DYNAMICS OF WASTE ACCUMULATION: DISPOSAL VERSUS RECYCLING *

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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

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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 For example, W. A. Brock, "A Polluted Golden Age," unpublished, University of Rochester, 1970.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 R. Wong, "Optimal Growth with Production Inhibited by Pollution Generation," unpublished, University of Southern California, 1970.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.

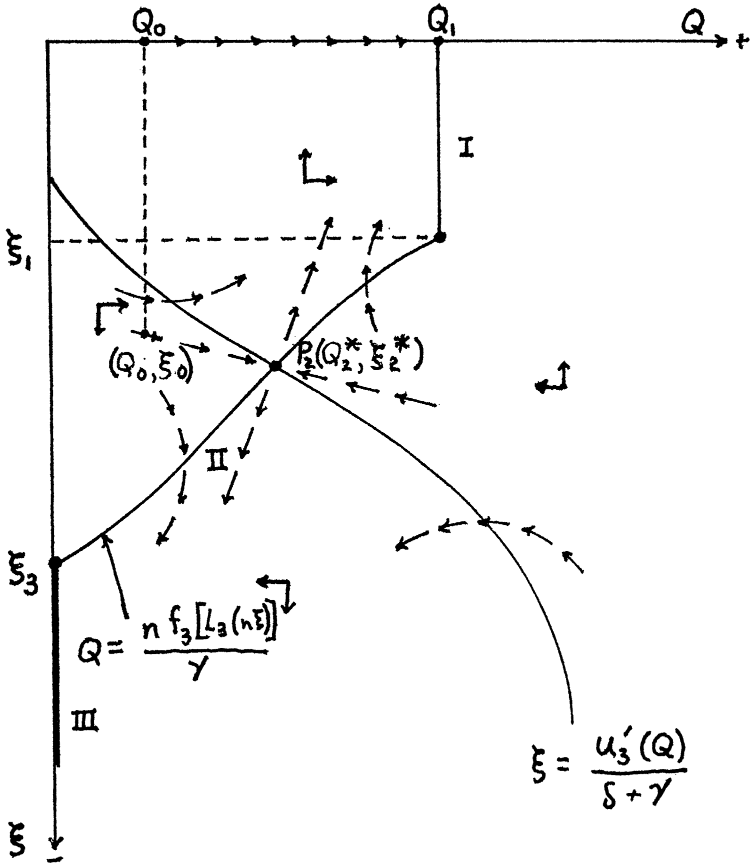

FIGURE I

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′) $u_1' = p_1 + s - n\xi,$

(7′) $-u_2' = s - n\xi.$

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

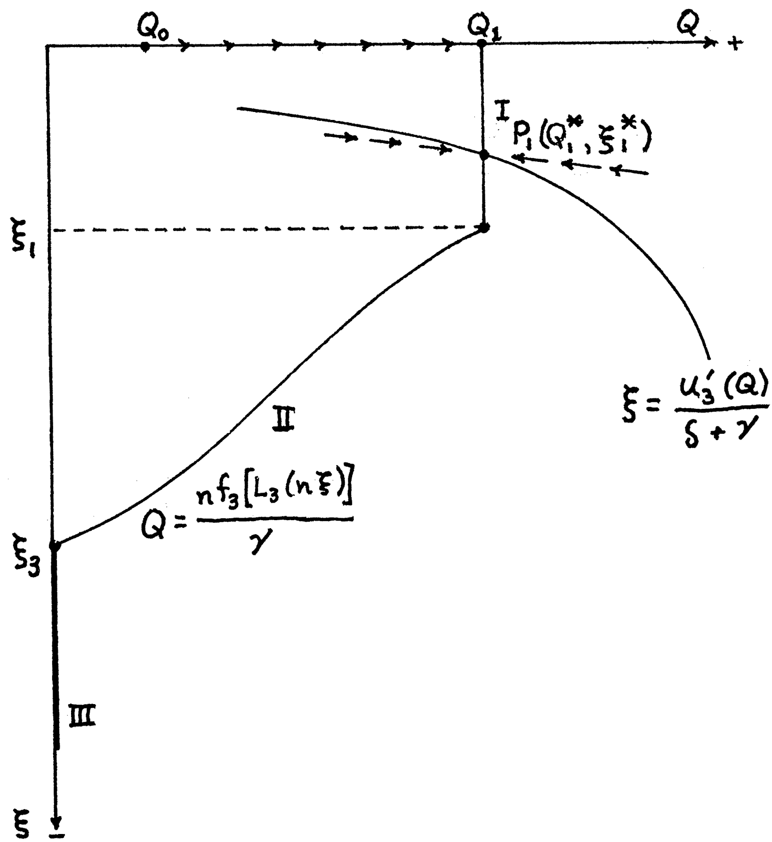

FIGURE IIa

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 $f_1(L_1)=f_3(L_3)$,

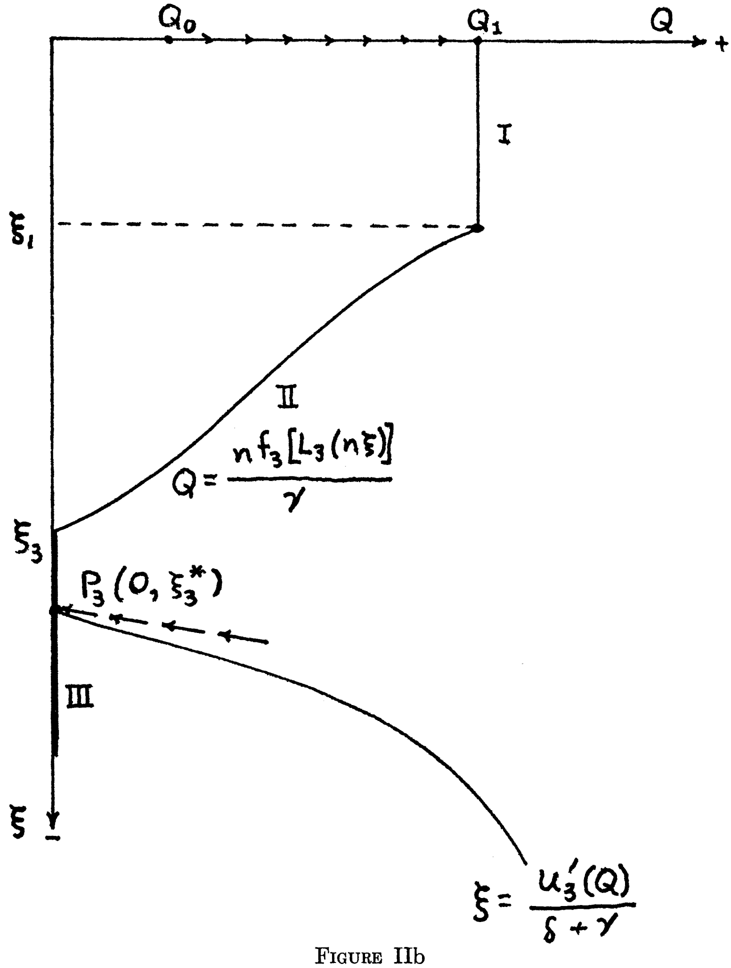

Figure IIb

$L = L_1 + L_3$; 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

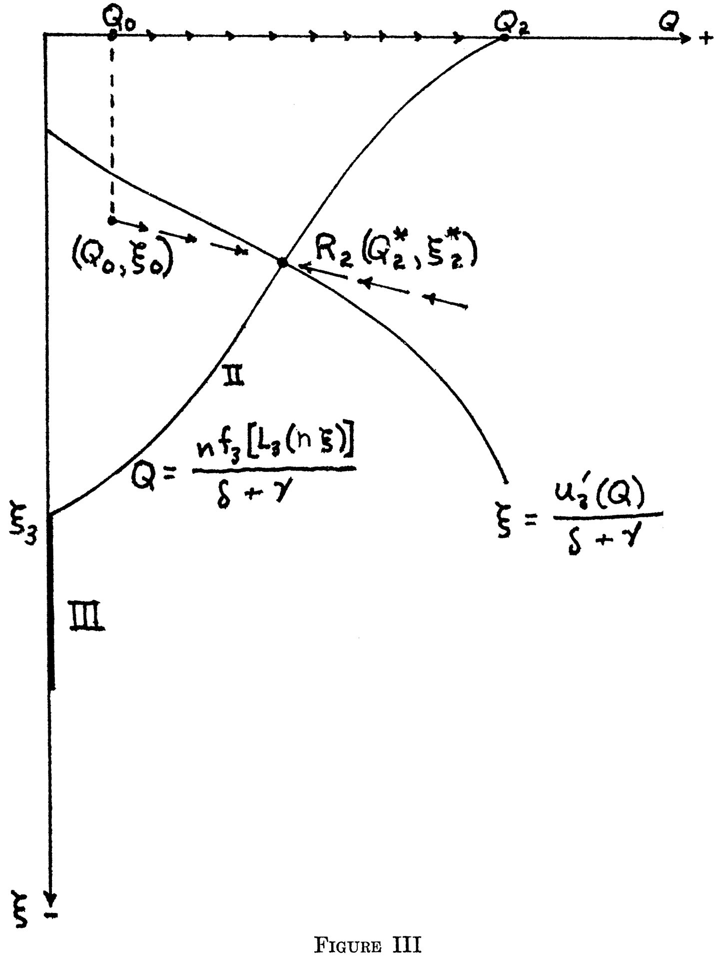

FIGURE III

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

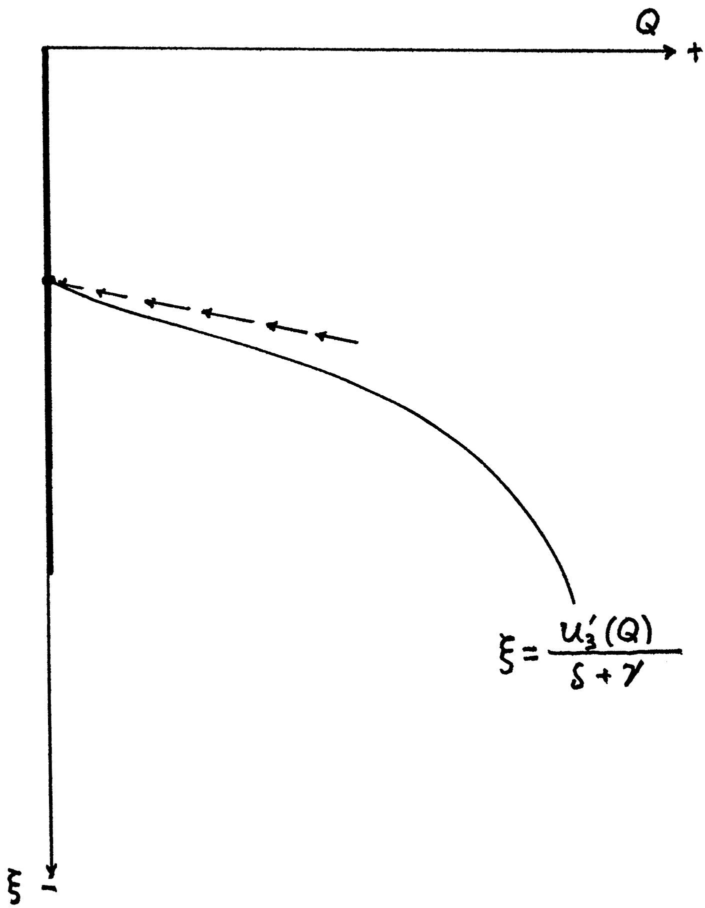

FIGURE IV

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

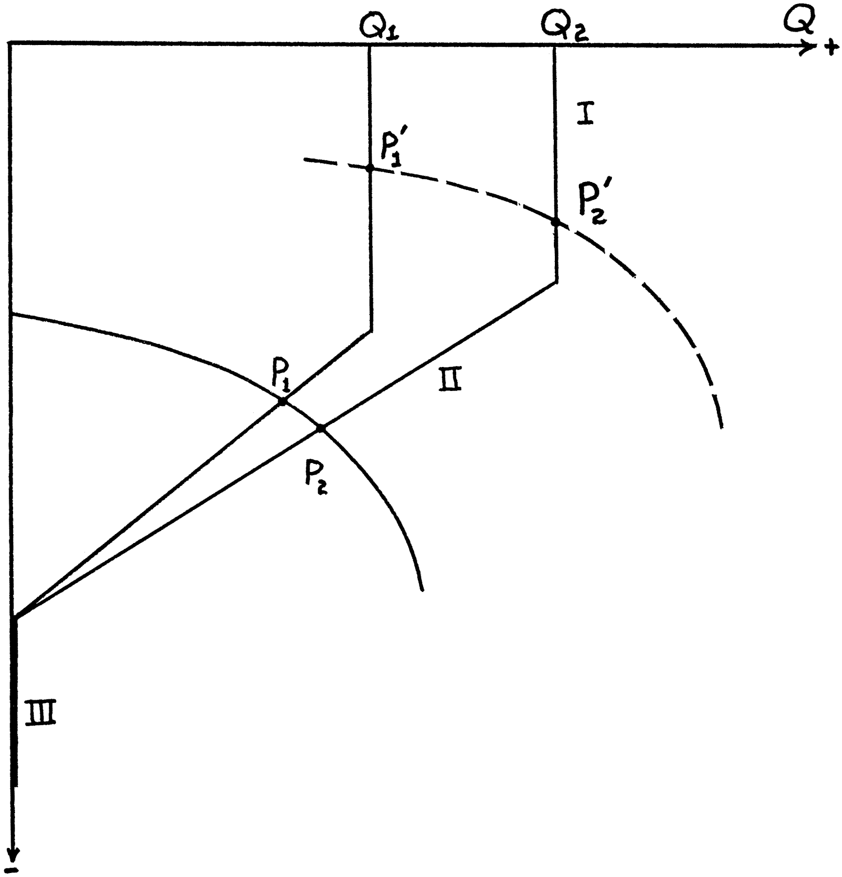

Figure V

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

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

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:

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

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

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

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

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

(15) $dM/dt = f(M) - f_3(L_3).$

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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