The Economics of Residential Solid Waste Management

Edited by
Thomas C. Kinnaman

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Series Preface

The *International Library of Environmental Economics and Policy* explores the influence of economics on the development of environmental and natural resource policy. In a series of twenty five volumes, the most significant journal essays in key areas of contemporary environmental and resource policy are collected. Scholars who are recognized for their expertise and contribution to the literature in the various research areas serve as volume editors and write an introductory essay that provides the context for the collection.

Volumes in the series reflect the broad strands of economic research including 1) Natural and Environmental Resources, 2) Policy Instruments and Institutions and 3) Methodology. The editors, in their introduction to each volume, provide a state-of-the-art overview of the topic and explain the influence and relevance of the collected papers on the development of policy. This reference series provides access to the economic literature that has made an enduring contribution to contemporary and natural resource policy.

TOM TIETENBERG
KATHLEEN SEGERSON
General Editors

Introduction

The market for municipal solid waste (MSW) collection and disposal has changed substantially over the past 30 years. Gone are the days when MSW was collected for local disposal in a town dump. In the United States, EPA regulations on landfill construction and operation, based primarily upon the Resource Conservation and Recovery Act (RCRA) of 1976, made the continued operations of most local dumps illegal. Under the RCRA, landfills, or solid waste disposal facilities as they are currently termed, must be designed to minimize odour and eliminate any seepages of leachate, the liquid byproduct of stored solid waste. A growing body of case law has encouraged disposal facilities to go beyond the requirements of the RCRA by completely eliminating neighbours' exposure to dust, litter and noise. The result of this evolution in solid waste disposal technology is the complete elimination of the local town dump and the growth of large, highly capitalized regional landfills owned and operated by Fortune 500 companies. Private and municipal MSW collection trucks must now transport their waste several miles to either a disposal facility or a transfer station where the MSW is repackaged into large overland motor carriers, rail cars, or ocean barges.[1] The most noticeable example of this evolution is the transportation of nearly all of New York City's MSW to disposal facilities in Pennsylvania, Ohio and Virginia due to the closure of New York City's local dump, the Fresh Kills Landfill.

Although the nature of the external costs of MSW have switched from odours and ground water contamination 30 years ago to truck noise and congestion today, these external costs have increasingly motivated local, state and international governments to look for ways of reducing the quantity of MSW generated by their households. The result has been the implementation of a wide variety of policies – most aimed at reducing MSW by increasing the quantity of material recycled. Recycling has existed to some extent since the beginnings of the manufacturing age and perhaps earlier. As long as the marginal revenue product of any scrap material exceeds the cost of salvaging and preparing it for production, then recycling is profitable. To the economist, recycling is efficient as long as the marginal revenue product of any scrap material *plus the external costs of disposing that material* exceed the costs of salvaging and preparing that material for production. As policy-makers' awareness of the external costs of MSW collection and disposal increased, a new set of materials became candidates for recycling. These materials included newspaper, glass, plastic and metal cans, originating primarily in the MSW generated by households each day. As a result, government-sponsored residential recycling opportunities have grown dramatically over the past 30 years.

Economics is particularly well suited to helping governments evaluate policies designed to change the disposal practices of households. Using standard economic assumptions related to consumer choice, a rich and diverse body of economic literature has been developed to suggest and evaluate policy options. This volume contains the heart of this literature and this introduction will help guide both newcomers and past contributors through:

1. the fundamental aspects of policies designed to reduce the external costs of MSW collection, and disposal;

2. the theoretical framework utilized by economists to model the disposal decisions of households; and
3. the important empirical relationships that, in the end, govern the selection of MSW policies.

Theoretical Aspects of Policy Alternatives

An interesting aspect about the market for MSW collection disposal is that several tax/subsidy instruments are available to correct for the single externality associated with MSW collection and disposal. The household's generation of MSW can be taxed directly at the kerbside or the household's recycling efforts can be subsidized. These two downstream policy instruments have attracted a great deal of attention from economists and have also been quite popular with municipal governments. Alternatively, either industry's use of virgin material or household consumption can be taxed. These two upstream approaches are less common in practice, but have still received a great deal of attention from economists. The combination of a tax on consumption and a subsidy for recycling, more commonly known as a deposit-refund programme, has some very desirable economic properties and has been implemented in some areas. However, many other combinations of these policies, including, for example, a combination of a tax on the household's generation of MSW with a tax on industry's use of virgin materials, is inefficient because it leads to double taxation (see the essay by Dinan, Chapter 4). This section summarizes some of the desirable and undesirable properties of each policy option.[2]

A Tax on Garbage Generation – The User Fee

Although the most common method to finance garbage collection and disposal costs is by general tax revenue or a flat monthly fee paid by all households, many municipalities in the United States require their residents to pay an extra fee for each bag of MSW presented for collection. Two types of programmes have been implemented. Several municipalities in the states of California and Oregon require each resident to presubscribe for the collection of a certain number of bins or cans each week. Households pay for the number of bins or cans they subscribe to, whether or not they actually fill them with MSW. Thus, true marginal cost pricing is not achieved. Because many of these programmes were implemented early in the twentieth century when the external costs of MSW were largely overlooked, their intent may have been to garner public revenue to finance collection and disposal costs rather than to create an instrument to change the economic incentives of households (see Nestor and Podolsky, Chapter 23).

The second type of user-fee programme requires households to purchase special programme bags, tags or stickers for each unit of MSW presented for disposal. This design better represents true marginal cost pricing. These programmes were first implemented in small suburban towns, particularly in the suburbs of Philadelphia and Chicago, in the early 1990s. Many of these towns also had a mature kerbside recycling scheme already in place. Several EU countries, including Belgium, Finland, France, Germany, Italy, Luxembourg and the Netherlands have also implemented some version of a user-fee programme, and the clear intent of many of these is to provide an economic incentive for households to reduce MSW by increasing recycling, rather than increasing public revenue.

Of all policies considered by economists, the per-bag user fee is the most direct because it is applied at the source of the externality – namely, the MSW generated by individual households. Many households find it fair because those that produce the largest amount of MSW pay the largest share of the cost of collecting and disposing of the material. The programme is also easy to implement efficiently because the only information that policy-makers need is the external marginal cost of MSW collection and disposal. The resulting increase in recycling would reduce prices of recyclable materials, thus stimulating their use in manufacturing. The user fee can also encourage manufacturers to design products that are easily recycled (see Fullerton and Wu, Chapter 7 and Calcott and Walls, Chapter 8).

The major drawback of user-fee programmes is the incentive they create to dump MSW illegally (see Fullerton and Kinnaman, Chapter 5 and Copeland, Chapter 3). The external costs of dumped MSW exceed that for MSW disposed in a sanitary disposal facility. Illegal dumping can be discouraged with local laws and tough enforcement measures, but such enforcement efforts can be costly. A second drawback of user fees is that the administrative costs of printing and distributing stickers or tags can exceed the total welfare gain realized from any reduction in MSW disposed in a landfill. Finally, as a means of raising public revenue, user fees may be more regressive than other public finance options (see Fullerton and Kinnaman, Chapter 19). Thus, many economists have sought options other than user fees to correct the inefficiencies created by the collection and disposal of MSW.

The Advanced Disposal Fee and Subsidy to Recycling

To preserve the incentive provided by user fees without encouraging illegal dumping, the household's recycling efforts can be subsidized. Subsidies by themselves could increase consumption inefficiently, so the recycling subsidy must be coupled with a tax on consumption, sometimes referred to as an advanced disposal fee. The result is essentially a deposit-refund system (Palmer, *et al.*, Chapter 21). Such programmes could provide for an efficient allocation of resources if the deposit and refund are set equal to the marginal external cost of MSW collection and disposal (Fullerton and Kinnaman, Chapter 5 and Palmer and Walls, Chapter 6). Deposit-refund programmes have been implemented on specific products, such as car tyres, batteries and beverage containers in several states in the United States. Similar programmes for beverage containers have also been implemented in Australia, Canada, France, Germany, Switzerland and in many of the developing countries in the Caribbean, including Barbados and St Lucia.

Countless local governments have implemented a broader, and perhaps more abstract, application of this policy approach – a general sales tax on all consumption goods (the deposit) and a kerbside collection programme that is free to households (the subsidy). The kerbside recycling programme represents a substantial subsidy to the household's recycling efforts because, without these programmes, households would be required to transport and market their materials directly to firms in the recycling industry. The Law on Waste Management implemented in Germany in 1991 can also be thought of in these terms. Under this law, manufacturers of several products must arrange for the collection and recycling of the material waste of their products. As a result, over 400 firms in Germany have formed the Duales System of Deutschland. The firms affix a green dot on to their packaging materials and jointly arrange to collect all materials carrying the green dot from households (Rousso and Shah, Chapter 16).

In essence, this scheme is a kerbside recycling programme run by private enterprise rather than by municipalities as is done in the United States and other parts of Europe. In general, the deposit/refund nature of these two policies is perhaps more consistent with the theoretical literature on MSW policy design than may be perceived by economists.

In theory, the recycling subsidy can also be applied at the industry level. Firms in the recycling industry could receive a subsidy for each unit of material they recover and convert for production. These firms would be expected to demand additional recycled materials, driving up their price. Municipalities could then be expected to expand the number of materials collected for recycling. As households recycle these additional materials, the external costs of MSW fall. The advantage of this policy approach is that the administrative costs of applying the subsidy to manufacturers are potentially lower than if they were given to households. Although several economists favour this policy approach, no governments are known to have pursued it in the United States, perhaps because such subsidies would have to be applied at the national level to be effective and, under the RCRA, individual states in the United States are responsible for setting MSW policy.

A Tax on Virgin Materials

Another policy approach to correct for the externalities associated with MSW collection and disposal is the implementation of a tax on virgin materials. Such a tax would increase the demand for recycled materials – a substitute for virgin materials in some production processes – thus driving up their price. The higher price could then encourage municipal governments to collect additional recycled materials and less MSW (see Miedema, Chapter 2). The tax would need to be coupled with a consumption subsidy to prevent an inefficiently low quantity of consumption in the economy (Palmer and Walls, 1994).

The advantage of this policy approach is the potential to reduce the external costs of MSW without promoting illegal dumping. Implementation difficulties arise because the government must have some knowledge of the production functions of all firms extracting virgin materials in order to set the tax efficiently – information not typically available to governments. Another implementation difficulty is the need to roll back current subsidies on the extraction of many types of virgin material. Ending these long-established subsidies could be politically challenging.

Command and Control Approaches

Rather than introducing incentives to improve the disposal and recycling decisions of households and firms, the command and control approach relies on laws and punishment for violating those laws to designed change behaviour. Command and control policies applied to MSW could include local laws that require households to recycle certain materials, state laws that require manufacturers to utilize certain recycled materials in their production processes and state laws that require municipalities to adopt kerbside recycling programmes. Although examples of these policies permeate throughout the policy world, economists rarely support such approaches because the information required by governments to achieve efficient outcomes is normally not available to them.

Empirical Aspects of Policy Alternatives

The choice over the best policy to implement to manage MSW efficiently is also guided by important empirical relationships in the economy. A large portion of the economics literature on MSW is devoted to measuring such relationships.[3] As each household chooses the quantity of MSW and recycling it generates, the success of every programme described above depends crucially on how households respond to a change in various incentives. Thus, household disposal behaviour has been modelled, and the implications of these models have been tested empirically, with the result that a great deal has been learned about the disposal behaviour of households. The behaviours of firms in the recycling industry, of firms extracting raw materials and of local governments are also important for designing certain policy measures. However, less is known about their disposal decisions.

The User Fee

The desirability of user fees depends on several empirical factors, the most important of which is the reduction of MSW generated by households. These benefits are illustrated in Figure 1.

The efficient quantity of MSW is B, where the social marginal benefit (SMB) of MSW is equal to the social marginal cost (SMC). In the absence of a user fee, households generate the quantity 'A' units of MSW. A user fee set equal to the social marginal cost of MSW will encourage households to reduce MSW to the efficient level. The total benefit of that reduction is the triangle illustrated in Figure 1. Several empirical essays included in this volume estimate these benefits in the range of \$3 to \$11 per person per year (Jenkins, Chapter 12; Fullerton and Kinnaman, Chapter 19; and Podolsky and Spiegel, Chapter 24). This estimate is sensitive to the difference between A and B.[4] In other words, the important empirical question is measured by the degree that households facing a user fee reduce MSW.

The desirability of user fees hinges on whether these benefits exceed the administrative costs of operating the user-fee programme plus the external costs associated with any additional illegal dumping. The administrative costs can be estimated with appropriate data and, if these costs alone exceed the benefits in Figure 1, the efficient user fee would be zero. In these cases, flat fees or property taxes should finance garbage collection services. Data on the external costs of illegal dumping are generally unavailable. As these costs might be higher in rural communities with many empty back roads or in densely populated urban areas with empty lots, alleyways and commercial dumpsters, it is quite plausible that user fees are only beneficial in suburbs and small towns where access to illegal dumping sites is minimal.

Recycling Subsidy

When coupled with a tax on consumption, a subsidy to recycling set equal to the social marginal cost of MSW can also generate the benefits illustrated in Figure 1 without encouraging illegal dumping. Such deposit-refund systems have been implemented throughout the world on specific materials such as beverage containers, car batteries, and motor oil. Incidentally, these deposit-refund programmes were established primarily to alleviate littering and improper disposal. However, applying a recycling subsidy on a broader list of materials may be administratively burdensome. Not only would these subsidies represent an additional public financial outlay,

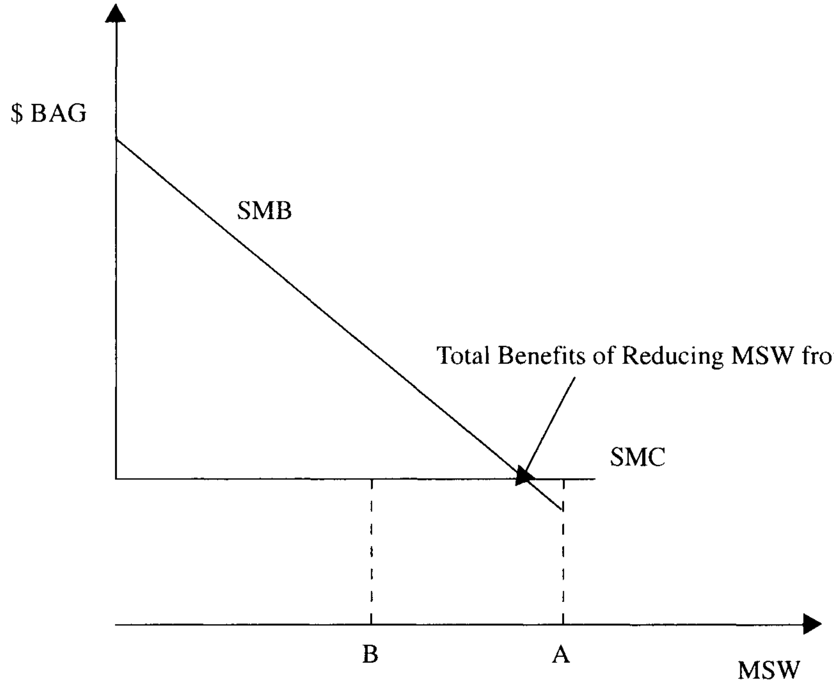

Figure 1 The benefits of reducing household-generated MSW

but also the costs of administering direct payments to households would likely be high. Perhaps for these reasons no broad-based financial subsidies to households have yet been attempted in practice.

Instead, many municipalities have encouraged the household's recycling efforts by providing storage containers, collection services and marketing services at no charge. Such kerbside recycling programmes represent a substantial, though perhaps not a financial, subsidy to the household. These types of scheme can be designed such that the subsidy is set approximately equal to the social marginal cost of MSW collection and disposal. The subsidy can be varied by changing the number of materials collected, the frequency of collection, the quality of the storage containers or by only providing drop-off facilities rather than kerbside collection services.[5]

Similar to the argument made above in the user-fee section, setting the recycling subsidy equal to the external marginal cost of MSW collection and disposal may still not be efficient if the net costs of operating the municipal recycling programme exceed the total benefits represented in Figure 1. These benefits increase with the magnitude of the reduction in MSW attributable to a kerbside recycling programme. Thus, another important empirical relationship is the reduction in MSW attributable to a municipal recycling programme. The net costs of operating such a programme include all resources needed to collect, process and market the materials less (1) the revenue earned from selling the material and (2) the reduction in the cost of transporting MSW to a disposal facility. Such data are generally available and are utilized by the literature (see Carroll, Chapter 17 and Judge and Becker, Chapter 14).

Recycling subsidies can also be offered at the manufacturing level. Firms receiving the subsidy would stimulate demand for recyclable materials and thus drive up prices in the secondary markets. But such price increases will have no effect on the quantity of MSW generated if the disposal incentives facing households do not change. Households do not typically interact directly with firms in the recycling industry. Instead, they turn over their materials to the municipality via a recycling programme. Thus, the rising prices must encourage local governments to either add more materials collected or improve the frequency of collection so that the quantity of MSW decreases. The relationship between prices and government behaviour is largely unknown. The resulting decrease in MSW generated by households produces benefits equal to the triangle in Figure 1, and these benefits must once again exceed the administrative costs of the policy. The administrative costs in this case equal the net costs of operating (or improving) a municipal recycling programme plus any costs associated with distributing the subsidy to firms in the recycling industry.

Virgin Materials Tax

The empirical links necessary for a tax on virgin materials to reduce MSW generated by the household are similar to those discussed above for the recycling subsidy paid to industry. The tax on specific material inputs to production would encourage firms within the broader manufacturing industry to look for recyclable materials as substitutes. The resulting increase in the demand for recycled materials would increase the price of these materials, thus encouraging local governments to introduce or improve a municipal recycling programme. These new or better programmes would subsidize the household's recycling efforts and thus reduce MSW. The magnitude of each of these links would have an impact on the total benefits of the policy, which can be compared directly to the administrative costs. However, the data required to measure these effects are substantial.

Conclusion

The responsiveness of households to changes in disposal incentives is critical to the effectiveness of every policy discussed above. In general, households must reduce MSW sufficiently for total benefits to exceed administrative costs and any external costs from increases in illegal dumping. The disposal behaviour of households has therefore been studied carefully, and several essays included in this collection estimate the household's demand for MSW collection as a function of economic, demographic and policy variables. The data demands of this literature have been intensive and, in many cases, original data were gathered for the estimates.

The literature has yet to reach a consensus on the best policy to proscribe. One important issue still to be resolved is the impact of a user fee on illegal disposal. Where this impact is small, user fees are perhaps the best policy by which to reduce MSW. Where illegal dumping is a problem, a tax on consumption, coupled with a subsidy to recycling, is widely considered as the best policy option. A very popular programme implemented in many parts of the United States and Europe is a kerbside or drop-off recycling programme. Although no money is exchanged, these programmes offer real subsidies on the household's recycling effort. Coupled with sales taxes, governments everywhere are closer to implementing the optimal policy design than is perhaps widely understood. If the net costs of operating these recycling programmes are excessive (and larger than the total benefits of any reduction in MSW), the best policy option might be to do nothing. But, before committing to a policy course of action, there is a clear need for additional empirical understanding of the relationships discussed above.

Notes

1 Ley *et al.* (Chapter 9) and Tawil (Chapter 25) examine the economic impact of restrictions on interstate MSW shipments.
2 See Smith (Chapter 1) for a dynamic model of waste accumulation and the impact of policy measures.
3 Stevens (Chapter 10) and Richardson and Havlicek (Chapter 11) pioneered empirical research on MSW issues.
4 Using separate data sources, several essays have estimated the reduction in MSW attributable to a user fee. See Jenkins (Chapter 12), Hong *et al.* (Chapter 13), Reschovsky and Stone (Chapter 15), Strathman *et al.* (Chapter 18), Fullerton and Kinnaman (Chapter 19), Callan and Thomas (Chapter 20), Podolsky and Spiegel (Chapter 24) and Kinnaman and Fullerton (Chapter 26).
5 See Tiller *et al.* (Chapter 22) for a further understanding of drop-off recycling programmes.

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Part I
Theoretical Aspects of Policy Alternatives

[1]

DYNAMICS OF WASTE ACCUMULATION: DISPOSAL VERSUS RECYCLING *

VERNON L. SMITH

INTRODUCTION

Several authors have explored recently the problem of pollution or waste disposal with models of social optimization over time.[1] The general hypothesis underlying these models is that waste, which is a public "bad," is created as a by-product of producing private goods. The classic example is of course smoke produced in the generation of electricity.

This paper focuses on the dynamics of recycling, using a rudimentary model emphasizing only those elements essential to the recycling problem.[2] The problem of waste accumulation is viewed as the joint result of household and firm decisions to "litter," i.e., let waste degrade by natural biological and chemical processes, instead of recycling waste into production. Consumption of the typical private good is assumed to leave a waste residue that is a consumer "bad," although it may have scrap value for recycling purposes. One paradigm is the beverage container, while another is the derelict automobile. If the container is of the no deposit, no return variety it has no recycling value (no "deposit" fee), and households have no incentive to do other than dispose of such waste either by littering or by city dump deposit, the latter alternative being merely a form of concentrated littering. The same applies to the junk automobile. In the absence of scrap value sufficient to pay for the return of junk

* Support by the National Science Foundation is gratefully acknowledged.

1. For example, W. A. Brock, "A Polluted Golden Age," unpublished, University of Rochester, 1970. C. G. Plourde, "A Model of Waste Accumulation and Disposal," *The Canadian Journal of Economics*, V (Feb. 1972). R. Wong, "Optimal Growth with Production Inhibited by Pollution Generation," unpublished, University of Southern California, 1970. R. Zeckhauser, M. Spence, and E. Keeler, "The Optimal Control of Pollution," *Journal of Economic Theory*, IV (March 1972).

2. The model abstracts from a capital goods sector and population growth, which have been the subjects of thorough study in the neoclassical growth literature.

automobiles to the steel furnaces, the self-interest is served by abandonment on the parkway, the vacant lot, or the river bank.

Almost everybody litters or pollutes in some form because the incentive structure favors waste discharge activities. Essentially the environment is viewed by each decision maker as a free resource for discharge purposes. Each individual's litter contributes marginally to the general discomfort, but in the aggregate may produce severe disruption of the environment. Since environmental quality is actually a scarce resource that has value, and since no one must pay for the right to discharge, the implicit effect is to subsidize pollution activities.

Underlying recent proposals to institute disposal charges or deposit fees on packaging materials and commodity materials is a desire to alter the incentive structure of the "system" in which everybody in some sense litters or pollutes, yet everybody protests that littering is a public bad. The final section of the paper discusses some of the features of a Senate bill designed to introduce "package pollution" charges.

A Model of Waste Reuse

Assume an economy of n households each with identical, strictly concave, utility function $u(q_1, q_2, Q)$ having continuous partial derivatives. The instantaneous quantity of commodity units consumed is q_1 (a "good") with $\partial u/\partial q_1 > 0$, but q_1 is equal also to the instantaneous quantity of waste units (a "bad") resulting as a by-product of consumption. The commodity is assumed to produce an undesirable residue following consumption or use, such as banana peels, junk automobiles, and newspaper trash, or else the commodity comes in a container that is a "bad," such as milk cartons, hamburger wrappers, and beer cans. 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. Thus, to households (in the absence of incentives to do otherwise), it is in the individual self-interest to litter beer cans and abandon junk automobiles. In the context of this model we do not distinguish between littering and disposal. Thus, "to litter" is also "to dispose" of waste in rivers, the ocean, or even city dumps since city dumps are an eyesore, and ultimately "disposal" by such means must spoil land or water or directly pollute the air by burning. Due to the law of conservation of mass, we make the reasonable assumption that, ultimately, there is *no* escape except by recycling.[3] That is, material commodity waste may be compacted, burned, or chemically treated for disposal, but there remains a physical mass of undesirable material that yields disutility. Only by recycling can the material again be embodied in service-yielding commodities. The quantity of recycled waste is $q_2 \leqslant q_1$, and since it may be more troublesome for households to retain and return waste for recycling than to litter or dispose of such waste, we have $\partial u/\partial q_2 \leqslant 0$.

The quantity of container units that are disposed, and that must be replaced by newly produced units, is $q_3 = q_1 - q_2$. Therefore new materials, such as glass, paper, or steel must be manufactured in order to replace the beer bottles, newspapers, and automobiles that are not recycled.

The stock of waste, Q, accumulates at a gross rate $n(q_1 - q_2)$, but as in Plourde and Brock we assume that waste degrades at a percentage rate γ applied to Q. Hence, the net accumulated rate of waste is $dQ/dt = n(q_1 - q_2) - \gamma Q$, and the accumulated stock of waste enters utility functions as a "bad," $\partial u/\partial Q \leqslant 0$.

We assume n identical firms that can perform any or all of three productive activities: the production of commodity (complete with container in the case, say, of beer or milk), according to the production function, $f_1(L_1)$; the reprocessing of waste residue into new containers or commodity materials, with production function $f_2(L_2)$; and the production of new containers or materials to replace waste units not recycled, $f_3(L_3)$. L_i is the quantity of some homogeneous, nonproduced resource, such as labor, used in productive activity i, and L is the total quantity of such a resource that is available for allocation. Each $f_i(L_i)$ is concave with continuous derivatives, and $f_i' > 0$, $f_i(0) = 0$.

These assumptions about technology and tastes imply that the cost of recycling is reflected in private utility losses $(\partial u/\partial q_2 \leqslant 0)$ and in the labor (L_2) required for reprocessing. The opportunity cost of recycling arises from the public utility losses $(\partial u/\partial Q \leqslant 0)$ of waste accumulation and the labor (L_3) required to produce new commodity materials or containers. The cost of raw material itself is zero, and there is a zero technological cost of disposal. Later sections will show how the model can be amended to deal explicitly with natural resources that can be saved by recycling, and how the model can be interpreted in terms of a pure waste or pollution reduction model.

3. See R. U. Ayres and A. V. Kneese, "Production, Consumption and Externalities," *American Economic Review*, LIX, No. 3 (June 1969).

For pedagogical purposes it will be assumed initially that some, but not all, waste material is recycled, i.e., $q_1>0$, $q_2>0$, $q_3=q_1-q_2>0$. This allows the problem to be formulated entirely in terms of equality constraints with interior solutions. The development will be interpreted graphically by means of the usual phase diagram. Then the important boundary solutions will be introduced with a graphical exposition. The boundary solutions are of immense economic significance, and are not a technical curiosity, for they constitute the cases in which there is total recycling and no recycling.[4]

For the interior case, on substituting $q_i=f_i(L_i)$, the social welfare problem is to choose the L_i (as functions of time) so as to maximize $\int_0^\infty u[f_1(L_1),\ f_2(L_2),\ Q]e^{-\delta t}dt$ subject to $L-L_1-L_2-L_3=0$, $f_3(L_3)-f_1(L_1)+f_2(L_2)=0$, and the differential equation $dQ/dt=nf_3(L_3)-\gamma Q$, where δ is the continuous rate of discount. The Hamiltonian for this autonomous system (L fixed in time) is[5]

$$H=u[f_1(L_1),f_2(L_2),Q]+\xi[n(f_1(L_1)-f_2(L_2))-\gamma Q]$$
$$+\lambda(L-L_1-L_2-L_3)+\mu[f_3(L_3)-f_1(L_1)+f_2(L_2)],$$

where the state variable (Q), control variables (L_1, L_2, L_3), and auxiliary shadow price variables (ξ, λ, μ) are understood to be functions of time.

The following first-order conditions must be satisfied along a maximal (interior) time path:

$$(1)\qquad \frac{\partial H}{\partial L_1}=\left(\frac{\partial u}{\partial q_1}\right)f_1'+n\xi f_1'-\lambda-\mu f_1'=0,$$

$$(2)\qquad \frac{\partial H}{\partial L_2}=\left(\frac{\partial u}{\partial q_2}\right)f_2'-n\xi f_2'-\lambda+\mu f_2'=0,$$

$$(3)\qquad \frac{\partial H}{\partial L_3}=-\lambda+\mu f_3'=0,$$

$$(4)\qquad d\xi/dt=\xi\delta-\frac{\partial H}{\partial Q}=(\delta+\gamma)\xi-\frac{\partial u}{\partial Q}$$

$$\lim_{t\to\infty} e^{-\delta t}\xi(t)\geqslant 0,\ \lim_{t\to\infty} e^{-\delta t}\xi(t)Q(t)=0.$$

4. The original version of this paper includes a mathematical appendix that derives characteristics of these boundary solutions more rigorously. Editorial considerations of space have persuaded me to omit the appendix from the published article, but interested readers can be provided this material by writing the author.

5. See K. J. Arrow, "Applications of Control Theory to Economic Growth," in G. B. Dantzig and A. F. Veinott, Jr., eds., *Mathematics of the Decision Sciences,* Part 2 (Providence: American Mathematical Society, 1968), pp. 335–45. A sufficient condition for a maximum is for H to be concave, which need not be the case given only the concavity of u and the f_i (since $-f_i$ need not be concave).

This solution is particularly simple and easy to illustrate where the utility function is additively separable, or

(5) $u(q_1, q_2, Q) \equiv u_1(q_1) + u_2(q_2) + u_3(Q)$,

with $\lim_{Q \to Q^\dagger} u_3'(Q) \to -\infty$, where $Q^\dagger$ is an intolerable level of litter pollution.

It is instructive to begin by interpreting the auxiliary variables (ξ, λ, μ), all of which are measured in utility (welfare) units per head. $(-n\xi)$ is the unit implicit social cost of the stock of waste, Q. λ is the implicit wage of the resource, while μ is the implicit price of new containers or commodity material. Therefore condition (3) states that the price of new containers must equal their marginal cost, $\mu = \lambda/f_3'$. Substituting from (5) and (3), condition (1) can be put in the form

(6) $u_1' = (\lambda/f_1') + (\lambda/f_3') - n\xi$,

where u_1' is the marginal utility of commodity, and $(\lambda/f_1') + (\lambda/f_3') + (-n\xi)$ is the marginal private cost of producing the commodity and its container or fabrication material, plus the public litter pollution cost resulting from its production. Condition (2) can be written

(7) $-u_2' + \lambda/f_2' = (\lambda/f_3') - n\xi$,

where $-u_2' + (\lambda/f_2')$ is the marginal cost of recycling to both households and firms, and $(\lambda/f_3') + (-n\xi)$ is the marginal private plus public litter pollution cost of producing a new unit of container or commodity material.

Equations (6) and (7), together with the labor constraint $L = L_1 + L_2 + L_3$ and the joint production constraint $f_3(L_3) = f_1(L_1) - f_2(L_2)$, determine (L_1, L_2, L_3) as functions of $n\xi$, given L, say $L_1(n\xi)$, $L_2(n\xi)$, $L_3(n\xi)$. Therefore the motion of the system in the phase space (ξ, Q) is governed by the differential equations,

(8) $dQ/dt = nf_3[L_3(n\xi)] - \gamma Q$,

(9) $d\xi/dt = (\delta + \gamma)\xi - u_3'(Q)$.

Figure I illustrates the locus of points $Q = nf_3[L_3(n\xi)]/\gamma$ such that $dQ/dt = 0$; i.e., the production of waste net of production recycling is just balanced by the rate at which waste is degraded by nature so that net accumulation is zero. Since it is shown in the appendix (omitted) that $\partial L_3/\partial \xi > 0$, this locus will be increasing. At any point above this locus, the social charge for waste disposal to the environment, $(-n\xi)$, is lowered, waste recycling is discouraged, and the net stock of waste will increase $(dQ/dt > 0)$. At any point below this locus, the waste disposal charge is increased, recycling is encouraged, and the net stock of waste will decrease.

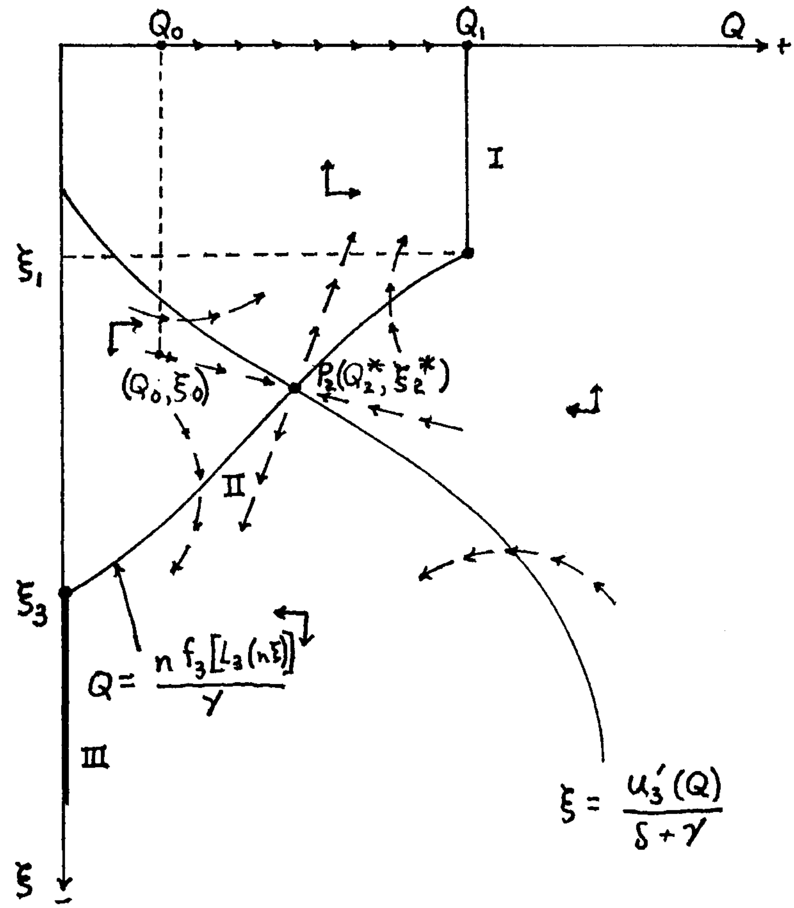

FIGURE I

Also in Figure I is illustrated the locus of points $\xi = u_3'(Q)/(\delta+\gamma)$ defined by $d\xi/dt = 0$; i.e., the price of waste discharge is stationary. At any point to the right of this locus the discounted marginal disutility of the stock of waste, $-u_3'(Q)/(\delta+\gamma)$, exceeds the price $(-\xi)$ associated with that stock of waste, and optimality requires this price to be decreasing, $(-d\xi/dt) < 0$. In like manner, at any point to the left of this locus, optimality necessitates increasing the social charge for waste emission. An optimal path, starting at some initial state (Q_0, ξ_0), and passing through the stationary state equilibrium at $P_2(Q_2^*, \xi_2^*)$, is shown in Figure I.

PRICES IN THE CONTROL MODEL

If p_1 is the price of a unit of commodity net of the recycling value of its container or material residue, s, then $P_1 = p_1 + s$ is the gross price of the commodity as sold. Thus P_1 is the price of a "coke" including the bottle, or the price of a car including its residual scrap value, and in equilibrium cannot differ from the marginal cost of producing the commodity plus its container or material, $P_1 = p_1 + s = (\lambda/f_1') + (\lambda/f_3')$. Under the condition that some but not all waste material is recycled, the marginal cost of producing new containers or commodity materials cannot differ from the scrap value of waste material plus the marginal cost of recycling it, i.e., $(\lambda/f_3') = s + (\lambda/f_2')$. Hence, (6) and (7) can be interpreted in terms of the scrap and net commodity prices (s, p_1):

(6′) $\quad u_1' = p_1 + s - n\xi,$

(7′) $\quad -u_2' = s - n\xi.$

In these equations s is a private, technological, scrap, or "deposit"

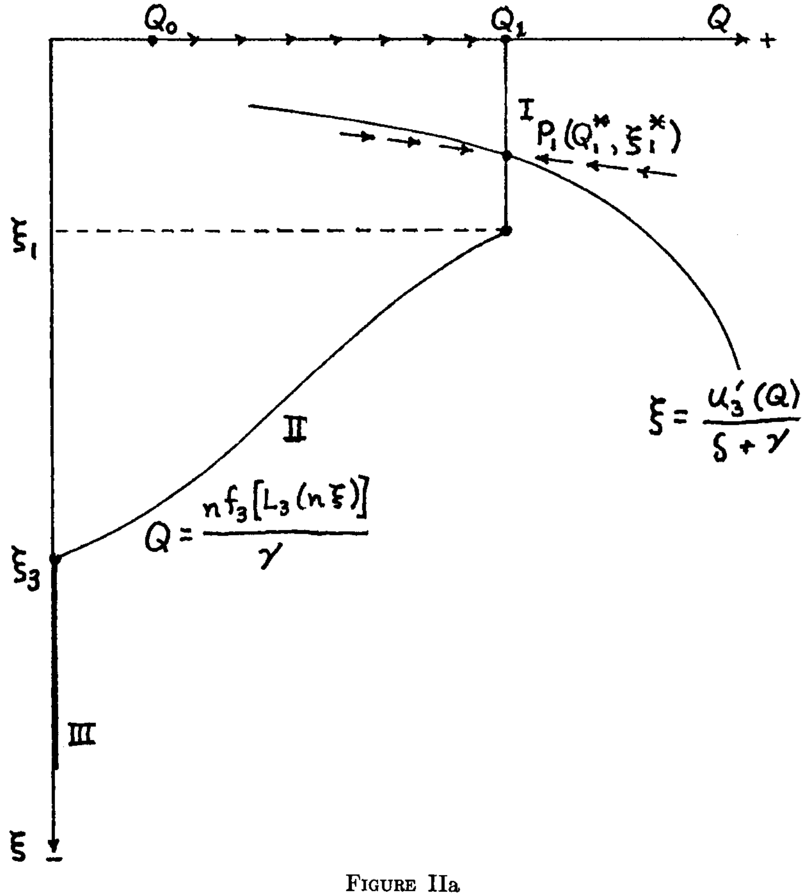

FIGURE IIa

fee, while $(-n\xi)$, the public cost of accumulated waste, represents the social (opportunity) cost of *not* recycling. Equilibrium requires scrap value to be $s-n\xi>s$ so that the recycling decision of firms can include this social opportunity cost.

Conditions for Complete and Zero Recycling

Polar cases of the above analysis occur when there is recycling of all or no waste material. If the charge for waste disposal to the environment is sufficiently small, it may be the case that no waste material will be recycled. Then $L_2=0$, $f_2(0)=0$, and $f_1(L_1)=f_3(L_3)$,

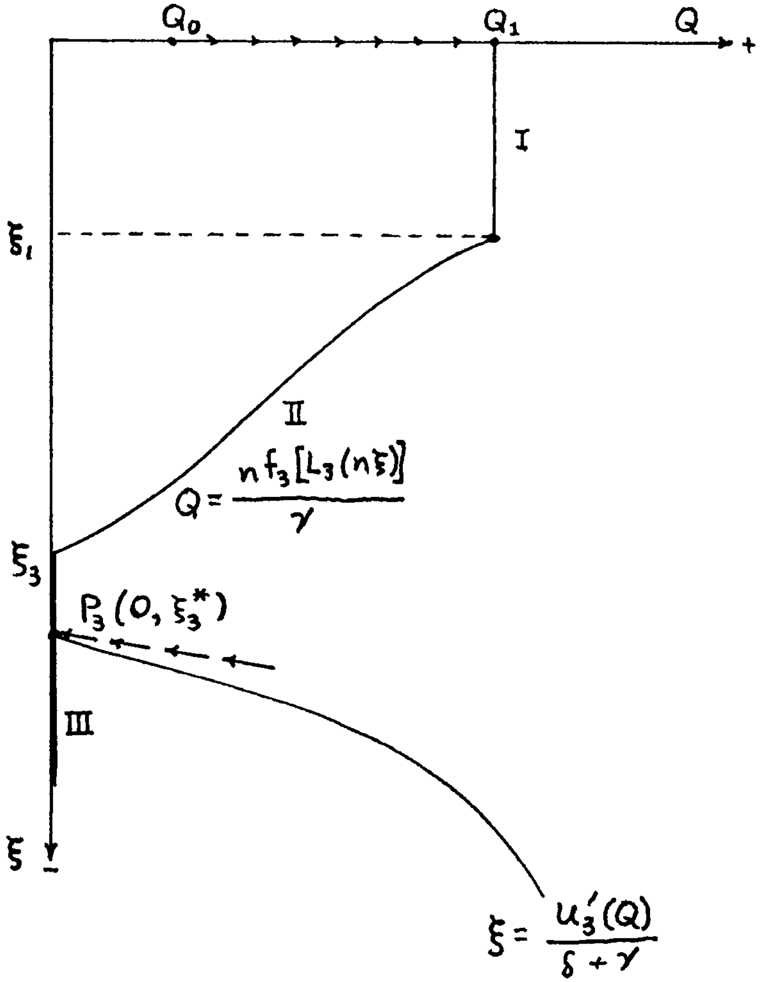

Figure IIb

$L = L_1 + L_3$; i.e., container or material production is determined jointly with commodity output. Under such conditions L_1 and L_3 will be independent of ξ, and the locus of points $Q = nf_3(L_3)/\gamma = Q_1$, a constant independent of ξ. If $L_2 = 0$ at $\xi = \xi_1$, say, then we have $Q = Q_1$ for all $\xi \geqslant \xi_1$ as shown in Figure I, segment I. An optimal path yielding a stationary equilibrium with no recycling is shown in Figure IIa.

If the charge $(-n\xi)$ is sufficiently large, we may have all waste material recycled, with $L_3 = 0$, $f_3(0) = 0$, and $f_1(L_1) = f_2(L_2)$, $L = L_1 + L_2$ so that the volume of recycling is determined jointly with commodity output. Then $Q = nf_3(0)/\gamma = 0$. In Figures I–III this case is assumed to occur for all $\xi \leqslant \xi_3$. An equilibrium path yielding a stationary equilibrium with complete recycling is shown in Figure IIb.

Pollution Under Free Competition

In a decentralized competitive economic organization, no market will exist to reflect the social cost $(-n\xi)$ of public pollution to household and firm decision makers. Each household and each firm will view waste disposal as a free activity. The stationary competitive solution is therefore obtained very simply by setting $\xi \equiv 0$ in the control model.

In Figure I, starting at the initial level Q_0, the decentralized competitive stock of waste will grow at the rate $dQ/dt = nf_3[L_3(0)] - \gamma Q > 0$ until $Q = Q_1$ as shown. In Figures I, IIa, and IIb three different optimal control solutions are illustrated for comparison with the competitive solution. In each case, the disutility of waste function is $u_3(Q)$, which yields the discounted marginal disutility of waste solution set $\xi = u_3'(Q)/(\gamma + \delta)$, for which $d\xi/dt = 0$.

If the discounted marginal disutility of waste is sufficiently low, as illustrated in Figure IIa, the control solution is at P_1, with $Q = Q_1$, and the competitive solution is also optimal.

In Figure I, representing a more odious level of discounted disutility of waste, the control equilibrium tends to P_2, at which the optimal waste stock, Q^*_2, is less than its competitively produced level, Q_1. Finally, in Figure IIb, waste is so odious, and the corresponding social cost $-\xi$ is so large, that at the stationary control equilibrium, P_3, all waste will be recycled. In such an equilibrium the social "deposit fee" on containers is large enough to induce 100 percent recycling of all such materials by firms and households. We have a "spotless" environment, and such a result, under the assumed conditions, is unattainable except through some mechanism for internalizing the public opportunity cost of waste production.

Figure III illustrates a configuration in which the private costs of recycling are sufficiently low to yield some recycling even when

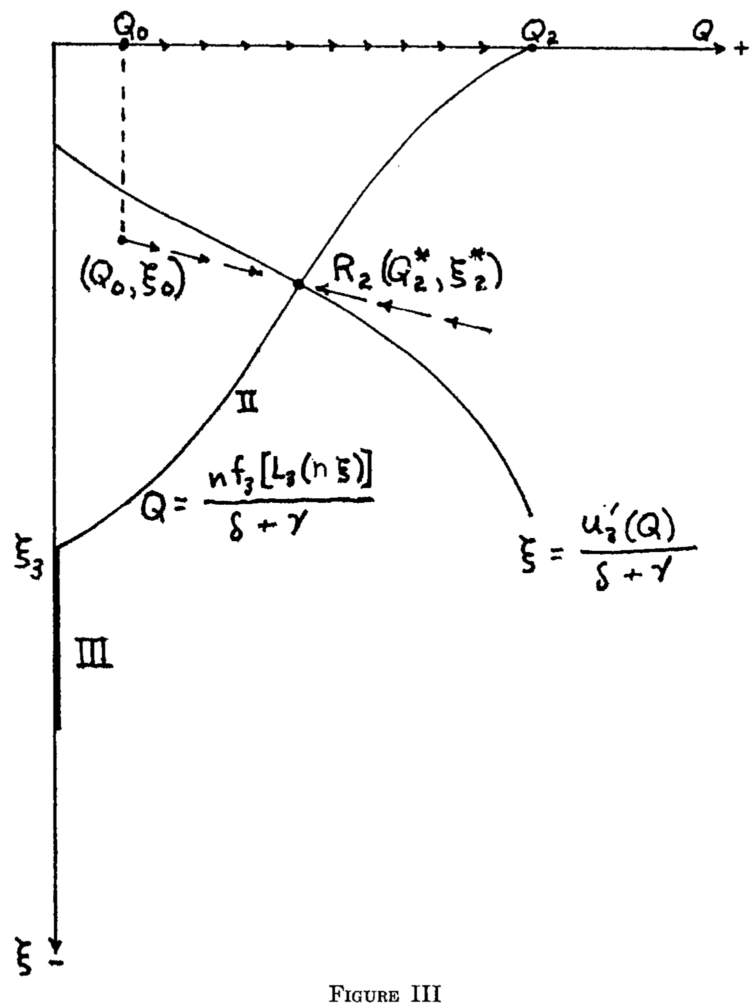

FIGURE III

the social charge $\xi = 0$. Consequently, the locus $Q = nf_3[L_3(n\xi)]/\gamma$ intersects the Q axis at some $Q = Q_2$. But $Q_2 = nf_3[L_3(0)]/\gamma$ now corresponds to the competitive stationary equilibrium stock of waste that involves some positive level of recycling based on private costs and incentives only. However, Q_2 is not a social optimum. For a social optimum still more recycling is necessary, and this occurs ultimately at the point R_2 with an appropriate waste charge ξ^*_2. An example of this configuration is to be found in the returnable milk, beer, and soft drink bottle. Until recently the private costs of recycling were low enough to induce partial recycling. But since deposit fees were modest, one can conclude that the advantages of recycling were slight. Many units were discarded at these low deposit fees, and recycling was incomplete. Eventually the returnable container gave way to the no deposit, no return unit with no recycling. One can speculate that recycling would have continued, if not increased, if deposit fees had reflected the social costs of container litter.

In Figure IV we assume that recycling cost is so much lower

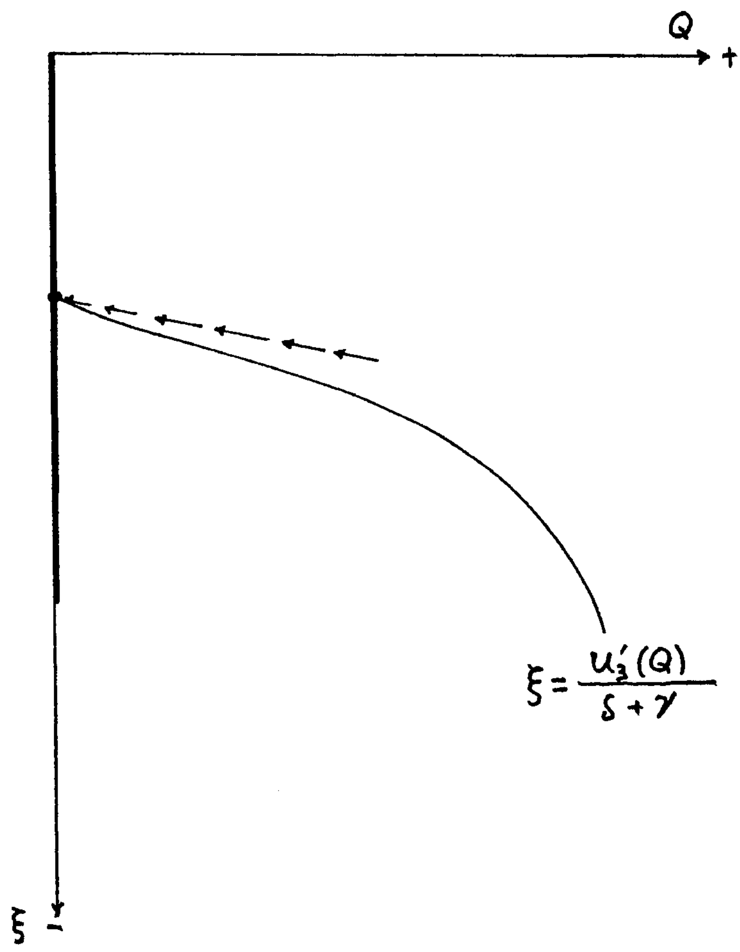

FIGURE IV

than the production of new units that the solution $L_3=0$ holds with zero disposal charge. Consequently, the stationary equilibrium is at $Q=0$, and this is achieved under decentralization competition.

Effects of Population

The effects of a change in the population level, n, on the steady state equilibrium can be determined from the resulting shift in the

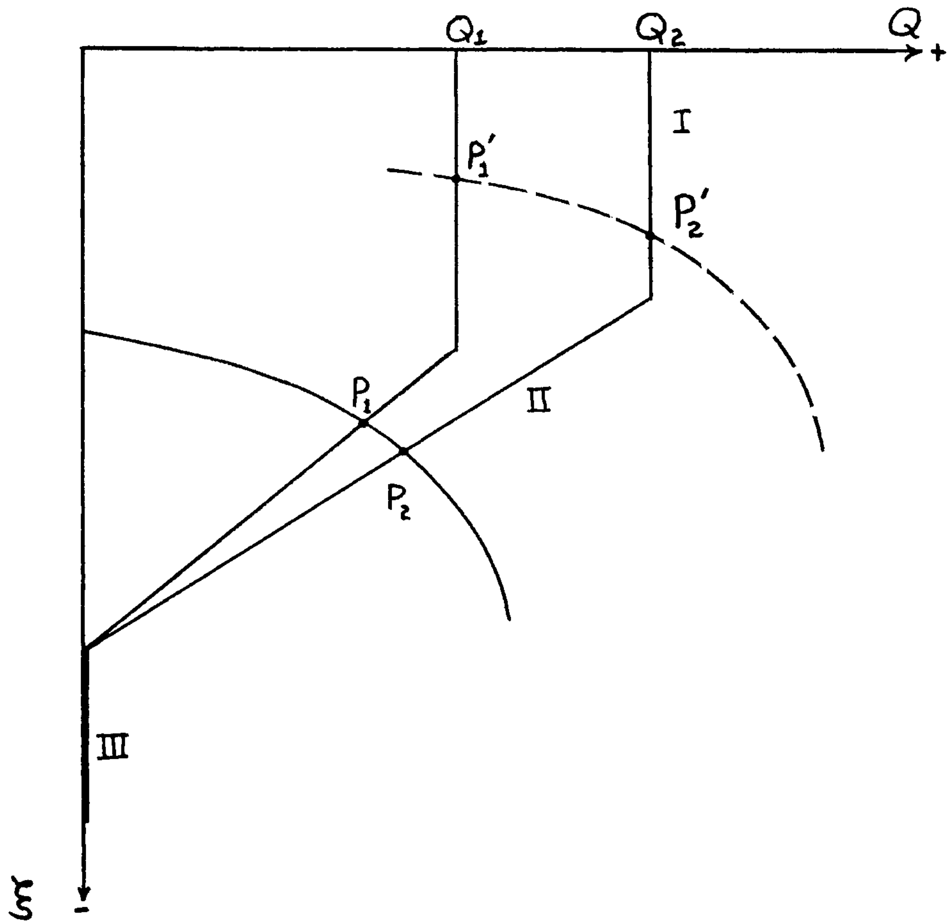

Figure V

locus $Q=nf_3[L_3(n\xi)]/\gamma$. For the three types of solutions we have $\partial Q/\partial n \geqslant 0$, as shown in the appendix (omitted). Consequently this locus shifts to the right as shown in Figure V. An increase in the population from n_1 to n_2 shifts the steady state equilibrium from

P_1 to P_2, for solutions in segment II, and from P_1' to P_2' for solutions in segment I. As expected, an increase in population increases the equilibrium stock level of waste residues, and increases the optimal equilibrium pollution charge.

Interpretation as a Waste Reduction Model

A pure waste or pollution reduction model is obtained as a special case of the model expressed in conditions (1)–(5). For each unit of commodity produced and consumed, let a unit of pollution be produced. The waste could be an industrial by-product instead of a household by-product. Pollution reduction can be obtained at a rate given by $q_2 = f_2(L_2)$, which now represents a control, or clean-up, technology. An example would be the industrial pollution of a river or lake that could be reduced by prefiltering of waste or by application of cleaning technology to the water resource itself. The resulting model is represented in (1)–(5) by setting $L_3 \equiv 0$ and removing condition (3). If only prefiltering were feasible, the constraint $q_1 \geqslant q_2$ would apply, but if the pollution stock can be reduced at any desired rate determined by $f_2(L_2)$, then $q_1 \gtreqless q_2$.

Material Production from Natural Resources

The assumption that the raw material cost of containers and commodities is zero will now be relaxed by introducing explicitly a natural extractive resource from which the material for commodities and containers is produced. The incentive for recycling will then depend not only on savings in labor and public waste reduction, but also on savings in extractive resources. We assume that material is recovered from the earth without despoiling it so that the only source of litter pollution activity is in the accumulation of unrecycled waste residues. If the mining or harvesting activity itself spoils the environment, then of course this becomes another public "bad" and a source of saving by recycling.

If the natural resource that provides the source of raw material is a nonreplenishable resource occurring in fixed initial amount, M_0, then the stock of unrecovered material at time t is $M(t) = M_0 - \int_0^t q_3(\tau)\,d\tau$, where the resource is measured in terms of commodity or container units, e.g., one automobile's worth of iron ore, or one newspaper's worth of wood. This adds a new state variable M to the system, and a new differential equation side condition $dM/dt = -q_3 = -(q_1 - q_2)$. If the resource (such as a forest) is replenishable through a natural growth process yielding new mass at the rate $f(M)$,[6] the differential equation side constraint is $dM/dt = f(M) - (q_1 - q_2)$.

It is also reasonable to assume that the material output of mines or forests depends not only on the labor input, but also on the stock of the resource, or $q_3 = q_1 - q_2 = f_3(L_3, M)$. Consequently, the production constraint becomes

$$f_3(L_3, M) - f_1(L_1) + f_2(L_2) = 0.$$

The Hamiltonian is now

$$\begin{aligned} H = u[f_1(L_1), f_2(L_2), Q] + \xi[n(f_1(L_1) - f_2(L_2)) - \gamma Q] \\ + \nu[f(M) - f_1(L_1) + f_2(L_2)] + \lambda(L - L_1 - L_2 - L_3) \\ + \mu[f_3(L_3, M) - f_1(L_1) + f_2(L_2)], \end{aligned}$$

where $f(M) \equiv 0$ in the case of a nonreplenishable resource like iron ore.

The motion of the system for the interior case must now satisfy the conditions:

$$u_1' = (\lambda/f_1') - \lambda/(\partial f_3/\partial L_3) - n\xi + \nu, \tag{10}$$

$$-u_2' + (\lambda/f_2') = \lambda/(\partial f_3/\partial L_3) - n\xi + \nu, \tag{11}$$

$$d\xi/dt = (\delta + \gamma)\xi - u_3', \tag{12}$$

$$d\nu/dt = (\delta - f')\nu - \mu(\partial f_3/\partial M), \tag{13}$$

$$dQ/dt = nf_3(L_3, M) - \gamma Q, \tag{14}$$

$$dM/dt = f(M) - f_3(L_3). \tag{15}$$

Equations (10) and (11) together with the labor and production constraints determine $L_1(n\xi, \nu, M)$, $L_2(n\xi, \nu, M)$, and $L_3(n\xi, \nu, M)$. The state of the system is then described by the four differential equations in (ξ, ν, Q, M). The shadow price of the natural resource stock, ν, now appears on the right side of (10) as a component of the marginal cost of a unit of commodity, and on the right side of (11) as a component of the marginal opportunity cost of recycling a unit of waste material. The right side of (11) now yields the three sources of marginal opportunity cost savings from recycling: labor cost, $\lambda/(\partial f_3/\partial L_3)$, public littering cost $(-n\xi)$, and material cost, ν.

6. See V. L. Smith, "Economics of Production from National Resources," *American Economic Review*, LVIII, No. 3 (June 1968), pp. 409–31; and J. P. Quirk and V. L. Smith, "Dynamic Economic Models of Fishing," in A. Scott, ed., *Economics of Fisheries Management* (Vancouver: University of British Columbia, Institute of Animal Resource Ecology, 1970).

Summary and Discussion of Policy

This paper has provided a simple control model of the economics of waste recycling. Pollution, litter, or waste disposal is assumed to enter the economic system as a public bad in household utility functions. The resulting subjective cost of using the environment for discharge is not borne directly by those whose decisions result in environmental degradation. The optimal control solution requires a price to be associated with waste discharge, depending upon the accumulated stock of waste, the interest rate, and the rate at which waste decomposes in nature. A competitive decentralized economy is generated by the model when the waste discharge price is identically zero. This corresponds to an unappropriated environment available to all as a free resource for waste discharge purposes. The control solution and the decentralized competitive solution approach the same stationary state equilibrium in two special cases: (1) The private costs of recycling are so high relative to the public disutility of waste that no recycling is economical either privately or socially. (2) The private costs of recycling are so low relative to the public disutility of waste that the decentralized economy will recycle all waste. Adding in the public cost of disposal cannot therefore increase recycling.

To economists the natural control device is a Pigouvian system of charges. The idea behind environmental "user" charges is to employ the pricing system to redirect resources in accordance with the reality of public costs associated with environmental use. A bill designed to implement this objective has been proposed in the United States Senate.[7]

The bill has two principal provisions on which the present paper has a direct bearing:

1. To establish a schedule of national packaging disposal charges that will reflect "the quantity of solid wastes which result from such packaging, the ultimate costs of disposal of such packaging, the toxicity and health effects of such packaging, the degradability of such packaging, and the likelihood that such packaging will be returned, reused, or recycled into the economy." [8]

2. The Treasury is instructed to place the revenues collected into a fund to be distributed "in each fiscal year in the form of

7. Senate bill S.3665, cited as the "Package Pollution Control Act of 1970," introduced April 1, 1970, by the Honorable Gaylord Nelson, 91st Congress, 2nd session.

8. Senate bill S.3665, p. 3.

grants to any State, municipality or interstate or intermunicipal agency for the construction of solid waste disposal and resource recovery facilities. . . ." [9]

The intent of this bill represents an effort to be commended. However, as is clear from the theory discussed in this paper, it is important that the charges be levied on packaging materials *net* of reprocessed material rather than that the charges merely take account of the "likelihood" that packaging materials will be recycled. It is essential for an effective reordering of incentives that the charge system raise the value of scrap materials relative to that of newly manufactured materials. There may be a great many circumstances in which it is economical to recycle packaging materials or commodity residue into an entirely different use.

To use the beverage container example once again, suppose reprocessing costs are such that, even with a sizable charge on net new container units, it does not pay to reuse old bottles. But with a little added incentive suppose it does pay the producers of concrete or asphalt road paving to pulverize old bottles and include such material in their output recipe. If the charge on glass containers is, say, one cent per ounce with an equivalent credit for each ounce recycled, then it is the paving material manufacturer who must receive this incentive credit. But if he produces no waste item subject to charge, his credit should be taken in the form of a direct subsidy from revenue generated by the charge system. The basic function of the bill should be to employ charges to impose the cost of waste disposal on *all* production and consumption activities that create waste, and to use the resulting revenues to subsidize *all* waste-*using*, as well as disposal, activities. In those cases in which the waste-producing and -using decisions are made by the same manufacturer (the beverage producer who can recycle used bottles, or the steel maker who can use scrap input), he will incur a charge liability, but also a subsidy credit, and should only pay on the difference. In those cases in which the waste-producing and -using decisions are made by different manufacturers, then charge funds collected from the waste producer must be transferred as subsidy funds to the waste user. Finally, and this is explicit in the bill, in cases where the waste is not used by anyone and the cost of disposal falls on states and municipalities, the charge funds are transferred to the states and municipalities to finance waste disposal.

Based on these considerations, the bill should be broadened to

9. Senate bill S.3665, p. 4.

permit payments to *any waste user* whose recycling credit exceeds any charge liability. If such a provision is not added, the bill is in danger of artificially stimulating high-cost waste disposal activities as a substitute for lower-cost waste-using activities.

Also, the bill deals only with "package pollution," and leaves open the problem of waste created by commodity residuals, such as old newspapers and magazines, derelict cars, and virtually all household durables. Charges on commodity residue would be most effectively levied on the manufacturer (and therefore also his customers) of the basic refined material (steel, copper, aluminum, paper). In each case the charge is levied on output net of scrap input. In one stroke this raises the manufacturer's incentive to bid for junk autos, refrigerators, pots and pans, cans, or whatever can be remelted into new material for fabrication into products. In the short run the effect is to decrease the profitability of plant technologies oriented to the refining of ore, relative to the profitability of plants capable of handling scrap input. In the long run it encourages development and investment in scrap-using technologies.

Discussion has centered on the use of "taxes" to internalize the costs of public waste discharge, but other devices, which are theoretically equivalent to a charge system, are possible and perhaps desirable in some cases.

One device, popular with legislatures, is the pollution quota, which is equivalent to a pollution charge when the quota is such that its shadow price is equal to the optimal public disposal charge. Under this condition the quota imposes a compliance cost on producer and household decision makers that is the equivalent of a user charge. This result, like the results generally in this paper, depends on the assumption that households share a common disutility of accumulated waste. Otherwise we have the public "bad" problem with implicit prices differing among individuals.

A decentralized alternative is that of the full-cost damage lawsuit, the use of which has been expanded by the legal institution of the class suit, wherein representatives of a class, such as the victims of oil spillage or "coke" bottle litter, bring suit against oil companies or bottlers to recover damages. This would be equivalent to the user charge system provided that the damage payments equal the discounted value of accumulated waste disutilities.

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FUNDAMENTAL ECONOMIC COMPARISONS OF SOLID WASTE POLICY OPTIONS*

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This paper examines the sources of externalities associated with post-consumer waste. A paradigm economy is constructed to compare the market and real income effects of disposal charges, recycling subsidies, user fees, and litter taxes with those of the status quo policy. The supply and demand equations of the general equilibrium system are derived and simulations are performed for each policy. Under certain assumptions, including zero transactions costs, it is concluded that real income can be maximized with a disposal charge policy, which is also the only innovative policy to assure no reduction of real income compared to the status quo, regardless of production technologies. User fees and litter taxes are found to be the next most desirable; and recycling subsidies, the least.

1. Introduction

In recent years several policy alternatives have been suggested for the management of solid waste. Disposal charges, recycling subsidies, user fees, and litter taxes have all been advanced to improve upon the inefficient pricing, institutional, and legal structures that generally dominate solid waste management in the U.S. today. Yet, theoretical comparisons of these policies are unavailable. Existing comparative work [e.g., Conn (1977)] generally consists of casual inferences about the effect of each policy on waste flows. With the aid of a very simplified model, this paper initiates a more rigorous evaluation of the solid waste policy options.

The four major inefficiencies related to solid waste management are virgin materials-biased tax policies, virgin materials-biased regulations, flat assessment pricing, and indirect subsidization of virgin materials.[1]

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[1]These inefficiencies have been observed by many others, including Anderson (1977), Fiekowsky (1975), Goddard (1975), Page (1977), and the Resource Conservation Committee (RCC) (1979). The presence of these inefficiencies diminishes the case — e.g., see Johnson (1960),

Virgin materials-biased tax policies. Current tax laws provide for virgin material depletion allowances, capital gains tax advantages on standing timber, and favorable treatment of expenses for exploration and development. All of these policies allegedly reduce the relative price of virgin materials and, hence, cause both the under-utilization of recyclables and the underpricing of waste intensive goods.

Virgin materials-biased regulations. Three administrative policies also distort relative prices of virgin and recycled materials. Many regulated freight rates are systematically lower for virgin than for recyclable materials. Second, an archaic federal law grants free mineral rights to those who make discoveries on open federal land. Finally, under the pretext of quality assurance, governments enforce virgin materials-biased labelling and procurement requirements.

Flat assessment pricing.[2] The predominant method of payment for post-consumer solid waste collection and disposal costs is flat assessments. Most commonly, flat assessments are administered through the application of property taxes, local income taxes, or federal revenue-sharing funds in payments for municipally provided services. Also prevalent is the direct administration of flat assessments by waste collection and disposal contractors. Wertz (1976, p. 269) argues that this financing method fails to make individuals aware of the waste collection and disposal component of the marginal social costs of the goods they purchase; discarding another unit of waste costs the individual nothing on the margin. Consequently, only the fairly weak, negative income effect from increased flat assessment rates will reduce the purchase of waste intensive goods. It is argued that waste volumes would be further reduced if the price of those goods were set at full marginal cost, including their waste handling costs. This presumably would engage the potentially more powerful substitution effect.

Indirect subsidization of virgin materials. Another less commonly mentioned distortion, as noted in Summers (1973, ch. 3), Smith (1974), and Train (1976, p. 1), is attributed to the market's failure to incorporate the eventual collection and disposal costs of some virgin materials in their prices. By comparison, not only do recyclable materials prices include collection costs,

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Becker (1965), and Arthur D. Little, Inc. (1966) — for 'materialism', defined as the relatively high consumption of waste intensive goods in developed countries. With efficient pricing, such consumption is said to enhance social welfare because it conserves other apparently scarcer resources such as labor, time, and energy.

[2]The potential inefficiencies of flat assessments have been noted elsewhere for such pricing schemes as fixed monthly billing for drinking water, single-price, unlimited-travel airline or rail passenger tickets, per capita cost sharing of party or meal costs, etc. In all cases, the marginal private cost of additional consumption is zero, potentially causing welfare losses, depending upon transaction costs and other market factors.

but also their use avoids disposal costs. Therefore, even apart from the distortions in the relative price of virgin and recyclable materials mentioned above, this indirect subsidy alone is allegedly accountable for underpriced virgin materials. Supposedly, this simultaneously induces excessive use of underpriced materials, and hence, excessive generation of wastes, while inhibiting the use of recyclables.

These inefficiencies would presumably be reduced by four proposed alternative solid waste management policies [e.g., see Sec. 8002 (j) of U.S. Congress (1976), RCC (1979), and U.S. Senate (1976)]. Disposal charges would essentially tax virgin materials that are eventually to be disposed as post-consumer solid waste; the tax rate would equal the marginal social cost of solid waste handling. Recycling subsidies would provide for direct payments to users of recycled materials on a unit basis. User fees would be direct, volume-sensitive charges for waste handling services in proportion to the extent that households and businesses use them. Litter taxes would be simple excise taxes for litter collection.[3]

This paper seeks to examine how effectively each of these four policy options deal with these inefficiencies. The four policies are compared to each other and to the status quo, under a variety of assumptions about production and recycling technologies. The ultimate goal is to learn whether there is a consistent ranking of these policies in terms of their effect on real income.

The analysis begins in section 2 with the development of a paradigm model of a simply economy. The model assumes the existence of only the flat assessment pricing problem and the indirect subsidization of virgin materials (the last two of the four major inefficiencies listed above). Downward biases in the relative prices of virgin materials are assumed to be non-existent.[4] Littering is also assumed to be non-existent, and transactions costs are assumed to be zero. In section 3, this paradigm is used to specify market equilibrium conditions under each of the five policy settings. Section 4 presents policy simulations which are used in section 5 to draw tentative conclusions about the relative real income, net waste, waste generation, resource recovery and recycling rate effects of the alternative policies.

The policy simulations generally show that the product disposal charge is consistently the most preferred policy; and recycling subsidies, the least preferred. They also show that the recycling rate can be a very poor indicator of social welfare. Additionally, the simulations illustrate very

[3]Generally the proposed litter tax rate is equal to the cost of collecting a unit of litter times the proportion of all units that are actually littered. Under such a scheme, the proceeds from the litter tax would just cover litter collection costs. For example, an official of the National Soft Drink Association has proposed a litter tax of 0.1 cent per beverage container [see NSDA (1977)].

[4]One justification for this approach is that virgin materials-biased taxes and regulations are likely best dealt with by direct removal rather than by applying countervailing policies.

effectively the constrained relationships among real income, total waste flows, recycling activities, and policy incentives. Although conclusions based on these simulations are obviously tentative, they do provide some interesting hypotheses for further investigation. Perhaps this work can proceed with a more realistic model or, at least, a model whose optimality conditions can be solved directly to obtain unambiguous statements of the comparative strength and weaknesses of each policy.

2. The model

Since the objective of this analysis is to make statements about the welfare characteristics of alternative solid waste management policies, it is necessary to define a very rudimentary general equilibrium model of a paradigm economy. The model development parallels that of neoclassical price theory, with appropriate departures to account for the materials flows that cause the solid waste problem. All model variables are defined in table 1.

The macroeconomic setting is assumed to be identical to that of the standard (timeless) general equilibrium model, except that a constitution and a government are assumed. The government represents all individuals through its constitutional authority to protect resource ownership and to expropriate (tax) and expend those resources. As usual, the economy is assumed to be autarkic and both exchange and (in this model) government functions are undertaken at no cost.

All production activities except recycling occur solely within m profit-maximizing competitive firms that are fully owned by individuals. The firms themselves are not endowed with resources and do not consume. Rather, all resources are owned and provided by individuals who are paid the value of the output (including rents) attributable to the resources they provide. Thus, the macro accounting identity is met: the total value of output (GNP) is identical to total national income.

A major departure of this model from the standard neoclassical model is that all resources other than a single natural resource are subsumed into a single factor of production. This resource endowment is a composite of human and physical capital from which a fixed total, $\bar{K}$ units, of services are available. The resource endowment is owned in equal shares by the individuals and is completely (and costlessly) mobile among all production activities in the economy. The society is also endowed with a 'mine' from which the natural resource, 'clay', is extracted. Once extracted, this material flows through the economy and can either be recycled or disposed to a sanitary landfill.

On the demand side, all individuals have identical but independent preference functions. Therefore, envy and benevolence are absent and a single indifference curve can be used to represent society's real income. In addition,