8 Recyclable Resources: Minerals, Paper, Bottles, and E-Waste

Man is endowed with reason and creative powers to increase and multiply his inheritance; yet up to now he has created nothing, only destroyed. The forests grow ever fewer; the rivers parch; the wildlife is gone; the climate is ruined; and with every passing day the earth becomes uglier and poorer.

—Anton Chekhov, *Uncle Vanya*, Act I (1896)

Introduction

Once used, energy resources dissipate into heat energy. They cannot be recycled. Other resources, in contrast, retain their basic physical and chemical properties during use and under the proper conditions can be recycled or reused. They therefore represent a separate category for us to examine.

What is an efficient amount of recycling? Will the market automatically generate this amount in the absence of government intervention? How does the efficient allocation over time differ between recyclable and nonrecyclable resources? We begin our investigation by describing how an efficient market in recyclable, depletable resources would work. We then use this as a benchmark to examine recycling in some detail.

An Efficient Allocation of Recyclable Resources

Extraction and Disposal Cost

How would an efficient market, one devoid of any imperfections, allocate a recyclable depletable resource? The models developed in Chapter 6 provide a point of departure for answering this question. In the earliest periods, reliance would generally be exclusively on the virgin ore, because it is cheapest. As more concentrated ores are extracted, the mining industry would turn to the lower-grade ore and to foreign sources for higher-grade ores.

In the presence of technological progress, the increasing reliance on the lower-grade ores would not necessarily precipitate an increase in cost (as shown in Example 6.1), at least initially. Eventually, however, as the sources became increasingly difficult to extract, a point would be reached at which the costs of extraction and prices of the virgin material would begin to rise.

At the same time, the costs of disposing of the products would probably rise as population density became more pronounced and wealth levels supported higher levels of waste. Over the last two centuries, the world has experienced a large increase in the geographic concentration of people. The attraction of cities and exodus from rural areas led an increasingly large number of people to live in urban or near-urban environments.

This concentration creates waste disposal problems. Historically, when land was plentiful and the waste stream was less hazardous, the remnants could be buried in landfills. But as land became scarce, burial became increasingly expensive. In addition, concerns over environmental effects on water supplies and economic effects on the value of surrounding land have made buried waste less acceptable.

The rising costs of virgin materials and of waste disposal increase the attractiveness of recycling. By recovering and reintroducing materials into the system, recycling not only provides an alternative to virgin ores, but it also reduces the waste disposal load.

Consumers, as well as manufacturers, play a role on both the demand and supply sides of the market. On the demand side, consumers would find that products depending exclusively on virgin raw materials are subject to higher prices than those relying on the cheaper recycled materials. Consequently, consumers would have a tendency to switch to products made with the recycled raw materials, as long as quality is not adversely affected. This powerful incentive is called the *composition of demand effect*.

As long as consumers bear the cost of disposal, they have the additional incentive to return their used recyclable products to collection centers. By doing so they avoid disposal costs and reap financial rewards for supplying a product someone wants.

This highly stylized version of how the market should work has to be complemented by some hard realities that must be faced in setting up actual markets. For the cycle to be complete, it is essential that a demand exist for the recycled products. New markets may ultimately emerge, but the transition may prove somewhat turbulent. Simply returning recycled products to the collection centers accomplishes little if they are simply dumped into a nearby landfill or if the supply is increased so much by mandatory recycling laws that prices for recycled materials fall through the floor (thereby destroying the incentive to continue supplying them).

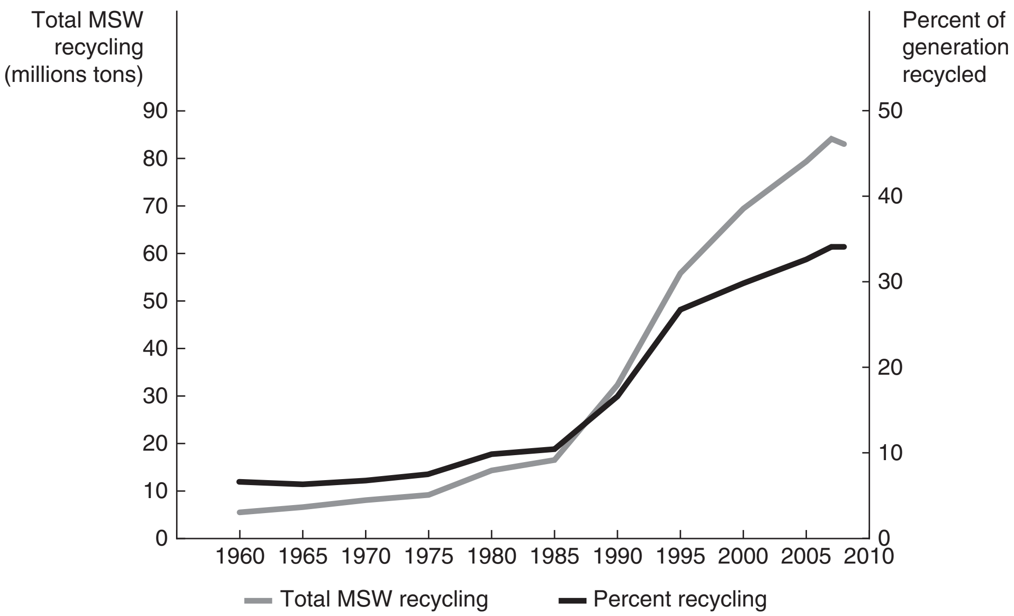
The purity of the recycled products also plays a key role in explaining the strength of demand for them. One of the reasons for the high rate of aluminum recycling and much lower rate of plastics recycling is the differential difficulty with which a high-quality product can be produced from scrap. Whereas bundles of aluminum cans have a relatively uniform quality, waste plastics tend to be highly contaminated with nonplastic substances or with plastics of very different types, and the plastics manufacturing process has little tolerance for impurities. Remaining contaminants in metals can frequently be eliminated by high-temperature combustion, but plastics are destroyed by high temperatures. Finally, waste that contains hazardous materials, such as mercury and lead, raises additional complexities. The rapidly growing stream of electronic waste (*e*-waste) contains both hazardous waste *and* valuable minerals, creating complicated dilemmas. As we discuss in a subsequent section of this chapter, markets for discarded electronics in industrializing countries may lack good enforcement mechanisms to ensure proper disposal of the hazardous components.

Recycling: A Closer Look

The model in the preceding section would lead us to expect that recycling would increase over time as virgin ore and disposal costs rose. This seems to be the case. Take copper, for example. During 1910, recycled copper accounted for about 18 percent of the total production of refined copper in the United States. By 2004 this percentage had risen to 29 percent. Approximately 40 percent of the world's copper demand today is met by recycling. And, according to the Bureau of International Recycling, an estimated 70 percent of the copper scrap exported by the United States is used by industries in China.

For other materials, recycling rates are on the rise. According to the U.S. EPA, the rate of recycled waste in the United States has risen to 33.2 percent in 2008 (Figure 8.1). For certain materials, the rates are even higher (99 percent for auto batteries, 71 percent for office paper, 48 percent for aluminum beer and soft

FIGURE 8.1 Municipal Solid-Waste Recycling Rates 1960–2008



Source: "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008," Figure 2. United States Environmental Protection Agency.

drink cans, 63 percent for steel packaging). Plastic polyethylene terephthalate (PET) bottles were recovered at a rate of 37 percent, high-density polyethylene (HDPE) bottles at a rate of 28 percent, and glass containers at a rate of 28 percent. According to another indicator, by 2006, over 8,600 curbside recycling programs were in existence. Twenty years earlier, only one curbside program was in place.

In most cases recycling is not cheap. While several types of costs are involved, transport and processing costs are usually especially significant. The sources of scrap may be concentrated around cities where most of the products are used, while for historical reasons the processing facilities are near the sources of the virgin ores. The scrap must be transported to the processing facility and the processed scrap to the market.

Labor costs are an important component of the processing costs. Collecting, sorting, and processing scrap is typically very labor intensive. Higher labor costs can make the recycled scrap less competitive in the input market. Recognizing the importance of labor costs raises the possibility that recycling rates would be higher in regions where labor costs are lower, which does seem to be the case. For example, Porter (1997) shows how vibrant markets for scrap have emerged in Africa.

Energy costs also matter. According to the Bureau of International Recycling (BIR), recycling offers significant energy savings over production from raw materials. For example, steel recycling expends 74 percent, aluminum 95 percent, copper 85 percent, paper 64 percent, and plastics 80 percent less energy. Additionally, producing materials via recycling results in less water and air pollution. BIR estimates that the production of paper via recycling causes 35 percent less water pollution and 74 percent less air pollution.

And, finally, since the processing of scrap as input into the production process can produce its own environmental consequences, compliance with environmental regulations can add to the cost of recycled input. In the United States, for example, relatively low world copper prices, coupled with high environmental compliance costs, created a cost squeeze that contributed to the closure of all U.S. secondary smelters and associated electrolytic refineries by 2001.

When recycling markets operate smoothly however, scrap becomes a cost-competitive input, and rather dramatic changes occur in the manufacturing process. Not only do manufacturers rely more heavily on recycled inputs, but also they begin to design their products to facilitate recycling. Facilitating recycling through product design is already important in industries where the connection between the manufacturer and disposal agent is particularly close. Aircraft manufacturers, which are often asked to scrap old aircraft, may stamp the alloy composition on parts during manufacturing to facilitate recycling. The idea is beginning to spread to other industries. Ski boot manufacturers in Switzerland, for example, are beginning to stamp all individual boot parts with a code to identify their composition.

Recycling and Ore Depletion

How does the efficient allocation of a recyclable resource compare with that of a nonrecyclable resource over time? Thinking back to the models in Chapter 6, perhaps the most important difference occurs in the timing of the switch point.

As long as the resource can be recycled at a marginal cost lower than that of the substitute, the market tends to rely on the recyclable resource longer than it does on a nonrecyclable resource with an identical extraction cost curve. This should not be surprising, since one effect of recycling is simply to add more of the resource.

This point can be illustrated using a simple numerical example. Suppose 100 units of a resource are contained in a product with a useful life of one year. Suppose further that 90 percent of the resource could be recovered and reused after one year. During the first year, the full 100 units could be used. At the end of the second year, 90 percent of the remaining 90 units could once again be recovered, leaving 81 units for the third year, and so on.

How much more of this resource was made available by recycling? Algebraically, if we let the original stock be A, and the recovery rate be a, then the total amount used would be an infinite sum of the form $A + Aa + Aa^2 + Aa^3$. It turns out that the sum of this series as time becomes infinitely long is $A/(1 - a)$.[1] Notice that nonrecyclable resources are represented by the special case where $a = 0$. In this case the sum of resource use equals the available stock. Whenever $a > 0$, however, as it would be when any of the resource was recycled, the sum of the resource flows exceeds the size of the original stock. The closer to 1.0 a is, the larger the sum of the resource flows. For example, if $a = 0.9$, as it was in our example, the sum of the flows is 10 times the size of the stock. The effect of recycling is to increase the size of the available resources by a factor of 10.

This formulation also points out another feature of recycling. Unless the recycling rate is 100 percent ($a = 1.0$), the sum of the resource flows is finite. This means that while some recycled materials can be recycled forever, the amount will become infinitesimally small as time goes on.

An efficient economic system will orchestrate a balance between the consumption of newly mined and recycled materials, between disposing of used products and recycling, and between imports and domestic production. Example 8.1 provides an example of how changing economic circumstances can lead to an increase in recycling.

Factors Mitigating Resource Scarcity

Recycling is promoted by resource scarcity, but resource scarcity is, in turn, affected by a number of other factors. Three alternatives have been particularly important: (1) exploration and discovery, (2) technological progress, and (3) substitution.

Exploration and Discovery

A profit-maximizing firm will undertake exploration activity until the marginal discovery cost equals the marginal scarcity rent received from a unit of the

[1] Note the similarity of $1/(1 - a)$ to the familiar multiplier used in introductory macroeconomics, $1/(1 - MPC)$.

EXAMPLE 8.1

Lead Recycling

The domestic demand for lead has changed significantly over the last 30 years. In 1972 dissipative, nonrecyclable uses of lead (primarily gasoline additives, pigments in paint, and ammunition) accounted for about 30 percent of reported consumption. And only about 30 percent of all produced lead came from recycled material.

Over the last three decades, however, congressional recognition of lead's negative health effects on children has led to a series of laws limiting the amount of allowable lead in gasoline and paints. This has resulted not only in a decline in the total amount of lead used, but also in the dramatic decline of the dissipative uses (which, by 1997, had fallen to only 13 percent of total demand). A declining role for dissipative uses implies that an increasing proportion of the production is available to be recycled. And, in fact, more is now recycled. By 2010, 80 percent of the domestic lead consumption came from recycled scrap. The lead-acid battery industry continues to be the largest user of lead.

Old (postconsumer) scrap accounts for nearly all the total lead scrap recovered. Used batteries supply about 90 percent of that old scrap. Battery manufacturers have begun entering buyback arrangements with retail outlets, both as a marketing tool for new batteries and as a means of ensuring a supply of inputs to their downstream manufacturing operations. Contrast this with aluminum, for example. In 2006, 64 percent of recycled aluminum came from new (manufacturing) scrap, while only 36 percent was from old scrap (beverage cans and other discaded aluminum products).

Source: U.S. Department of the Interior. *Minerals Yearbook* available on the Web at: http://minerals.usgs.gov/minerals/pubs/mcs/

resource sold.[2] Since the marginal scarcity rent—the difference between the price received and the marginal cost of extraction—is the marginal benefit received by the firm engaging in exploration activity, the level of activity should be increased to maximize profits until this marginal benefit is equal to the marginal cost.

An understanding of this relationship between scarcity rent and marginal discovery cost allows us to think about how exploration activity would respond to population and income growth. Since both of these factors contribute to rising demand over time, they raise the marginal user cost and the scarcity rent, stimulating producers to undertake larger marginal discovery costs.

How much this demand pressure is relieved depends upon the amount of exploration activity and the amount of resources discovered per unit of exploration activity undertaken. If the marginal discovery cost curve is flat (implying a large amount of relatively available resources), increases in scarcity rent can stimulate

[2]This is strictly true only when no uncertainty is associated with exploration. Even with uncertainty, however, marginal discovery cost is highly related to scarcity rent. See Devarajan and Fisher (1982).

large amounts of successful exploration activity. If the marginal discovery cost curve is steeply sloped (as would be the case when exploration had to take place in increasingly hostile and unproductive environments), increases in scarcity rent stimulate less exploration activity.

Technological Progress

Technological progress reduces the cost of ore by discovering new ways to extract, process, and use it. In Chapter 6, for example, we showed the significant impact of pelletization on the cost of producing steel from iron ore. The effect was so dramatic that production costs actually fell over time in spite of the need to use a lower-grade ore.

It is important to realize that the rate and type of technological progress are influenced by the degree of resource scarcity. Rising extraction costs create new profit opportunities for the development of new technologies. These profit opportunities are largest for technologies that economize on scarce resources and utilize abundant ones. In periods when labor is scarce and capital abundant, new technologies tend to use capital and save labor. If population growth were to reverse the relative scarcity, subsequent technological progress would concentrate on using labor and saving capital. In the past, when fossil-fuel energy was abundant and cheap, newly discovered technologies relied heavily on this energy source. As fossil-fuel supplies decline, technological progress can be expected to economize by increasing the amount of useful energy received per unit of fossil-fuel input and by replacing fossil-fuel energy with forms of renewable energy.

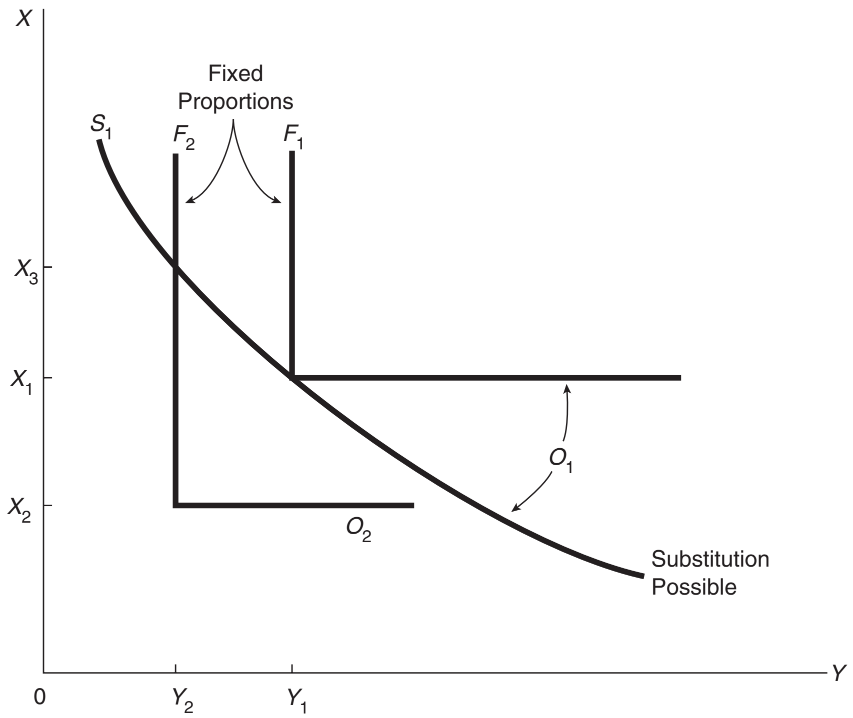
Substitution

The final way in which adverse consequences of resource scarcity can be mitigated is by substituting abundant resources for scarce ones. The easier the substitution of abundant depletable or renewable resources, the smaller will be the impact of declining availability and rising costs (see Figure 8.2).

In the graph, three isoquants (S_1, F_1, F_2) are plotted. An *isoquant* portrays all the possible combinations of inputs that can produce a given level of output. The two right-angled isoquants (F_1 and F_2) depict the fixed-proportions case, the case in which no input substitution is possible. The fixed-proportions isoquant nearer the origin (F_2) refers to a lower output level than the other fixed-proportion isoquant (F_1). The third isoquant (S_1) does show some possibility for input substitution and is drawn in such a way as to produce the same output level (O_1) as F_1. Naturally it implies a different production technology or set of technologies from F_1.

We can illustrate the significance of input substitution on output using Figure 8.2. Assume that the amount of some input Y (a depletable resource) is reduced from Y_1 to Y_2. If the technology involved is characterized by S_1, the constant output level (O_1) can be maintained by increasing the amount of the other resource

FIGURE 8.2 Output Levels and the Possibilities for Input Substitution



Source: Adapted from Table 3.9 in J. B. Opschoor and Dr. Hans B. Vos, *Economic Instruments for Environmental Protection* (Paris: Organization for Economic Cooperation and Development), p. 53.

used from X_1 to X_3. This increase in X compensates for the reduction in Y, leaving output unaffected.

Notice what happens, however, when the production process is characterized by F_1 instead of S_1. A reduction in the availability of Y from Y_1 to Y_2 necessitates a reduction in output from O_1 to O_2. No substitution of X for Y is possible. In addition, because inputs must be used in fixed proportions, the amount of X would be reduced from X_1 to X_2. Any more X would be redundant; it would not result in any additional output. These examples serve to illustrate a basic premise—the wider the array of substitution possibilities, the smaller the impact of resource scarcity on output.

This short review suggests that some factors (e.g., rising population and incomes) increase the likelihood of resource scarcity, while others (e.g., exploration and discovery, technological progress, and input substitution) mitigate the seriousness of scarcity. If resource scarcity is increasing in some sense, we should be able to discover that natural resource prices are rising more rapidly than prices in general (see Example 8.2). Resource prices, in turn, affect incentives to recycle as do the marginal costs of disposal.

EXAMPLE 8.2

The Bet

In 1980 each of two distinguished protagonists in the scarcity debate "put his money where his mouth is." Paul Ehrlich, an ecologist with a strong belief in impending scarcity, answered a challenge from Julian Simon, an economist known for his equally strong belief that concerns about impending scarcity were groundless. According to the terms of the bet, Ehrlich would hypothetically invest $200 in each of any five commodities he selected. (He picked copper, chrome, nickel, tin, and tungsten.) Ten years later the aggregate value of the same amounts of those five commodities would be calculated in real terms (after accounting for normal inflation). If the value increased, Simon would send Ehrlich a check for the difference. If the value decreased, Ehrlich would send Simon a check for the difference.

In 1990 Ehrlich performed the calculations and sent Simon a check for $576.07. Real prices for each of the five commodities were lower; some were less than half their former levels. New sources of the minerals had been discovered, substitutions away from these minerals had occurred in many of their uses (particularly computers), and the tin cartel, which had been holding up tin prices, collapsed.

Would the outcome of the Simon-Ehrlich wager have been the same if the bet had covered the entire twentieth century? According to a subsequent analysis of the data on these same minerals by McClintock and Emmett (2005), despite ups and downs in prices over the course of the past century, Simon would also have won even a century-long wager.

Finally, how would Simon have fared in decades other than the one covered by the bet? Was he just lucky to have picked the 1980s? It turns out that to some extent he was lucky. Of the ten decades in that century he would have won in five decades (the 1900s, 1910s, 1940s, 1980s, and 1990s) and lost in the remaining five. He would have lost by a few dollars in the 1950s and by more significant amounts in the other four decades. Does this evidence provide a lesson for the future? You be the judge.

Sources: John Tierney, "Betting the Planet." THE NEW YORK TIMES MAGAZINE, December 2, 1990, pp. 52–53, 74, 76, 78, 80–81; and D. McClintick and Ross B. Emmett, "The Simon-Ehrlich Debate." PERC Reports 23 (2005) (3), pp. 16–17.

Market Imperfections

As we discovered in the discussion of the role of oil in national security, when mineral imports are critically important and come from risky sources, the market perceives a biased price ratio, one that fails to incorporate some of the social costs of imports. The result would be an inefficient and excessive reliance on imports.

Other market imperfections are apparent as well. An unbalanced treatment of waste by producers and consumers can lead to biases in the market choices between recycling and the use of virgin ores. Since disposal cost is a key ingredient in determining the efficient amount of recycling, the failure of an economic agent to bear the full cost of disposal implies a bias toward virgin materials and away from recycling. We begin by considering how the method of financing the disposal of potentially recyclable waste affects the level of recycling.

Disposal Cost and Efficiency

The efficient level of recycling depends on the marginal cost of disposal. Suppose, for example, it costs a community \$20 per ton to recycle a particular waste product that can ultimately be sold to a local manufacturer for \$10 per ton. Can we conclude that this is an inefficient recycling venture because it is losing money? No, we can't! In addition to earning the \$10 per ton from selling the recycled product, the town is avoiding the cost of disposing of the product. This avoided marginal cost is appropriately considered a marginal benefit from recycling. Suppose the marginal avoided disposal cost was \$20 per ton. In this case, the benefits to the town from recycling would be \$30 per ton (\$20 per ton avoided cost plus \$10 per ton resale value) and the cost would be \$20 per ton; this would be an efficient recycling venture. Both marginal disposal costs and the prices of recycled materials directly affect the efficient level of recycling.

The Disposal Decision

Potentially recyclable waste can be divided into two types of scrap: old scrap and new scrap. *New scrap* is composed of the residual materials generated during production. For example, as steel beams are formed, the small remnants of steel left over are new scrap. *Old scrap* is recovered from products used by consumers.

To illustrate the relative importance of new scrap and old scrap, consider that in the U.S. aluminum industry, about 40 percent of the recovered aluminum scrap comes from old scrap. The difficulties in recycling new scrap are significantly less than those in recycling old scrap. New scrap is already at the place of production, and with most processes it can simply be reentered into the input stream without transportation costs. Transport costs tend to be an important part of the cost of using old scrap.

Equally important are the incentives involved. Since new scrap never leaves the factory, it remains under the complete control of the manufacturer. Having the joint responsibility of creating a product and dealing with the scrap, the manufacturer now has an incentive to design the product with the use of the new scrap in mind. It would be advantageous to establish procedures guaranteeing the homogeneity of the scrap and minimizing the amount of processing necessary to recycle it. For all these reasons, it is likely the market for new scrap will work efficiently and effectively.

Unfortunately, the same is not true for old scrap. The market works inefficiently because the product users do not bear the full marginal social costs of disposing of their product. As a result, the market is biased away from recycling old scrap and toward the use of virgin materials.

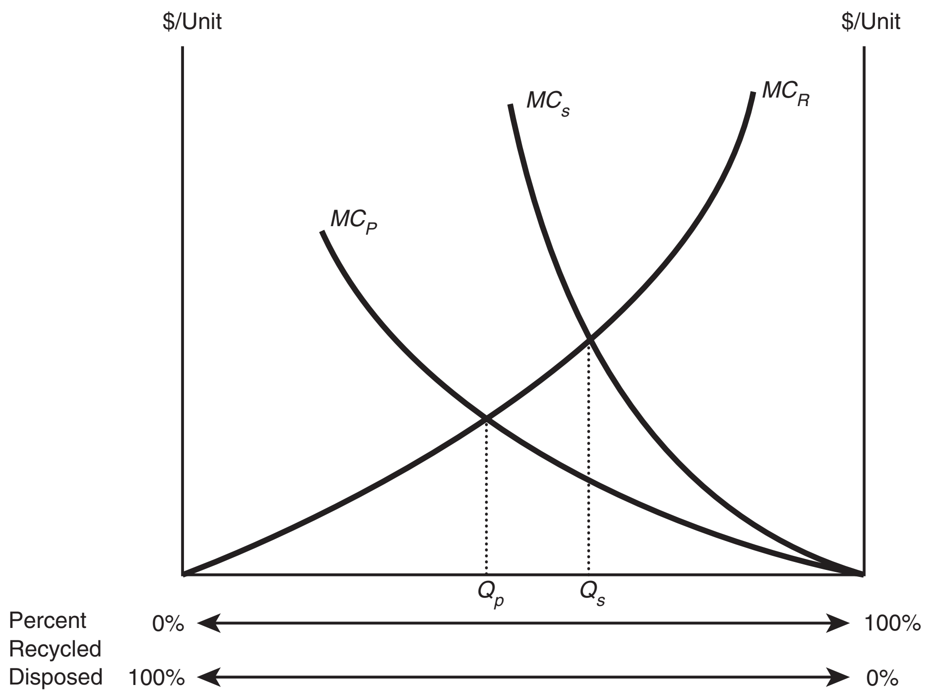
The key to understanding why these costs are not internalized lies in the incentives facing individual product users. Suppose you had some small aluminum products that were no longer useful to you. You could either recycle them, which usually means driving to a recycling center, or you could toss them into your trash. In comparing these two alternatives, notice that recycling imposes one cost on you (transport cost), while the second imposes another (disposal cost).

It is difficult for consumers to act efficiently because of the way trash collection has traditionally been financed. Urban areas have generally financed trash collection with taxes, if publicly provided, or a flat-rate fee, if privately provided. Neither of these approaches directly relates the size of an individual's payment to the amount of waste. The *marginal* cost to the homeowner of throwing out one more unit of trash is negligible, even when the cost to society is not. The marginal private disposal cost and the cost to society as a whole diverge (see Figure 8.3).

When the private marginal cost of disposal (MC_P) is lower than the marginal social cost of disposal (MC_s), the market level of recycling [where the marginal cost of recycling (MC_R) is equal to the marginal private disposal cost] is inefficient. Only if all social costs are included in the marginal cost of disposal will the efficient amount of recycling (Q_s) be attained.[3]

This point can be reinforced by a numerical example. Suppose your city provides trash pickup for which you pay $150 a year in taxes. Your cost will be

FIGURE 8.3 The Efficient Level of Recycling



[3]According to Figure 8.3, would 100 percent recycling normally be efficient? Does that conclusion make sense to you? Why or why not?

$150 regardless (within reasonable limits) of how much you throw out. In that year your additional (marginal) cost from throwing out these items is *zero*. Certainly the marginal cost to society is not zero, and, therefore, the balance between these alternatives as seen by the individual homeowner is biased in favor of throwing things out.[4]

Littering is an extreme example of what we have been talking about. In the absence of some kind of government intervention, the cost to society of littering is the aesthetic loss plus the risk of damage to automobile tires and pedestrians caused by sharp edges of discarded cans or glass. Tossing used containers outside the car is relatively costless for the individual, but costly for society.[5]

Disposal Costs and the Scrap Market

How would the market respond to a policy forcing product users to bear the true marginal disposal cost? The major effect would be on the supply of materials to be recycled. Recycling would now offer consumers a way to avoid disposal costs and possibly even be paid for discarded products. This would cause the diversion of some materials to recycling centers, where they could be reintegrated into the materials process. If this expanded supply allows dealers to take advantage of previously unexploited economies of scale, this expansion could well result in a lower average cost of processing, as well as more recycled materials.

The total consumption of inputs would increase because the price falls. The use of recycled materials increases as well. The amount of virgin ore falls. Thus, the correct inclusion of disposal cost would tend to increase the amount of recycling and extend the useful economic life for depletable, recyclable resources.

Subsidies on Raw Materials

Disposal costs are only part of the story. Inputs derived from recycling can only compete with raw materials if the playing field is level. Subsidies on raw materials are another troubling source of inefficiencies that create a bias away from recycled inputs.

Subsidies can take many forms. One form is illustrated by the U.S. Mining Law of 1872. This law, which was originally passed more than 150 years ago to promote mining on public lands, is still on the books. Under this law, miners can stake lode claims (for subsurface minerals) and placer claims (for surface minerals) for mineral prospecting on public lands. A claim can be maintained for a payment of only $100 a year. If minerals are discovered in a claim area and at least $500 has been invested in development or extraction, the land could actually be bought for $5 an acre on lode claims or $2.50 an acre on placer claims. In 1999 the U.S. Congress enacted a moratorium on land purchases, but not on staking claims.

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[4]The problem is not that $150 is too low; indeed it may be too high! The point is that the cost of waste disposal does not increase with the amount of waste to be disposed.

[5]Using economic analysis, would you expect transients or residents to have a higher propensity to litter? (Why?)

These prices for access to public lands are so low relative to market prices that they constitute a considerable implicit subsidy. As a result of this subsidy, taxpayers not only don't receive the true value of the mining services provided by public lands, but the subsidy has the effect of lowering the cost of extracting these raw minerals. As a result, raw materials are artificially cheap and can inefficiently undermine the market for recycled inputs.

Corrective Public Policies

Why are recycling rates so low? No doubt some of the responsibility lies in improper incentives created by inappropriate pricing. Can the misallocation resulting from inefficiently low disposal cost be corrected?

One approach, volume pricing, would impose disposal charges reflecting the true social cost of disposal (see Example 8.3).

A preimplementation concern about volume pricing was that it might impose a hardship on the poor residents of the area. Strategies based on higher prices always raise the specter that they will end up placing an intolerable burden on the poor. In the case examined by Example 8.3 that concern was apparently misplaced. Under the old system of financing trash collection, every household paid the same fee regardless of how much trash is produced. Since lower-income

EXAMPLE 8.3

Pricing Trash in Marietta, Georgia

In 1994 the people of Marietta, Georgia participated in a demonstration project that changed the way in which waste was priced. The traditional $15 monthly fee for trash pickup was cut to $8 per month. In addition, half of the residents faced a per-bag price on waste ($0.75 per bag), while the rest faced a monthly fee for pickup that depended on the maximum number of cans per month that the customer wished to have picked up per month. This number was contracted in advance by the customer and did not vary from month to month. The fee was $3 or $4 per can (depending upon the number).

Economic theory suggests that while both plans should reduce waste and increase recycling, the per-bag fee should promote more. (Can you see why?)

And indeed that is what happened. The can program reduced nonrecycled waste by about 20 percent, whereas the bag program reduced it by as much as 51 percent. Both programs had an equally strong effect on encouraging households to recycle. Both programs not only diverted waste into recycling, they also reduced the amount of waste generated.

Could the costs associated with the program be justified in benefit–cost terms? According to the economists who conducted the study, they were. The net benefits for the city were estimated to be $586 per day for the bag program and $234 per day for the can program.

Source: G. L. Van Houtven and G. E. Morris. "Household Behavior Under Alternative Pay-as-You-Throw Systems for Solid Waste Disposal," *Land Economics* Vol. 75, No. 4 November 1999, pp. 515–537.

households produce less trash, they were, in effect, subsidizing wealthier households. Under the new system, lower-income households pay only a flat fee since they don't need to purchase stickers for additional disposal. The expense of these stickers is less than the average cost of disposal, which was the basis for the previous fee. Poor households have turned out to be better off, not worse off, under the new pricing system.

Another suggestion for promoting recycling now being applied in many areas is the refundable deposit. Already widely accepted for beverage containers, such deposits could become a remedy for many other products.

A refund system is designed to accomplish two purposes: (1) the initial charge reflects the cost of disposal and produces the desired composition of demand effect; and (2) the refund, attainable upon turning the product in for recycling, helps conserve virgin materials. Such a system is already employed in Sweden and Norway to counter the problem of abandoned automobiles.

The recycling of aluminum beverage cans has been one clear beneficiary of deposit refund schemes.[6] Quite a few countries, including Germany, Finland, Norway, Denmark, Sweden, Barbados, Canada, and the state of South Australia, and 11 U.S. states have container deposit refund programs in place. Although not all states have passed bottle bills, over 50 percent of aluminum beverage cans are now recycled in the United States. As a result, aluminum old scrap has become an increasingly significant component of total aluminum supplies. Recycling aluminum saves about 95 percent of the energy that is needed to make new aluminum from ore. The magnitude of these energy savings has had a significant influence on the demand for recycled aluminum as cost-conscious producers search for new ways to reduce energy costs. Debate 8.1 explores why only some states have implemented refundable bottle deposits.

Beverage container deposits also reduce illegal disposal (littering) because an incentive is created to bring the bottle or can to a recycling center. In some cities, scavenging and returning these bottles has provided a significant source of income to the homeless. One Canadian study found that recycling creates six times as many jobs as landfilling.

Deposit-refund systems are also being used for batteries and tires. New Hampshire and Maine, for example, place a surcharge on new car batteries. Consumers in these states receive a rebate if they trade in their used battery for a new one. Oklahoma places a $1 fee on each new tire sold and then returns $0.50 to certified processing facilities for each tire handled.

Some states in the United States, as well as some developing countries, also use deposit-refund systems to assure that pesticide containers are returned after use. Since these containers usually contain toxic residues after use, which can contaminate water and soil, collecting the containers and either reusing them or properly decontaminating them can eliminate this contamination threat.

Some areas attempt to enlist economic incentives by imposing a disposal or recycling surcharge on the product. Paid at the time of purchase of a new product,

[6] A very strong demand for aluminum scrap was also influential. In fact, the price for aluminum scrap went so high in 1988 that pilferers were stealing highway signs and guardrails for their aluminum content.

DEBATE 8.1

"Bottle Bills": Economic Incentives at Work?

Ten U.S. states—California, Connecticut, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Oregon, and Vermont—have passed "bottle bill" legislation. One city, Columbia, Missouri, also passed legislation, but it was repealed in 2002. Delaware's bottle-deposit system was repealed in 2010, effective February 2011. Every year, several states either have proposed new legislation or proposed expansions of existing legislation. More often than not, these proposed bills do not pass. Bottle deposits in the United States range from \$0.05 to \$0.15 and laws vary on which containers are redeemable for deposits.

While on average, U.S. container recycling rates have been below 40 percent, recycling rates in bottle-deposit states are much higher, averaging around 80 percent. Michigan's \$0.10 beverage can deposit produced recycling rates close to 100 percent. Statistics on litter reduction show the largest gains in bottle-deposit states.

Although bottle-deposit states have recycling rates double those of states without deposits, that is not sufficient evidence to suggest that it would be efficient for all states to have them.

Economic studies on the efficiency of bottle deposits are limited. Porter (1983) estimated the costs and benefits of the then newly passed Michigan bottle bill. He found that for most estimates of costs and benefits, the bill passed a benefit–cost test. Ashenmiller (2009) finds that bottle deposits increase the numbers of recycled containers and reduce waste stream costs by diverting these containers away from curbside programs. Using survey data from California, he finds between 36 percent and 51 percent of materials at redemption centers would not have been collected using existing curbside programs alone (without the complementary deposit-refund system). Interestingly, however, some of the success of the California program can be attributed to its design—its curbside programs use volume-based pricing for trash. This analysis also notes that curbside programs work best in densely populated areas and that cash recycling programs can be an important income source for the working poor.

Since the efficiency of deposit–refund systems depends on their cost, they may be efficient for some states, but not others. Key determinants of the relative costs of bottle deposits vary from state to state. Disposal costs depend on landfill availability, and return rates depend on population densities and distances to redemption centers. States with bottle deposits may incur the extra expense of illegal returns from bottles purchased in nearby states that do not require a deposit. Enforcement across state lines is costly and imperfect. States with large bottlers like Coca-Cola are usually opposed to bottle deposits. Does your state have a bottle deposit? Does that seem the right choice?

Sources: http://globalwarming.house.gov/mediacenter/pressreleases?id=0126; www.containerrecycling institute.org; Richard C. Porter, "Michigan's Experience with Mandatory Deposits on Beverage Containers." LAND AND ECONOMICS, 59 (1983); Bevin Ashenmiller, "Cash Recyling, Waste Disposal Costs, and the Incomes of the Working Poor: Evidence from California." LAND ECONOMICS, 85(3), August 2009.

this surcharge would normally be designed to recover the costs of recycling the product at the end of its useful life; more-difficult-to-recycle products would have larger fees. These fees would normally be coupled with a requirement that the revenue be used by sellers to set up recycling systems. Assuming these fees correctly internalize the costs of recycling, they will provide consumers with incentives to take the recycling and disposal costs into account, since easier-to-recycle products would have a lower price (including the fee). Note, however, that these recycling surcharges do not provide any incentive against illegal disposal, since the consumer gets no rebate for dropping the product off at a collection center, but it they provide no specific incentive for illegal disposal either. Since the surcharge is paid up front, it cannot be avoided by illegal disposal. In this sense, the deposit-refund system is clearly superior to either recycling surcharges or volume pricing of trash.

The tax system can also be used to promote recycling by taxing virgin materials and by subsidizing recycling activities. The European approach to waste oil recycling, reinforced by the high cost of imported crude oil, was to require both residential and commercial users to recycle all waste oil they generate. Virgin lubricating oils are taxed, and the resulting income is used to subsidize the recycling industry. As a result, many countries collect up to 65 percent of the available waste oil.

In the United States, which does not subsidize waste oil recycling, the waste oil market has been rather less successful, but it is growing. In California in 2005, almost 60 percent of used lubricated oil was recycled. Laws in most states prohibit used oil disposal.

Many areas are now using tax policy to subsidize the acquisition of recycling equipment in both the public and private sectors. Frequently taking the form of sales-tax exemptions or investment tax credits to private industries or loans or grants to local communities, these approaches are designed to get recycling programs off the ground, with the expectation that they will ultimately be self-sustaining. The pioneers are being subsidized.

Examining Oregon's program can serve to illustrate how a tax approach works. From 1981 to 1987, to reduce energy consumption as well as to promote recycling, the Oregon Department of Energy granted tax credits to 163 projects. Being granted this credit allows companies a five-year period in which to deduct from their taxes an amount equal to 35 percent of the cost of any equipment used solely for recycling. Oregon also offers a broader tax credit that covers equipment, land, and building purchases. Paper companies, the major recipients of both types of credits, have used them to increase the capacity to use recycled newsprint and cardboard in the papermaking process. According to Shea (1988), these incentives helped to raise Oregon's newspaper recycling rate (65 percent) to twice the national average.

Any long-run solution to the solid-waste problem must not only influence consumer choices about purchasing, packaging, and disposal, it must also influence producer choices about product design (to increase recyclability), product packaging, and the use of recycled (as opposed to virgin materials) in the production process. One general approach is called extended producer responsibility, and it involves requiring producers to take back packaging, and even their products, at the end of their useful life (see Example 8.4).

EXAMPLE 8.4

Implementing the "Take-Back" Principle

According to the "take-back" principle, all producers should be required to accept responsibility for their products—including packaging—from cradle to grave by taking them back once they have outlived their useful lives. In principle, this requirement was designed to encourage the elimination of inessential packaging, to stimulate the search for products and packaging that are easier to recycle, and to support the substitution of recycled inputs for virgin inputs in the production process.

Germany has required producers (and retailers as intermediaries) to accept all packaging associated with products, including such different types of packaging as the cardboard boxes used for shipping hundreds of toothbrushes to retailers, to the tube that toothpaste is sold in. Consumers are encouraged to return the packaging by means of a combination of convenient drop-off centers, refundable deposits on some packages, and high disposal costs for packaging that is thrown away.

Producers responded by setting up a new, private, nonprofit corporation, the Duales System Deutschland (DSD), to collect the packaging and to recycle the collected materials. This corporation is funded by fees levied on producers. The fees are based on the number of kilograms of packaging the producers use. The DSD accepts only packaging that it has certified as recyclable. Once certification is received, producers are allowed to display a green dot on their product, signaling consumers that this product is accepted by the DSD system. Other packaging must be returned directly to the producer or to the retailer, who returns it to the producer.

The law has apparently reduced the amount of packaging produced and has diverted a significant amount of packaging away from incineration and landfills. A most noteworthy failure, however, was the inability of the DSD system to find markets for the recycled materials it collected. Some German packaging even ended up in neighboring countries, causing some international backlash. The circumstance where the supply of recycled materials far exceeds the demand is so common—not only in Germany, but in the rest of the world as well—that further efforts to increase the degree of recycling will likely flounder unless new markets for recycled materials are forthcoming.

Despite the initial difficulties with implementing the "take-back" principle, the idea that manufacturers should have ultimate responsibility for their products has a sufficiently powerful appeal that it has moved beyond an exclusive focus on packaging and is now expanding to include the products themselves. In 2002, the European Union (EU) passed a law that makes manufacturers financially responsible for recycling the appliances they produce. In 2004, the European Union's Waste Electrical and Electronic Equipment (WEEE) directive came into effect, making it the responsibility of the manufacturers and importers in EU states to take back their products and to properly dispose of them.

As part of the WEEE program, a pilot study was conducted in Beijing, Delhi, and Johannesburg. This study found that e-waste recycling has developed in all three countries as a market-based activity.

Sources: A. S. Rousso and S. P. Shah. "Packaging Taxes and Recycling Incentives: The German Green Dot Program," *National Tax Journal* Vol. 47, No. 3 (September 1994): 689–701; Meagan Ryan. "Packaging a Revolution," *World Watch* (September–October 1993): 28–34; Christopher Boerner and Kenneth Chilton. "False Economy: The Folly of Demand-Side Recycling," *Environment* Vol. 36, No. 1 (January/February 1994): 6–15; R. Widmer, H. Oswald-Krapf, D. Sinha-Khetriwal, M. Schnellmann, and H. Boni. "Global Perspectives on E-waste," *Environmental Impact Assessment* Vol. 25 (2005): 436–458.

Markets for Recycled Materials

Successful recycling programs depend to a large extent on the existence of markets (buyers) for recycled materials. Consider plastics, for example. Currently, PET bottles are primarily used in carpet fiber and textiles including fleece. Other potential future uses for recycled PET bottles include waterproof shipping containers and coating for paper. HDPE plastics are primarily made into bottles and garden products, such as lawn edging and lawn chairs.

The market for plastics is expanding in some areas where the capacity to process the postconsumer waste and the demand for that material is greater than the amount recovered. As new uses expand, this market can be expected to grow. According to the U.S. EPA, the American Society for Testing and Materials (ASTM) is using new test methods that are facilitating the use of recycled plastics in building materials.

E-Waste

Recognizing the dangers from improperly disposed electronic equipment (e-waste), some states have enlisted economic incentives to promote recycling. The EPA reports that in 2006–2007, 2.5 million tons of TVs, computers, computer accessories, and cell phones were discarded; 82 percent (1.84 million tons) were discarded in landfills. This does not include the approximately 235 million units (not including cell phones) that have accumulated in storage (as of 2007). Although this represented less than 2 percent of the municipal solid-waste stream, electronics waste is a fast-growing segment of it, bringing with it rising concerns about the environmental and health effects of some of this waste. Lead, mercury, cadmium, and brominated flame retardants are all widely used in electronics. All of these substances have been linked to health risks, especially for children, and are considered hazardous waste.

Did you upgrade your cell phone this year? Perhaps you got a new laptop for school. Or maybe you got a new MP3 player or iPad. What happened to the old one? The US Geological Survey (USGS) reports some 1 billion cell phones were in use worldwide in 2002. In the United States alone, the USGS reports that cell phone subscribers increased from 340,000 in 1985 to 180 million in 2004. Moreover, 130 million cell phones were retired in 2005. The U.S. EPA reports that currently less than 1 percent of cell phones discarded are recycled. Are the minerals used to make cell phones (primarily copper, iron, nickel, silver, and zinc, with smaller amounts of aluminum, gold, lead, palladium, and tin) valuable? Apparently quite valuable! Table 8.1 shows the estimated value of the metals in cell phones in the United States.

Table 8.2 lists the 24 states with e-waste legislation. To take an early example of this legislation, California passed a bill in 2003 that charges consumers a fee for buying computer monitors or televisions and pays recyclers to dispose of the displays safely when users no longer want them. Fees depend on the size of the monitor. In 2009, the fee to dispose of a monitor smaller than 15 inches was \$8, \$16 if the monitor is 15–35 inches, and \$25 for greater than 35 inches. In 2004,

TABLE 8.1 Weight and Gross Value of Selected Metals in Cell Phones in the United States

The average weight (wt) of a cell phone is estimated to be 113 grams (g), exclusive of batteries and charger (Nokia 2005). Metal contents are weights in metric tons (t), unless otherwise noted. Values in U.S. dollars are calculated by using the average of prices for 2002–2004 from USGS Mineral Commodity Summaries 2005 (Amey, 2005; Edelstein, 2005; Hilliard, 2005a, 2005b). The gross values do not include costs of recycling. Data may not add to totals shown because of independent rounding.

Metal	Metal Content and Value Estimated for a Typical Cell Phone		Metal Content and Value for 180 Million Cell Phones in Use in 2004[1]		Metal Content and Value for 130 Million Cell Phones Retired in 2005[1]		Metal Content and Value for 500 Million Obsolete Cell Phones in Storage in 2005[1]	
	Wt[2] (g)	Value ($)	Wt[3] (t)	Value ($ million)	Wt[3] (t)	Value ($ million)	Wt[3] (t)	Value ($ million)
Copper	16	0.03	2,900	6.2	2,100	4.6	7,900	17
Silver	0.35	0.06	64.1	11	46	7.9	178	31
Gold	0.034	0.40	6.2	72	3.9	52	17	199
Palladium	0.015	0.13	2.7	22.7	2.0	16	7.4	63
Platinum	0.00034	0.01	0.06	1.4	0.04	1	0.18	3.9
Total	2,973			113	2,152	82	8,102	314

[1]Number of cell phones in use in 2004 from Charny (2005). Number of cell phones retired in 2005 from U.S. Environmental Protection Agency, 2005. Number of obsolete cell phones projected to be in storage in 2005 from Most (2003).

[2]Metal content (wt) calculated from weight of a typical cell phone (Nokia 2005) and data from Rob Bouma, Falconbridge Ltd., written and oral communications, 2005.

[3]Metal content (wt) calculated from data from Rob Bouma, Falconbridge Ltd., written and oral communications, 2005.

Source: Daniel Sullivan. "Recycled Cell Phones—A Treasure Trove of Valuable Materials." USGS (2007), http://pubs.usgs.gov/fs/2006/3097/fs2006-3097.pdf.

TABLE 8.2 Current Electronics Recycling Laws in Effect and Year Passed

2003	California
2004	Maine
2005	Maryland
2006	Washington
2007	Connecticut, Minnesota, Oregon, Texas, North Carolina
2008	New Jersey, Oklahoma, Virginia, West Virginia, Missouri, Hawaii, Rhode Island, Illinois, and Michigan
2009	Indiana, Wisconsin
2010	Vermont, South Carolina, New York, Pennsylvania

Source: www.electronicsrecycling.org and www.epa.gov.

California passed a bill that makes it unlawful for retailers to sell mobile phones without the establishment of a collection, reuse, and recycling system for proper disposal of used cell phones. This bill places the responsibility for recycling squarely upon the industry, but leaves the implementation details up to them. While this approach allows the industry to minimize recycling costs, it remains to be seen whether the resulting policy promotes reuse of the materials in a manner that is safe for human health and the environment.

Other states have also focused on the manufacturer.[7] These states use market share as the basis for allocating responsibility for recycling to the manufacturers of televisions and video games. For example, for 2011 in the state of Maine, Samsung had a 19.6 percent share of recycling responsibility. Sony had a 11.3 percent share, Vizio 9.9 percent, etc., all the way to Audiovox with a 0.1 percent share.[8]

Are these laws working? Table 8.3 shows recycling rates for televisions, computer products, and cell phones in 2006–2007. While rates are up to 18 percent (from 15 through 2005), we still have a long way to go. It remains to be seen what effect the new laws and market share requirements will have.

Internationally, the Basel Convention regulates the movement of electronic waste across international boundaries (UNEP, 1989), although not all countries have ratified this treaty. One component of the convention would prohibit the export of e-waste from developed to industrializing countries since, in addition to valuable materials, the waste contains hazardous materials, such as lead and mercury.

In their analysis of trends of e-waste, Widner et al. (2005) find that for countries such as China and India, e-waste is rapidly growing from both domestic sources and illegal imports. These countries are just beginning to impose laws to control e-waste imports, but enforcement is lacking and the valuable materials create a business opportunity. Widner et al. estimate that 50–80 percent of collected domestic e-waste from nonratifying Basel Convention countries, such as the United States, is shipped to China and other Asian countries.

TABLE 8.3 Electronics Recycling Rates 2006–2007.

	Generated (million of units)	Disposed (million of units)	Recycled (million of units)	Recycling Rate (by weight)
Televisions	26.9	20.6	6.3	18%
Computer Products[1]	205.5	157.3	48.2	18%
Cell Phones	140.3	126.3	14.0	10%

[1]Computer products include CPUs, monitors, notebooks, keyboards, mice, and hard copy peripherals.

Source: Environmental Protection Agency (EPA), http://www.epa.gov/wastes/conserve/materials/ecycling/manage.htm.

[7]Details of each state's program can be found at http://www.electronicsrecycling.org/public/ContentPage.aspx?pageid=14

[8]http://www.maine.gov/dep/rwm/ewaste/manufacturers.htm

Pollution Damage

Another situation influences the use of recycled and virgin ores. When environmental damage results from extracting and using virgin materials and not from the use of recycled materials, the market allocation will be biased away from recycling. The damage might be experienced at the mine, such as the erosion and aesthetic costs of strip mining, or at the point of processing, where the ore is processed into a usable resource.

Suppose that the mining industry was forced to bear the cost of this environmental damage. What difference would the inclusion of this cost have on the scrap market? The internalizing of this cost results in a leftward shift in the supply curve for the virgin ore. This would, in turn, cause a leftward shift in the total supply curve. The market would be using less of the resource—due to higher price—while recycling more. Thus the correct treatment of these environmental costs would share with disposal costs a tendency to increase the role for recycling.

Disposal also imposes external environmental costs in the form of odors, pests, and contaminants leaching into water supplies; obstruction of visual landscapes; and so on. Kinnaman and Fullerton (2000) note that while the number of landfills in the United States has been decreasing, the aggregate capacity of these landfills has been increasing, as small-town facilities are replaced by large regional sanitary landfills. Since local opposition from potential host communities is likely to rise with landfill size, locating these facilities can be extremely contentious.

While governments now regulate landfills to protect public safety, these regulations rarely eliminate all unpleasant aspects of these landfills for the host communities. As a result, many communities are all for the existence of these facilities as long as they are not located in their community. If every community felt this way, locating new facilities could be difficult, if not impossible.

One technique for resolving this Not In My Back Yard (NIMBY) problem relies on the imposition of host fees. Host fees compensate the local community (and sometimes surrounding communities) for accepting the location of a waste facility within their community. This approach gives local communities veto power over the location, but it also attempts to share the benefits of the regional facility in such a way that makes the net benefits sufficiently positive for them that the communities will accept the facility.

In one example, Porter (2002) reports that a host fee agreement between Browning Ferris Industries and the township of Salem, Michigan, involves sharing with the town 2.5 percent of all landfill revenues and 4 percent of all compost revenues. The town also shares in the revenues derived from the sale of landfill gases (used for energy) and it can use the site free of charge for all town refuse, without limit on volume. These benefits are estimated to be worth about $400 per person per year, apparently enough to overcome local opposition.

Host fees are not a perfect resolution of the siting problem. Note, for example, that the fact that Salem can dispose of its waste free of charge provides no incentive for source reduction. In addition, it is important to ensure that locating these facilities does not raise environmental justice concerns. Although we consider this issue in much greater depth in Chapter 19, let it suffice here to point out that at a minimum, the local community has to be fully informed of the risks it will face from a regional sanitary landfill and must be fully empowered to accept or reject the proposed compensation package. As we shall see, these preconditions frequently did not exist in the past.

Additional complexities arise with hazardous wastes. Because hazardous wastes are more dangerous to handle and to dispose of, special polices have been designed to keep those dangers efficiently low. These policies will be also be treated in Chapter 19.

Summary

One of the most serious deficiencies in both our detection of scarcity and our ability to respond to scarcity is the failure of the market system to incorporate the various environmental costs of increasing resource use, be they radiation or toxics hazards, the loss of genetic diversity or aesthetics, polluted air and drinking water, or climate modification. Without including these costs, our detection indicators give falsely optimistic signals, and the market makes choices that put society inefficiently at risk.

As a result, while market mechanisms automatically create pressures for recycling and reuse that are generally in the right direction, they are not always of the correct intensity. Higher disposal costs and increasing scarcity of virgin materials do create a larger demand for recycling. This is already evident for a number of products, such as those containing copper or aluminum.

Yet a number of market imperfections tend to suggest that the degree of recycling we are currently experiencing is less than the efficient amount. The absence of sufficient stockpiles and the absence of tariffs mean that our national security interests are not being adequately considered. Artificially low disposal costs and tax breaks for ores combine to depress the role that old scrap can, and should, play. Severance taxes could provide a limited if poorly targeted redress for some minerals.

One cannot help but notice that many of these problems—such as pricing municipal disposal services and tax breaks for virgin ores—result from government actions. Therefore, it appears in this area that the appropriate role for government is selective disengagement complemented by some fine-tuning adjustments.

Disengagement is not the prescription, however, for environmental damage due to illegal disposal, air and water pollution, and strip mining. When a product is produced from virgin materials rather than from recycled or reusable materials, and the cost of any associated environmental damage is not internalized, some government action may be called for.

The selective disengagement of government in some areas must be complemented by the enforcement of programs to internalize the costs of environmental damage. The commonly heard ideological prescriptions suggesting that environmental problems can be solved either by ending government interference or by increasing the amount of government control are both simplistic. The efficient role for government in achieving a balance between the economic and environmental systems requires less control in some areas and more in others and the form of that control matters.

Discussion Questions

1. Glass bottles can be either recycled (crushed and re-melted) or reused. The market will tend to choose the cheapest path. What factors will tend to affect the relative cost of these options? Is the market likely to make the efficient choice? Are the "bottle bills" passed by many of the states requiring deposits on bottles a move toward efficiency? Why?
2. Many areas have attempted to increase the amount of recycled waste lubricating oil by requiring service stations to serve as collection centers or by instituting deposit-refund systems. On what grounds, if any, is government intervention called for? In terms of the effects on the waste lubrication oil market, what differences should be noticed among those states that do nothing, those that require all service stations to serve as collection centers, and those that implement deposit-refund systems? Why?
3. What are the income-distribution consequences of "fashion"? Can the need to be seen driving a new car by the rich be a boon to those with lower incomes who will ultimately purchase a better, lower-priced used car as a result?

Self-Test Exercises

1. Suppose a product can be produced using virgin ore at a marginal cost given by $MC_1 = 0.5q_1$ and with recycled materials at a marginal cost given by $MC_2 = 5 + 0.1q_2$. (a) If the inverse demand curve were given by $P = 10 - 0.5(q_1 + q_2)$, how many units of the product would be produced with virgin ore and how many units with recycled materials? (b) If the inverse demand curve were $P = 20 - 0.5(q_1 + q_2)$, what would your answer be?
2. When the government allows private firms to extract minerals offshore or on public lands, two common means of sharing in the profits are bonus bidding and production royalties. The former awards the right to extract to the highest bidder, while the second charges a per-ton royalty on each ton extracted. Bonus bids involve a single, up-front payment, while royalties are paid as long as minerals are being extracted.
   a. If the two approaches are designed to yield the same amount of revenue, will they have the same effect on the allocation of the mine over time? Why or why not?
   b. Would either or both be consistent with an efficient allocation? Why or why not?
   c. Suppose the size of the mineral deposit and the future path of prices are unknown. How do these two approaches allocate the risk between the mining company and the government?
3. "As society's cost of disposing of trash increases over time, recycling rates should automatically increase as well." Discuss.

4. Suppose a town concludes that it costs on average $30.00 per household to manage the disposal of the waste generated by households each year. It is debating two strategies for funding this cost: (1) requiring a sticker on every bag disposed of such that the total cost of the stickers for the average number of bags per household per year would be $30 or (2) including the $30 fee in each household's property taxes each year.
   a. Assuming no illegal disposal what approach would tend to be more efficient? Why?
   b. How would the possibility of rampant illegal disposal affect your answer? Would a deposit-refund on some large components of the trash help to reduce illegal disposal? Why or why not? What are the revenue implications to the town of establishing a deposit-refund system?

Further Reading

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Additional References and Historically Significant References are available on this book's Companion Website: http://www.pearsonhighered.com/tietenberg/