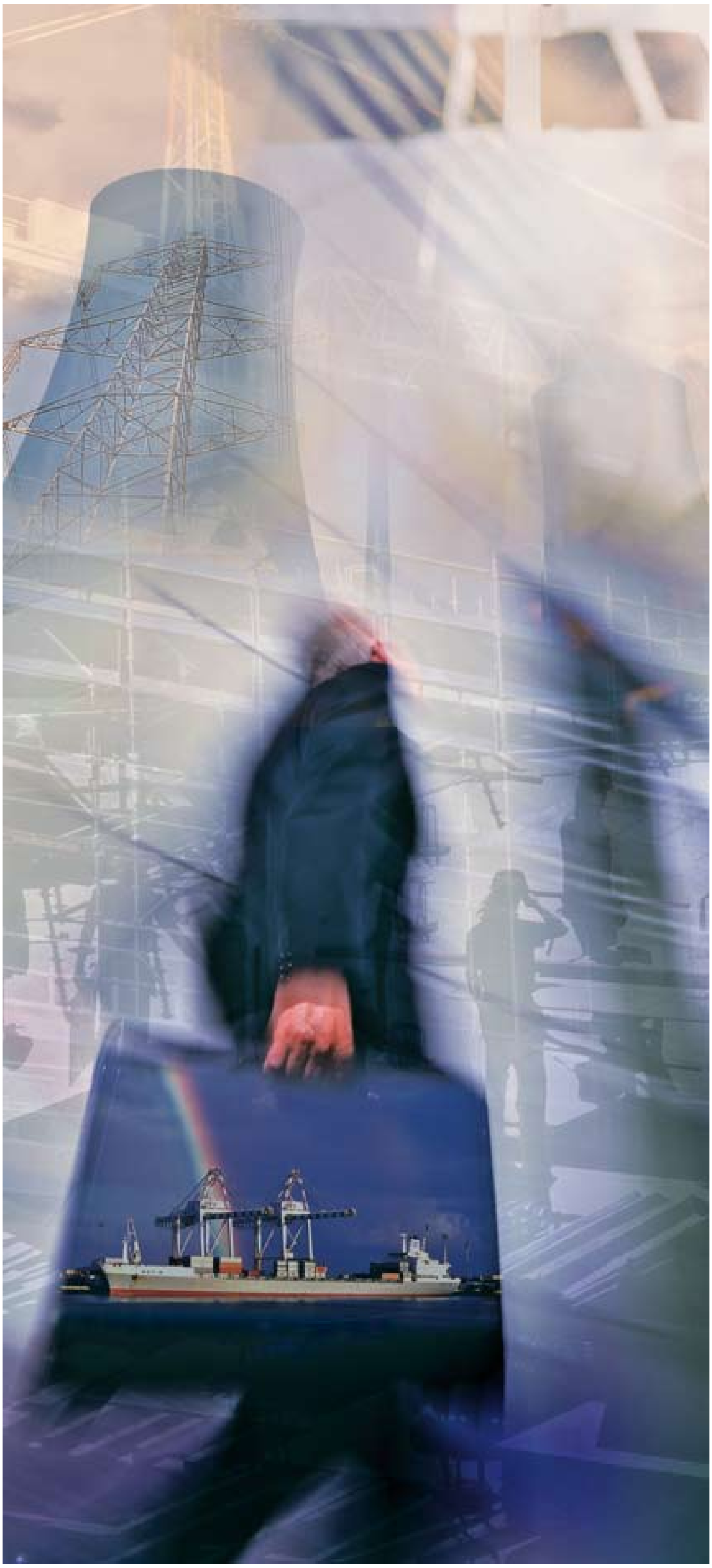


Queensland

The Economic Society of Australia Inc.

# Proceedings of the 37th Australian Conference of Economists

# Papers delivered at ACE 08

30th September to 4th October 2008

Gold Coast Queensland Australia

ISBN 978-0-9591806-4-0

# Welcome

The Economic Society of Australia warmly welcomes you to the Gold Coast, Queensland, Australia for the 37th Australian Conference of Economists.

The Society was formed 83 years ago in 1925. At the time, the Society was opposed to declarations of policy and instead focused on open discussions and encouraging economic debate. Nothing has changed today, with the Society and the conference being at the forefront of encouraging debate.

This year we have a large number of papers dealing with Infrastructure, Central Banking and Trade.

Matters of the greatest global importance invariably boil down to be economic problems. Recent times have seen an explosion of infrastructure spending, after world-wide population growth has seen demand outpace aging supply. The world has become more globalised than at any time since World War I but the benefits of this (and the impact on our climate) has been questioned by some.

At the time of preparing for this conference we could not have known that it would have been held during the largest credit crisis since the Great Depression. The general public and politicians both look to central banks for the answers.

We are also very pleased to see a wide selection of papers ranging from applied economics to welfare economics. An A – Z of economics (well, almost).

Another feature of this conference is that we have gone out of our way to bring together economists from all walks of life, in particular from academia, government and the private sector. We are grateful to all of our sponsors, who are as diverse as the speakers.

### The Organising Committee

James Dick
Khorshed Alam (Programme Chair)
Michael Knox
Greg Hall
Allan Layton
Rimu Nelson
Gudrun Meyer-Boehm
Jay Bandaralage
Paula Knight

Published November 2008

GPO Box 1170
Brisbane Queensland Australia
ecosocqld@optushome.com.au

### Our Gold Sponsors

QIC

AUDAX AT FIDELIS
QUEENSLAND TREASURY CORPORATION

Reserve Bank of Australia

Queensland Government
Department of Infrastructure and Planning

### Keynote Sponsors

Australian Government
Productivity Commission

Australian Government
The Treasury

QUT
Queensland University of Technology
Faculty of Business
School of Economics and Finance

The University of Queensland
Australia

Goldman Sachs JBWere

The University of Queensland
Australia

NCER National Centre for Econometric Research

ES Central Council

### Special Session Sponsors

Griffith University

The Higher Education Academy Economics Network

Unless we have specifically been requested to do otherwise, all the papers presented at the conference are published in the proceedings in full. A small number of papers will have versions that have also been made available for special editions of Journals, Economic Analysis and Policy, and the Economic Record. Authors will retain the right to seek additional publication for papers presented at the conference so long as it differs in some meaningful way from those published here.

The opinions expressed in the papers included in the proceedings are those of the author(s) and no responsibility can be accepted by the Economic Society of Australia Inc, Economic Society of Australia (Queensland) Inc, the publisher for any damages resulting from usage or dissemination of this work.

The Paper following forms part of - *Proceedings of the 37th Australian Conference of Economists*
ISBN 978-0-9591806-4-0

# Recycling versus Landfilling: A Cost Minimization Approach to Municipal Waste Management*

Hide-Fumi Yokoo

*Graduate School of Economics, Kyoto University*

*JSPS Research Fellow*

May 2008

**Abstract**

Consider a municipality that must design a waste management program that integrates recycling and landfilling. This paper analyzes a simple utility maximization problem of a representative household incorporating waste disposal. Even if recycling entails some initial costs and a marginal cost that rises in proportion to recycling, recycling or a dual waste management policy is, nevertheless, optimal for a local government. By determining the relationships among the marginal cost of landfilling, recycling, initial costs, and household in-

*This work was supported by a Grant-in-Aid for JSPS Fellows 20-5428.

come, conditions are identified under which recycling will reduce total waste management costs adequately, so that municipal recycling will be optimal.

## 1 Introduction

The processing of solid household waste has become an increasing problem in many countries. Until recently, the most popular method for treating nonhazardous solid waste has been to place it in landfills. However, there is another way to process solid waste, i.e., recycling. Developed countries, such as the United States, Germany, and Japan, have recognized the benefits of recycling. Municipal recycling by local goverments is being encouraged by the legislatures of these countries. Although many municipalities are developing new waste management programs based on recycling, there still remain some questions. Is it really costless to recycle municipal waste? If so, then how much should we recycle? This paper studies the optimal conditions of waste management. In particular, we show that in a situation where households do not gain any utility from recycling, there still exists a condition in which recycling is less costly than landfilling.

Some economists considered that recycling waste is too expensive. For example, William Baumol was suspicious about recycling [1]. Highfill and McAsey [6] presented interesting controversy to us.

In the present paper, we investigate the optimal levels of recycling in terms of waste management cost. We assume that a community has two different waste management alternatives. The first is landfilling and the second is recycling, and both alternatives require some costs. We are not concerned with the resource scarcity and the disutility from the waste. We will compare recycling and landfilling from the viewpoint of minimizing waste management cost.

Landfilling involves some cost per unit of waste, which is assumed simply to be a constant. On the other hand, the expense of recycling rises as the amount of waste that is recycled increases. Therefore, the cost of recycling per unit of waste is dependent on the proportion of the waste processed by recycling. In addition, if a municipality chooses to recycle, then it must provide for some initial costs. This can be recognized as the cost of establishing a recycling center or infrastructure. The model presented in this paper is fundamentally static. Under several conditions, we show that there are cases in which recycling is more advantageous to a municipality and cases where using both alternatives are optimal. Also, we demonstrate the optimal recycling proportion in the case of dual waste management.

The next section provides a brief summary of the literature focusing on the waste management cost. Section 3 presents the formal model. Section 4 analyzes three cases: one in which landfilling is the best alternative; another in which recycling is the best; and the third in which dual management is the most favorable. Section 5 provides a summary of our results.

## 2 Summary of the literature

Since the 1970s, economists have investigated waste management and recycling. In earlier studies, waste was considered as pollution. Dynamic models including those by Plourde [12], Smith [13], and Lusky [9] assumed recycling as an option to increase consumers' utility or decrease the stock of pollution.

Over the past decade, several studies have been made on recycling. Fullerton and Kinnaman [3] studied the policy options including a Pigouvian tax on recycling, Highfill and McAsey [6] considered the space constraints of landfilling, Fullerton and Wu [4] analyzed recycling and product design, and Higashida and Jinji [5] investigated countries' strategic choices of recovery rates with international trade. Although these papers investigated recycling as waste management, they did not include management cost in the model explicitly.

Some past studies discussed recycling from the viewpoint of waste management cost. Eichner and Pethig [2] considered policies encouraging green product design. They used a general equilibrium model that includes extracting material, recycling, and waste treatment. The material is modeled as being embodied in consumption goods through a production process. After the goods are consumed, they are turned into residuals. Residuals can be the inputs to generate materials with the help of a recycling process. The "recyclability" of residuals depends on the proportion of material contained in the goods. It means that the recycling costs decrease as the material content of residuals increases. Eichner and Pethig's model had an interesting formulation about recycling costs, but they did not consider disposing (such as landfilling) costs since their focus was on the production design.

Morris and Holthausen [10] developed a model that describes a household's waste generation and disposal behavior. They examined the interaction among household preferences, their waste production options, and costs or fees for waste collection. In their model, they assumed that waste collection entails a fixed fee that is irrelevant to the amount disposed. They also assumed marginal cost for waste collection and recycling. Their specification is similar to our model, except that marginal cost of recycling is constant.

The model closest to ours can be found in Highfill et al. [7]. The main aim of their model was to examine the optimal location of a recycling center. They considered a rectangular shaped area in which households are distributed uniformly. The households should dispose waste at the landfilling area or recycling center. Disposal of waste entails a transportation cost per unit of waste. Further, the municipality chooses a recycling center location that minimizes the total transportation costs. Therefore, they described waste management cost explicitly in their model.

Huhtala [8] has an interest very similar to the present paper. He developed an optimal control model that includes physical costs of recycling, the social costs of landfilling, and consumers' environmental preferences. Although he accounted for the external costs of waste management, we ruled out the social costs. Also, Huhtala's model is dyanamic and considering about long-term problem, while the present model is static and examines a short-term problem of municipal decision making.

There is one planning period in which a municipality determines whether or not to establish a recycling facility, and if it does, then how much it recycles. Dynamic considerations such as the eventual closing of the landfill or accumulation of waste are not considered. To a certain extent, the model concentrates on answering the question: what conditions indicate that the city should engage in a municipal recycling? The next section describes landfilling and recycling costs.

# 3 A model of waste management

## 3.1 The basic framework

It is assumed that waste is a fixed fraction of consumption, i.e., $w = (1-\alpha)c$, where $\alpha$ is the proportion of consumption that local governments do not have to process and $c$ is the amount of goods consumed. Note that $\alpha$ might be greater than zero because some consumption does not generate waste.

There are two ways to manage waste: landfilling and recycling. The cost of landfilling is assumed simply to be a constant, $\beta$, per unit of waste. If a municipality decides to landfill all the waste generated, then the cost of waste management is $\beta w$.

However, when a municipality decides to recycle some waste, then it incurs some initial cost. This can be recognized as the cost of establishing recycling facilities. The fixed initial cost for the municipality is denoted by $F$. After constructing a recycling center, the municipality decides the quantity to recycle. I denote $\gamma \in [0, 1]$ for the fraction of waste that the municipality recycles. It is assumed that the cost of recycling per unit of waste increases exponentially as $\gamma$ rises. This can be considered as a technology constraint. As $\gamma$ reaches 1, the cost of recycling per unit of waste will increase. Thus, the marginal cost of recycling is $s(\gamma + 1)$, where $s$ is a given coefficient. To simplify the language, this coefficient will be called the"recycling parameter". I add 1 to $\gamma$ since $\gamma \leq 1$. If the municipality decides to recycle all the waste generated, which means $\gamma = 1$, then the cost of waste management is $2sw$.

There are $N$ consumers in this municipality. The total costs of waste management for a representative consumer, $Z(\gamma)$, can be written as

$$Z(\gamma) = \begin{cases} \beta(1-\alpha)c, & \gamma = 0 \\ [\gamma\, s(\gamma+1) \; + \; (1-\gamma)\beta]\,(1-\alpha)c \; + \; f, & \gamma \in (0,1] \end{cases} \tag{1}$$

where $f = F/N$.

Let $U(C)$ be a utility function and assume that $U$ is concave. The price of the good is set to be 1. The income of a representative consumer is given as $I$, and $I$ is sufficiently larger than $f$. Then, the problem for a household is

$$max_c \quad U(c)$$

$$s.t. \quad c + Z(\gamma) \leq I$$

Households wish to maximize their utility, which depends only on the aggregate consumption good $c$, which is taken as the numeraire. It should be noted that recycling does not generate utility by itself. Thus, after paying for their share of waste management and recycling costs, households spend the rest of their income on consumption. Therefore, the budget constraint for the representative household can be written as

$$c \leq I - Z(\gamma) \tag{2}$$

The problem for the consumer is to choose consumption $c$ and the percentage of municipal recycling $\gamma$ to maximize $U(c)$ subject to the budget constraint

(2). Since the utility function is increasing, it is necessary to consider only the budget constraint and select the value of $\gamma$ that gives the largest consumption $c$. Therefore, the objective of a municipality in the model is to find the optimal fraction of recycling $\gamma$ to maximize the consumption $c$.

## 3.2 The budget constraint

In this section, I use an approach presented by Highfill et al. [7].

To examine the budget constraint, it will be helpful to rewrite (2) using (1)

$$c \le I - \beta(1-\alpha)c, \quad \gamma = 0$$

$$c \le I - [\gamma\, s(\gamma+1) + (1-\gamma)\beta]\,(1-\alpha)c + f, \quad \gamma \in (0,1]$$

On rearranging these inequalities so that consumption $c$ is expressed as a function of the percentage level of municipal recycling $\gamma$, we deduce

$$c \le \frac{I}{1+\beta(1-\alpha)} \equiv H, \quad \gamma = 0 \tag{3}$$

$$c \le \frac{I-f}{1+[\gamma\, s(\gamma+1) + (1-\gamma)\beta]\,(1-\alpha)} \equiv h(\gamma), \quad \gamma \in (0,1] \tag{4}$$

A municipality should select the fraction of recycling $\gamma$ to maximize the right-hand side of (3) or (4).

Let us begin with examining $h(0)$. When $\gamma = 0$, the denominators of (3) and (4) are equivalent. Thus, $h(0)$ is always lower than $H$. This result is deduced from the initial costs of recycling.

Further, the first derivative of $h(\gamma)$ is obtained as

$$h'(\gamma) = \frac{(I-f)\,[2(1-\alpha)s\gamma + (1-\alpha)(s-\beta)]}{\{1+[\gamma\, s(\gamma+1) \;+\; (1-\gamma)\beta]\,(1-\alpha)\}^2} \tag{5}$$

Note that the denominator of (5) is always positive for $\gamma \in (0,1]$. Whether $h'(\gamma)$ is positive or negative for $\gamma \in (0,1]$ depends solely on the numerator. Since we assumed $I$ is larger than $f$, our main interest is in the brackets. As an $\alpha \in (0,1)$ is fixed, then the relation between $\beta$ and $s$ is our next concern. If $h(\gamma)$ is a decreasing function for $\gamma \in [0,1]$, then optimal waste management entails simply to landfill all the waste. If it is increasing or it has the largest value in the range of $\gamma = 0$ to 1, then we need to take a closer look at the parameters.

# 4 Recycling versus landfilling: A cost minimization approach

In this section, we will examine the effect of the relationships between $\beta$ and $s$ on the consumption level. Since $I$ is sufficiently larger than $f$, the function $h(\gamma)$ is always nonnegative. Inserting (5) equal to 0 and rearranging it, we deduce

$$\gamma = \frac{\beta - s}{2s} \tag{6}$$

This gives the maximum level of $h(\gamma)$. The relationship among landfilling cost $\beta$, the recycling parameter $s$ and the consumption level $h(\gamma)$ is summarized as follows:

($a$) If $(\beta - s)/2s \leq 0$, then $h(\gamma)$ is a decreasing function for $\gamma \in (0, 1]$.

($b$) If $(\beta - s)/2s \geq 1$, then $h(\gamma)$ is an increasing function for $\gamma \in (0, 1]$.

($c$) If $0 < (\beta - s)/2s < 1$, then there is a maximum point for $\gamma \in (0, 1]$.

On rewriting these conditions, we obtain three cases:

($a$) $\beta \leq s$,

($b$) $s \leq \frac{\beta}{3}$,

($c$) $\frac{\beta}{3} < s < \beta$.

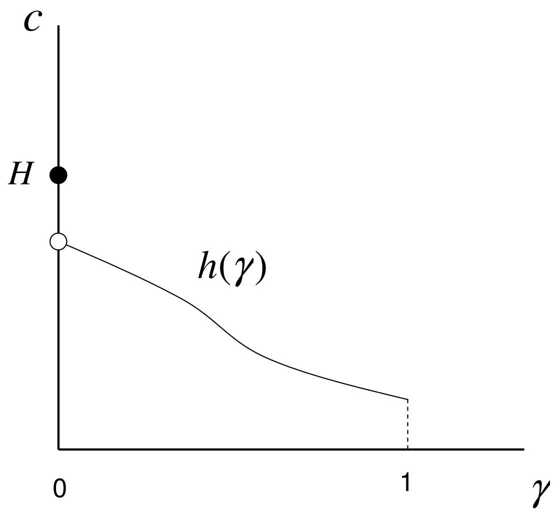
In the sections bellow, we examine these three cases precisely.

### 4.1 The case of no recycling: $\beta \leq s$

When $\beta \leq s$, then the maximum point of function $h(\gamma)$ is nonpositive. It means that the form of function $h(\gamma)$ is downward sloping for $\gamma \in (0, 1]$. Figure 1 illustrates this form.

As mentioned before, $h(0)$ is always smaller than $H$. Therefore, a municipality should choose not to recycle in this case. When they decide to engage in recycling, it always costs more than landfilling. Therefore, if the recycling fraction $\gamma$ is zero, they will landfill all the waste generated.

Figure 1: The graph of $h(\gamma)$ when $\beta \leq s$



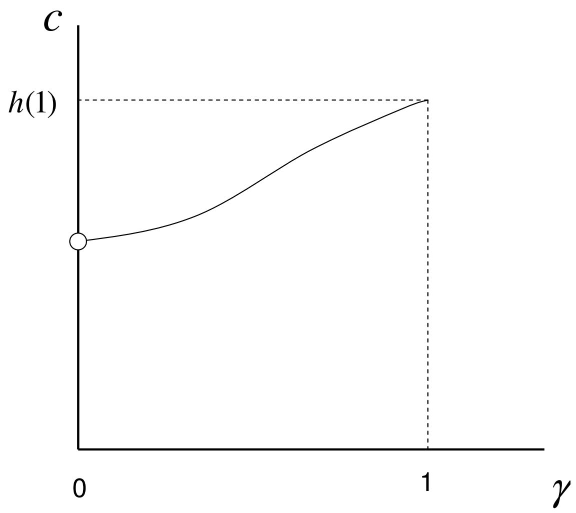

## 4.2 The case of full recycling: $s \leq \frac{\beta}{3}$

Further, we consider the case in which the recycling parameter is relatively very small. When the relationship of $\beta$ and $s$ is $s \leq \frac{\beta}{3}$, then the maximum value of function $h(\gamma)$ is larger than $\gamma = 1$. Thus, the form of function $h(\gamma)$ is upward sloping for $\gamma \in (0, 1]$. Figure 2 illustrates this form.

In this case, the municipality compares landfilling with the recycling program.

Since $h(\gamma)$ is upward sloping for $\gamma \in (0, 1]$, it takes the largest consumption level at $\gamma = 1$. The municipality should compare $H$ with $h(1)$ to decide the waste management program. The difference $h(1) - H$ gives us a simple indication. If it is larger than 0, then the municipality should recycle all the

Figure 2: The graph of $h(\gamma)$ when $s \leq \frac{\beta}{3}$




waste generated. Inserting $\gamma = 1$ to (4), we get

$$h(1) = \frac{I - f}{1 + 2(1-\alpha)s}$$

Then, $h(1) - H > 0$ can be written as

$$\frac{I - f}{1 + 2(1-\alpha)s} - \frac{I}{1 + (1-\alpha)\beta} > 0$$

Rearranging this for $s$, we get

$$s < \frac{I - f}{2I}\beta - \frac{f}{2I(1-\alpha)} \equiv J \tag{7}$$

Whether $s$ is larger than $J$ or not depends on the parameters $(\alpha, \beta, I, f)$. If $J < s$, then the municipality shall choose not to recycle. (This is illustrated

Figure 3: $s \leq \frac{\beta}{3}$, $J \leq s$

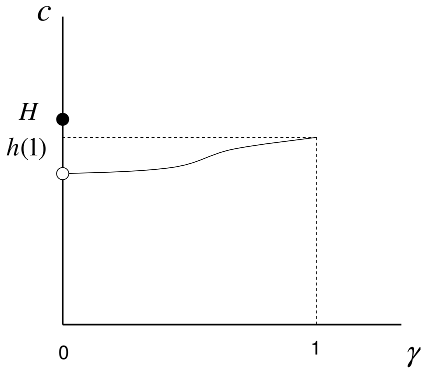
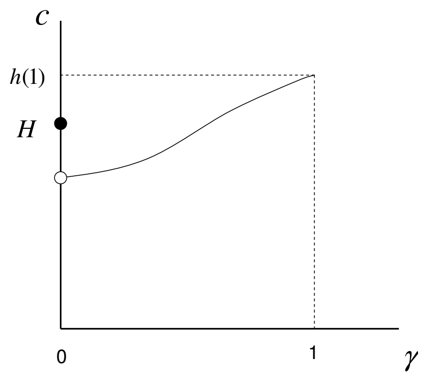



Figure 4: $s \leq \frac{\beta}{3}$, $s < J$

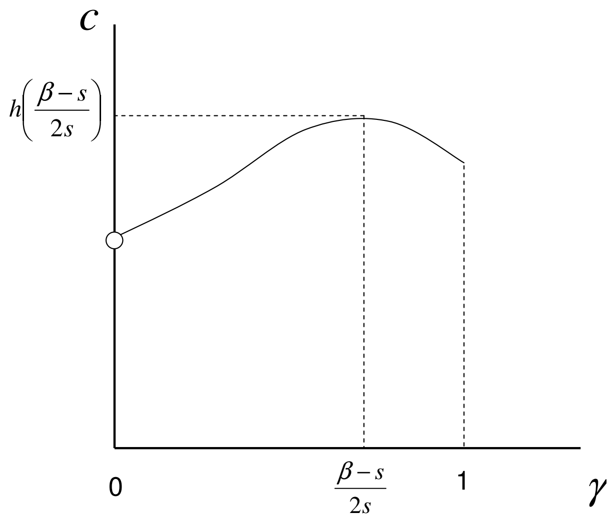



in Figure 3.) If $s < J$, then a municipality shall choose all the waste to recycle, which means $\gamma = 1$. (This is illustrated in Figure 4.)

### 4.3 The case of dual waste management: $\frac{\beta}{3} < s < \beta$

For $\beta/3 < s < \beta$, the largest value of $h(\gamma)$ depends on $\gamma \in (0, 1]$. As discussed above, function $h(\gamma)$ takes its maximum value at point $\gamma = (\beta - s)/2s$. If the municipality decides to recycle, it is optimal when the recycling fraction

Figure 5: The graph of $h(\gamma)$ when $\frac{\beta}{3} < s < \beta$



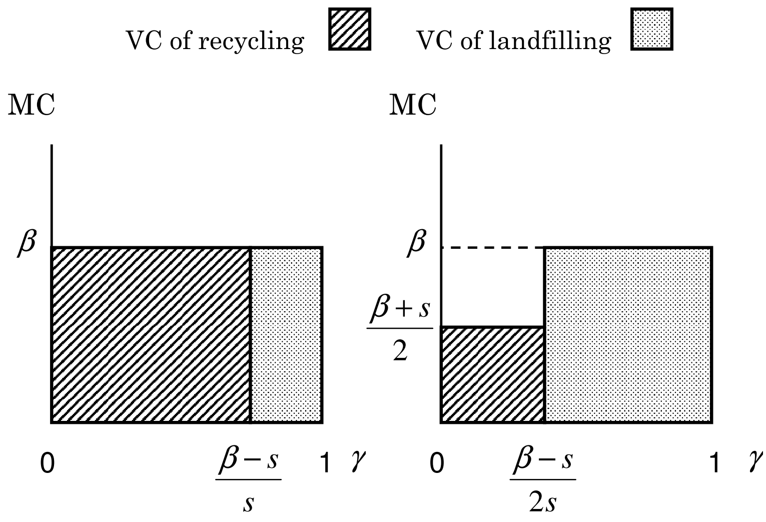

is $\gamma = (\beta - s)/2s$. It means they will landfill $1 - [(\beta - s)/2s]$ of the waste. Therefore this is a dual waste management policy, involving both recycling and landfilling. The situation where $\gamma = (\beta - s)/2s$ gives the maximum value of $h(\gamma)$ is illustrated in Figure 5.

At this fraction, the marginal cost of recycling is

$$\begin{aligned} s(\gamma + 1) &= s(\frac{\beta - s}{2s} + 1) \\ &= \frac{\beta + s}{2} \end{aligned}$$

This differs from the marginal cost of landfilling $\beta$. To an extent, it is smaller than $\beta$ in the case of $\frac{\beta}{3} < s < \beta$. This result comes from the characteristic of the recycling cost. For the benchmark, let us now consider the case in which

Figure 6: Comparison of two cases $\gamma = \frac{\beta - s}{s}$ and $\frac{\beta - s}{2s}$




the marginal costs of recycling and landfilling are equal:

$$\begin{aligned} s(\gamma + 1) &= \beta \\ \gamma &= \frac{\beta - s}{s}. \end{aligned}$$

The variable cost for a unit of waste (cost of waste management without fixed cost of recycling) in this case and the optimal case is illustrated in Figure 6. The vertical axis is the marginal cost and the horizontal axis is the fraction of recycling. The shaded area is the variable cost of both landfilling and recycling per unit of waste. Since marginal cost of recycling changes with the proportion of recycling, marginal cost of recycling and landfilling differ at the optimum.

To decide whether to recycle or not, the municipality should compare $H$

with $h((\beta - s)/2s)$. If $h((\beta - s)/2s)$ is larger than $H$, then the municipality should decide to adopt dual waste management. If not, it should simply landfill all the waste.

$h((\beta - s)/2s) - H$ provides a simple indication. If it is larger than 0, then the municipality should choose the dual policy. Inserting $\gamma = (\beta - s)/2s$ to (4), we obtain

$$h(\frac{\beta - s}{2s}) = \frac{I - f}{1 + \left[\frac{\beta - s}{2s}\, s(\frac{\beta - s}{2s} + 1) \; + \; (1 - \frac{\beta - s}{2s})\beta\right](1 - \alpha)}$$

Therefore, $h((\beta - s)/2s) - H > 0$ can be written as

$$\frac{I - f}{1 + \left[\frac{\beta - s}{2s}\, s(\frac{\beta - s}{2s} + 1) \; + \; (1 - \frac{\beta - s}{2s})\beta\right](1 - \alpha)} - \frac{I}{1 + (1 - \alpha)\beta} > 0$$

On rearranging this for $s$, we deduce[1]

$$s < \beta + \frac{2f[1 + (1 - \alpha)\beta] - \sqrt{f[1 + (1 - \alpha)\beta][4I(1 - \alpha)\beta - 1]}}{I(1 - \alpha)} \equiv K \qquad (8)$$

Whether $s$ is larger than $K$ or not depends on the parameters $(\alpha, \beta, I, f)$. If $\beta/3 < s < K$, then the municipality should choose the dual policy, which means $\gamma = (\beta - s)/2s$. (This is illustrated in Figure 7.) If $K < s$, then the municipality should choose not to recycle. (This is illustrated in Figure 8.)

[1] Rearranging the above inequality, we get two conditions. One is $s < K$ and the other is

$$\beta + \frac{2f[1 + (1 - \alpha)\beta] + \sqrt{f[1 + (1 - \alpha)\beta][4I(1 - \alpha)\beta - 1]}}{I(1 - \alpha)} < s.$$

The latter condition is inconsistent with $\beta/3 < s < \beta$; therefore, we focus only on the former condition.

Figure 7: $\frac{\beta}{3} < s < K$

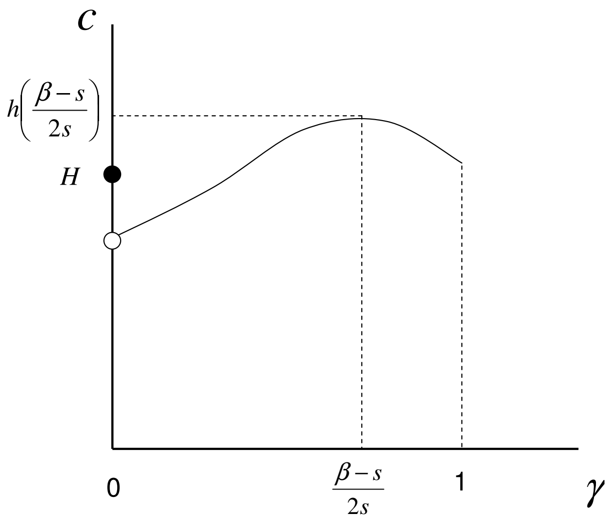
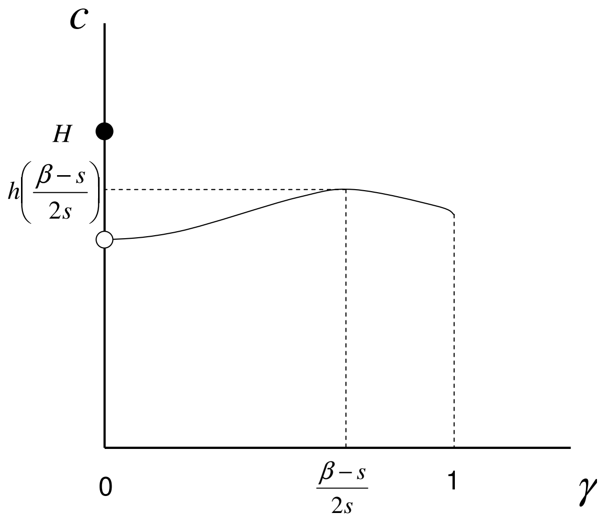



Figure 8: $\frac{\beta}{3} < s < \beta,\ K < s$



# 5 Concluding remarks

In this paper, we analyzed the simple utility maximization problem that incorporates waste management. The relationship between the two parameters, the marginal cost of landfilling and the coefficient of recycling cost, is the focus of the paper. In addition, critical factors that affect the economic optimization of recycling include (1) proportion of consumption that does not generate waste, (2) fixed initial cost of establishing recycling infrastructure, and (3) household income. The model presented in this paper gives several important conclusions. First, the establishment of a municipal recycling program does not require a direct contribution to societal utility from recycling activities. Second, although there is an initial cost and a proportionally increasing marginal cost for recycling, there still exists a case in which recycling is the optimal management policy. Third, in some conditions, a dual policy that includes both recycling and landfilling is preferred.

# References

[1] W. Baumol "On Recycling as a Moot Environmental Issue", *Journal of Environmental Economics and Management*, 4, (1977), 83-87.

[2] T. Eichner and R. Pethig "Product Design and Efficient Management of Recycling and Waste Treatment", *Journal of Environment Economics and Management*, 41, (2001), 109-134.

[3] D. Fullerton and T. Kinnaman "Garbage, Recycling, and Illicit Burning or Dumping", *Journal of Environmental Economics and Management*,

29, (1995), 78-91.

[4] D. Fullerton and W. Wu "Policies for Green Design", *Journal of Environmental Economics and Management*, 36, (1998), 131-148.

[5] K. Higashida and N. Jinji "Strategic use of recycled content standards under international duopoly", *Journal of Environmental Economics and Management*, 51, (2006), 242-257.

[6] J. Highfill and M. McAsey "Municipal Waste Management: Recycling and Landfill Space Constraints", *Journal of Urban Economics*, 41, (1997), 118-136.

[7] J. Highfill, M. McAsey and R. Weinstein "Optimality of Recycling and the Location of a Recycling Center", *Journal of Regional Science*, Vol. 34, No. 4., (1994), 583-597.

[8] A. Huhtala "A Post-Consumer Waste Management Model for Determining Optimal Levels of Recycling and Landfilling", *Environmental and Resource Economics*, 10, (1997), 301-314.

[9] R. Lusky "Optimal taxation policies for conservation and recycling", *Journal of Economic Theory*, 11, (1975), 315-328.

[10] G. Morris and D. Holthausen, Jr. "The Economics of Household Solid Waste Generation and Disposal", *Journal of Environmental Economics and Management*, 26, (1994), 215-234.

[11] K. Palmer, H. Sigman and M. Walls "The cost of reducing municipal solid waste", *Journal of Environmental Economics and Management*, 33, (1997), 128-150.

[12] C. G. Plourde "A model of waste accumulation and disposal", *Canadian Journal of Economics*, 5, (1972), 119-125.

[13] V. Smith "Dynamics of Waste Accumulation: Disposal Versus Recycling", *The Quarterly Journal of Economics*, Vol. 86, No. 4., (1972), 600-616.