Review

An Evaluation of Optimal Application of Government Subsidies on Recycling of Recyclable Waste

Chen, Chung-Chiang*

Graduate Institute of Environmental Management, Nan Hua University, 32 Chung Keng Li, Dalin, Chiayi 622, Taiwan

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Abstract

The major purpose of this paper is (1) to find out the criteria for voluntary recycling by a for-profit recycler and for state intervention with recycling for a particular recyclable waste, (2) to present models to determine the private and social optimal recycling rates respectively, and (3) to determine optimal implementation policy by providing economic incentives to motivate recycling. The results of the analysis conclude that (1) an increase in conversion efficiency, the price of secondary material, and carbon taxes will lead to an increase in recycling rates, (2) the subsidy based on secondary material recovered will result in a higher recycling rate and will improve recovery technology more than a subsidy for recyclable wastes collected and sorted.

Keywords: recycle, recovery, incentive scheme, household waste, resource scarcity

Introduction

Rapid industrial development, human affluence, and the changes in packaging patterns that have arisen from consumption habits have caused a considerable increase in solid waste generation. Municipal Solid Waste (MSW) management has become a serious problem to municipalities. Many authors use mathematical models to plan and manage the construction of notorious facilities for MSW treatments to expand public interests (e.g. [1-3]). On the contrary, a great number of studies in the literature focus on the recycling of wastes. Smith [4] argues: "In general, it is assumed that such waste units can be reprocessed or recycled into the productive system, but not without utility losses to households. ... Due to the law of conservation of mass, we make the reasonable assumption that, ultimately, there is no escape except for recycling" (p. 601). Many authors suggest that recycling, reuse, and recovery of solid waste is an effective way to reduce environmental burdens when facing a scarcity of resources [5-8].

Keeler & Renkow [9] present a model to examine three competitive options: incineration in energy recovery facilities, landfilling, and recycling. They assume that the residual ash can be disposed by landfilling without any bad effect on the environment. In their model the damage effect is not taken into consideration and resource scarcity reflecting the price rise-up of the resource over time is also not taken into consideration. Mainwaring [10] offers a model to show a recycling scheme that depends on international cooperation. He assumes that social welfare is a function of consumption, leisure, and 'a good environmental conscience'. Menell [11] studies the effect of public policies on recycling from the perspective of household behaviors.

As the public's environmental concerns on solid waste management become more serious (as people become more aware of the potential hazards of waste collecting and final disposal), many authors have suggested a resource tax on the consumption of primary resourc-

*e-mail: ccchen@mail.nhu.edu.tw

es in order to undertake deposit/refund programs, to subsidize recycled material production, or to determine recycled content standards when considering the goal of sustainable development (see [12-15]). Most can agree that recycling has good potential and is quite valuable in reducing amounts for final disposal, but recycling activity is still slow in most countries without governmental regulation [16] and recycling practices lack technical specifications on recycled materials and lack economic incentives to encourage recycling activity and the application of secondary materials that form as a constraint to recycling [16].

In this paper we intend to analyze the optimal recycling rate θ (sorting and collecting rate of the recyclables) and develop an appropriate implementation policy based on an economic analysis for the policy planner. Section 2 describes the MSW disposal process and basic assumptions. Section 3 explains the traditional reasons for recycling and presents our criticisms. Section 4 develops the criteria for a profit-seeking recycler to recycle autonomously. Section 5 develops the criteria for the government to intervene with compulsory recycling. Section 6 presents a mathematical model to determine the optimal recycling rate. Section 7 develops an appropriate implementation policy of an economic incentive mechanism for the government to motivate voluntary recycling and then a brief conclusion is made in Section 8. In addition, Section 7 analyzes the effects of the exogenous parameters such as the price of secondary material, conversion efficiency, and carbon taxes on the socially optimal recycling rate.

General Description of the Waste Disposal Process and Basic Assumptions

A municipal solid waste management system basically consists of three phases: collection, transfer station (hauling), and final disposal (landfill, incineration, or secondary material recovery). The collection of household wastes is mainly carried out by the municipality and a small portion of household waste is collected by private haulers. Taipei Municipality imposes a waste treatment fee on households based on waste collected through garbage bag selling[1], but has a free charge on recyclable wastes[2]. Thus, we assume that sorting is undertaken by households autonomously and collecting is undertaken by the government in the account of the municipality. The recyclable wastes after collecting and sorting are delivered to a recovery plant operated by a private firm (we call this plant a recycler[3] in this paper).

We assume that household wastes contain a fixed amount of a particular recyclable waste W depicted in Fig. 1. Sorting (the separation of the recyclable parts from household waste) is implemented perfectly at the source (households) before collecting[4]. The recycler for this particular recyclable waste is a profit seeker by investing in and operating the recovery plant. The cost[5] for recycling a particular recyclable waste is a function of the recyclable waste collected, i.e. $C = C(\theta W)$, with properties $C'(\theta W) > 0$ and $C''(\theta W) > 0$, where θ is the recycling rate. The recycler (the recovery firm) must be responsible for collection in the city with the collection cost in the account of the municipality. The possible risk associated with damage occurrence and the environmental quality reduction around the collecting-sorting area are neglected.

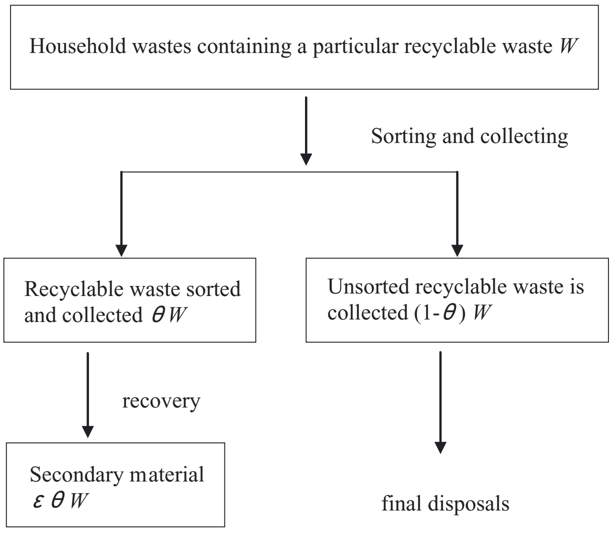

Fig. 1. The description of MSW recycling process.

[1]Empirical studies find that households will be encouraged to participate in sorting and recycling if they bear the cost of waste disposal [17]. The solid waste management implemented by Taipei Municipality by asking households to bear the cost of waste disposal shows that the recycling rate has increased and waste generation (collected for final disposal) has fallen.

[2]This policy has encouraged households to sort waste into recyclables and non-recyclables according to governmental regulations before waste collecting. According to Taiwan EPA, recyclable waste is classified into Category A (i.e. packaging containers) and Category B (i.e. objects where reverse recycling is deemed possible, such as motor vehicles, lubricating oils, tires, lead accumulators, dry batteries, pesticide containers, special environmental sanitary chemicals containers, and electronic appliances). Each item of recyclable waste should be recycled and separate recycling foundations are required to be developed. The recyclable wastes are separated into metal, glass, papers, and plastics for recycling by households before waste collection.

[3]In this paper we define that recycling means to sort waste and deliver the recyclables for re- processing so as to recover the valuable resources.

[4]The complexity of sorting and collecting (such as the type of materials collected, the number of fractions separated at the collection level, and the channel from collecting to the recovery plant) is not addressed in this paper.

[5]As

Why Recycling - The Conventional Reasoning

As for the scarcity of resources and environmental concerns, recycling is believed to be a major factor to conserve resources, save energy, and protect the environment and eventually sustain development. It has become an important MSW management policy in a growing society. Recycling a product made from a renewable resource such as paper or board, or an exhaustible resource such as plastic containers, has become a popular commonsense initiative and is believed to be socially beneficial [18]. The driving force to recycle comes from awareness of environmentalism and resource scarcity [10, 18]. The awareness stimulates recycling as a trend to treat waste and encourages people to participate in waste reduction through recycling programs.

McKenzie-Mohr and Smith [19] argue that the public's commitment to sustainable waste management is an important method for solid waste management. Environmental attitudes and consumption behaviors are seen as the major consequences of environmental deterioration or conservation, which are critical to the successful achievement of environmental programs [20, 21]. Therefore, some authors suggest studying the determinants that affect environmental behavior through a scientific approach for a solution of the current ecological crisis [22]. A great number of researchers focus on the identification of demographical factors of residents who participate in recycling [23-27]; some attempt to examine the motivation factor of economic incentives for people's recycling behaviors [28-30]; other studies have attempted to find out the obstacles that local councils must overcome in order to facilitate recycling policies [25, 31-34]; and some other authors have analyzed the relationship between environmental attitudes and voluntary recycling [26-27, 35-36]. The results of these studies are mainly employed to design an environmental program that aims to increase the resident's voluntary effort in recycling.

Self-interest, however, is believed to be the main power to promote economic welfare and initiate people to take some effective measures on solid waste treatment in perspective of management practice. Without economic incentives or statutory regulations, people may hesitate to participate in recycling. In Section 4 we will discuss the criteria for a voluntary recycling behavior based on an economic analysis.

Criteria to Recycle for a Private Recycler

As a profit-seeking firm, a recycler is concerned about the prices of secondary material (the recovered resources from the waste) and the operation costs to recover the valuable resources. Thus, recovery will occur autonomously in the case of $p\varepsilon\theta W - C(\theta W) > 0$, where p is the price of secondary material[6] and ε is the recovery rate depending on the recovery process of current technologies. Optimal recycling rate θ will be determined at the point where the marginal benefits equal marginal costs, i.e.

$$p\theta = C'(\theta W) \quad (4.1)$$

as the driving force of profit-seeking will attract entrepreneurs to set up the recovery plant. Economically, no firms intend to recycle the waste if the net profit is negative. For example, Smith [4] argues that "In the absence of scrap value sufficient to pay for the return of junk automobiles to the steel furnaces, self-interest is served by abandonment on the parkway, the vacant lot, or the river bank" (p. 600).

The price of secondary materials in reality is a function of primary materials. If the market price of primary materials goes up, the price of secondary materials also will rise and will attract more labor to join the collection of recyclable wastes and the recycling process. Thus, the optimal recycling rate $\theta^{\#}$ determined by Equation (4.1) will rise, too. As the price of primary resources may be distorted and pressed down on purpose by people's negligence on the future opportunity costs of resource utilization and political intervention, recycling is discouraged.

Recycling in practice does not bring any profit to the recycler if governmental intervention is removed. Keeler and Renkow [9] state: "Recycling reduces the amount of waste ... but does so at a cost to the local government, since the revenue from the sale for recycled materials are generally not enough to offset setup, collection, storage, and delivery charges" (p. 206). Powell et al. [37] also finds that "the financial costs of recycling schemes fail to account for external costs and benefits such as environmental pollution, road congestion and accidents." In this case, the free market system fails to account for the necessity of recycling. Without state intervention by regulating the recycling rate, firms will follow the economic rule and be reluctant to invest in recycling and recovery.

Why Recycling is Necessary – a Policy Planner's Perspective

Municipal waste is in general disposed by landfilling or incineration and only a small proportion of the MSW stream (about 2%) is recycled or treated by biological composting. Landfilling, pragmatically, was once the most popular method of disposal internationally, but today the available space for landfilling has become scarce and is increasingly difficult to obtain [38]. For example, most of the existing landfills in Taiwan have reached their upper capacity and must be shut down. As landfilling also yields negative impacts on the environment caused by odors, groundwater

[6]We assume that the market for secondary material is competitive so that price p is given and fixed, and primarily dependent on the price of primary material.

contamination, and the aesthetic deterioration of the landscape, neighboring residents will oppose the construction of a landfill due to the greenbelt policy of local authorities and "Not In My Back Yard" (NIMBY) effects [39]. Therefore, landfilling for MSW disposal has lost its advantage over other methods and has gradually been discarded in Taiwan[7]. However, the incineration method does not solve disposal completely and results in strong oppositions from local residents, because of the following facts:

1) **Treatment cannot be perfect.**
Waste disposal by an incineration process cannot remove toxic chemicals completely due to the limit of technology and generates flue gas containing a high amount of CO_2 emission [9]. The scrubbing of flue gas generated by the incineration process is accompanied by sludge, which may contain heavy metals or other kinds of hazardous substances. These hazardous substances finally will return to the earth. The pollutant just changes its form from a solid state to gas state, from gas state to liquid state, etc., and finally it still exists on earth from one plot of land to another. In practice, there is no way to achieve zero-pollution abatement by means of current technology. Montague (1999, extracted from Miller, Jr. [40], p. 66) argues that, "All waste disposal - landfilling, incineration, deep-well injection - is polluting because "disposal" means dispersal into the environment." Montague's advocacy sentences solid waste disposal like an incineration process that is inefficient in achieving the environmental goals of sustainability.
2) **Treatment requires consumption of additional resources.**
Pollution reduction or waste disposal represents a substitution process of natural resources consumption for a cleaner environment. Forster [41] advocates that, "The antipollution activity reduces pollution, but it also reduces the energy supply, since energy is needed to clear up pollution" (p. 327).
3) **The incineration process may generate potential damage.**
The extent of the damage effect caused by pollution in general may be determined by three factors: the chemical nature, the concentration, and the persistence of the pollution [40]. Some damage, which is not identified now but does exist, is called potential damage. Chen and Chen [42] argue that, "Potential damage may be caused by limited capacity of the earth (the environmental resource) or the impossible decomposition of the used commodities" (p. 306). The residues generated by an incineration process do not show any harmful effect on the environment now, but its damage may appear in the future. For example, the warming effect resulting from CO_2 emission has not been identified until recently. The international bans on carbon emission or other gases have provided a warning to the use of incineration process for solid waste treatment. According to the 1990 Clean Air Act Amendments (CAAA), the emissions of Sulfur Dioxide (SO_2) are scheduled to be limited to 8.95 million tons, down from about 19 million tons in 1980 (please see [43]). Framework Convention on Climate Change (FCCC) regulates CO_2 emission to be kept at the level of emission in 1980 before 2000. In the long run, the payment for carbon emission should be enforced.

Table 1. The criterion for waste recycling in various perspectives.

Decision makers	Criteria for recycling (autonomous recycling)
Conventional reasoning (Behavioral theory)	1. environmental conscience 2. environmental awareness
A recycler's perspective	$p\varepsilon\theta W - C(\theta W) > 0$
A policy planner's perspective	1. $f(\theta W) + g(\theta W) + t\varepsilon\theta W + p\varepsilon\theta W - C(\theta W) > 0$ 2. $p\varepsilon\theta W - C(\theta W) < 0$

Under such a circumstance, recycling the valuable resources from MSW is claimed. If recycling rate θ is implemented, then the extra benefits (positive externality) compared to traditional final disposals include cost savings of final disposal and potential hazards $f(\theta W)$, and the cost saving of carbon tax $t\delta\theta W$, where θ is a carbon tax per unit of CO_2 emissions, and t is the conversion rate of solid wastes into CO_2 emissions. Thus, compulsory recycling should be regulated and enforced if the total social welfare $S = f(\theta W) + t\delta\theta W + p\varepsilon\theta W - C(\theta W) > 0$. We combine the criterion of waste recycling discussed in Sections 3, 4, and 5 and list it in Table 1.

How to Regulate Recycling Behavior

To determine the socially-optimal recycling rate θ, the policy planner needs to solve the problem of

$$\max_{\theta} S = f(\theta W) + t\delta\theta W + p\varepsilon\theta W - C(\theta W),$$

subject to

(P1.1)) $f(\theta W) + g(\theta W) + t\theta W + p\varepsilon\theta W - C(\theta W) > 0$, and
(P1.2) $0 < \theta < 1$.

The first-order condition for optimal recycling rate θ^* is

$$0 = \frac{\partial S}{\partial \theta} = Wf'(\theta W) + t\delta W + p\varepsilon W - W\,C'(\theta W) \qquad (6.1)$$

Rearranging Equation (6.1) yields

$$f'(\theta W) + t\delta = -p\varepsilon + C'(\theta W) \qquad (6.2)$$

[7]Under such a circumstance, the final disposal of MSW switched to incineration according to Taiwan's EPA policies in which it plans to install an incinerator in each county.

Equation (6.2) demonstrates that the saving of environmental damage arising from disposal is equal to recycling costs (the negative profit of recycling).

The costs of recycling vary greatly among a variety of recyclable wastes. Some are easy to collect, sort, and recover with low recycling costs while some recyclable waste is prohibitively expensive to recycle. Some secondary materials can sell at high prices while others cannot. Different solid waste is attributed with different conversion efficiencies ε under a certain technology level and different prices of secondary material p. The sensitivity analysis concludes that the effect of conversion efficiency θ on recycling rate θ is positive and the effect of the prices of secondary material p is also positive, i.e.

$$\frac{d\theta^*}{d\varepsilon} > 0, \quad \frac{d\theta^*}{dp} > 0, \text{ and } \frac{d\theta^*}{d\delta} > 0$$

1. The effects of recovery technology conversion efficiency on the recycling rate is positive, i.e.

$$\frac{d\theta^*}{d\varepsilon} > 0$$

   In fact, technological innovation and progress have improved recovery and the re-use of construction waste [44] and recycling options for solid construction waste also are increasing [45]. Technology progress can provide a partial solution for the escalation of environmental degradation [46] so that "Residuals do not necessarily have to be discharged to the environment. In many instances, it is possible to recycle them back into the productive system" [47].
2. The effect of the price of secondary materials is positive, i.e.

$$\frac{d\theta^*}{dp} > 0$$

   The recycler will increase the recycling rate and will actively go for collecting recyclable wastes while the market price of secondary materials increases. The result suggests that the development of the re-use of secondary materials may encourage the market demand and eventually will lead to an increase in the recycling rate. In fact, recycling is a somewhat different story from the production of the primary material. Recycling is determined to respond to changes in the price gap between primary materials and secondary materials.
3. The effect of carbon tax is positive, i.e.

$$\frac{d\theta^*}{d\delta} > 0$$

   The result shows that an increase in carbon taxes will encourage the recycler to increase recycling. Some innovative international agreements on new designs or economic mechanisms have been developed to reduce greenhouse gas emissions. These mechanisms include emission permit trading, joint implementation, and clean development mechanism. Facing international pressure for the reduction of CO_2 emission, carbon taxes should be implemented. The implementation of carbon taxes is believed to encourage the development of environmentally friendly technology and to retard the rate of accumulation of green gases.

The Implementation Policy

To encourage people to participate in recycling, many researchers conclude that economic incentives or rewards are necessary to keep a positive relationship with the recycling rate [24. 48]. The policy planner needs to subsidize the recycler such that the recycler's profit is positive, i.e. $p\varepsilon\theta W - C(\theta W) + \textit{subsidizing amount} > 0$. In this section we intend to analyze how to subsidize the recycler: is it based on the recyclable waste collected or on the output of secondary material recovered? We attempt to find out which kind of subsidy can encourage the recycler to comply with the socially-optimal recycling rate θ^* and compare the relative advantages of the two implementation polices.

Case I: subsidy based on recyclable waste collected and recycled.

The recycler will determine the optimal recycling rate by maximizing the net profit of

$$\pi = p\varepsilon\theta W - C(\theta W) + s\theta W,$$

where s is the subsidy for each recyclable waste collected and recycled with $s > 0$. The recycler will determine its optimal recycling rate $\theta^\#$ according to

$$s = -p\varepsilon + C'(\theta^\# W) \tag{7.1}$$

To encourage the recycler to determine its optimal recycling rate $\theta^\#$ complying with the socially-optimal rate θ^*, the policy planner must set up a subsidy based on

$$s = f'(\theta W) + t\delta \tag{7.2}$$

This is derived by substituting (7.1) into (6.2).

Case II: subsidy based on resources recovered from recyclable wastes.

When a subsidy is based on resources recovered from recyclable resources, the recycler will care about the level of recovery rate ε which in practice is a function of technology that the recovery plant has adopted and operated, i.e. $\varepsilon=\varepsilon(T)$. Thus, the recycler will determine the optimal recycling rate $\theta^\#$ and technology level $T^\#$ simultaneously by maximizing the net profit of

$$\pi = p\varepsilon\theta W - C(\theta W) + \tau\varepsilon(T)\theta W,$$

where τ is the subsidy for each resource recovered from recyclable wastes. The necessary conditions are

$$0 = \frac{\partial \pi}{\partial \theta} = p\varepsilon(T)W - C'(\theta W)W + \tau\varepsilon(T)W \qquad (7.3)$$

$$0 = \frac{\partial \pi}{\partial T} = p\varepsilon'(T)\theta W + \tau\varepsilon(T)\theta W \qquad (7.4)$$

Rearranging (7.3) yields

$$\tau\varepsilon(T^{\#}) = - p\varepsilon(T^{\#}) + C'(\theta^{\#}W) \qquad (7.5)$$

To encourage the recycler to determine its optimal recycling rate $\theta^{\#}$ complying with socially-optimal rate θ^{*}, the policy planner must set up a subsidy based on

$$\tau\varepsilon(T^{\#}) = f'(\theta W) + t\delta \qquad (7.6)$$

This is derived by substituting (7.5) into (6.2).

The recycler will find an optimal technology $T^{\#}$ to increase the recovery rate in order to increase its profit by (7.4) in Case II, while the recycler remains at the original recovery rate ε_0 as Case I. It is self-explanatory that $\varepsilon(T^{\#}) > \varepsilon_0$. This result shows that a subsidy based on resources recovered from recyclable wastes may encourage the recycler to improve technology in the recovery process.

Technological developments in the past few years have led to widespread diffusions in all corners for the production of intermediate materials and final products with a high consumption of primary materials. Very few policies are concerned with the incentive for the generation of new technology on the recovery of valuable resources that will yield a tremendous benefit on the environment and society. The policy by subsidy based on the amount of secondary material recovered presented in this paper will encourage the recycler to develop a new technology based on a cost-effective solution in compliance with governmental recycling policy [49].

To compare the relative advantage of the two implementing polices, we assume that the subsidy amount is the same between the two cases, i.e. $\tau\varepsilon(T^{\#}) = s$ by comparing (7.2) and (7.6). As θ $(T^{\#}) > \varepsilon_0$, we conclude that the recycling rate in Case II will be higher than that in Case I, i.e. $\theta_2 < \theta_3$, where θ_2 represents the optimal recycling rate determined by the policy planter by subsidy, according to recyclable waste collected, and θ_3 is the optimal recycling rate by subsidy, according to secondary material recovered (Fig. 2). This result demonstrates that the subsidy should be based on the performance of resource recovery that depends on both the efforts of collecting/sorting and recovery technology.

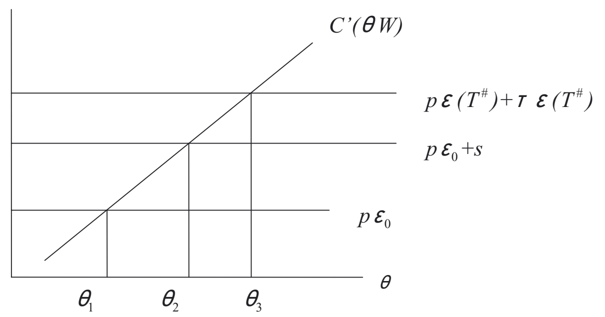

Fig. 2. The comparison of two implementation policies, where θ_1 represnts the recycler optimal recycling rate without a subsidy, θ_2 is a subsidy based on recyclable waste collected, and θ_3 is a subsidy based on a secondary material recovered.

Conclusions

The results of the analysis in this paper provide some valuable information for both solid waste management and economic efficiency for secondary materials. A profit-seeker recycler needs to examine the feasibility on all alternatives based on cost-effective analysis in order to support a manager's decision-making processes for a given facility [50-52]. This paper analyzes the criteria for a private firm to engage in voluntary recycling and for the government to intervene in the enforcement of recycling. This study also suggests that the implementation policy of recycling should be based on a subsidy according to the amount of the secondary material recovered instead of the recyclable wastes collected and sorted.

Many researchers argue that a policy planner needs to set up a policy to encourage the public in voluntary efforts to recycle and persuade the public to change their recycling behaviors in addition to economic incentives (subsidy) [8, 53]. This is the key factor to affect successful recycling which may depend on the total participation of the public consisting of households and the recycler [54]. The households' environmental beliefs and behaviors play environmental roles in affecting voluntary recycling, which serve as an economic subsidy to the recycler. The enforcement of recycling polices or programs must be communicated to the public through a series of public education or public discussions on environmental policies so that residents' environmental attitudes and behaviors can be changed for the better, enabling the objectives of recycling and recovery to be achieved [27, 55-56]. The policy planner needs to provide sufficient environmental knowledge and information to encourage the public in environmental consumption and promote engagement in recycling programs.

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