THE ECONOMICS OF MUNICIPAL SOLID WASTE

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This article examines the generation and management of municipal solid waste through the lens of economics. The authors estimate that the global burden of municipal solid waste amounted to 1.3 billion metric tons in 1990, or two-thirds of a kilogram of waste per person per day. Industrial countries account for a disproportionately high share of the world's waste relative to their share of world population, while developing countries account for a disproportionately high share of the world's waste relative to their share of world income. Analyses across countries and over time reveal that the generation of municipal solid waste is positively related to variations in per capita income and that the generation of municipal solid waste per capita does not vary with population size among countries with comparable per capita income.

Practices for collecting, processing, and disposing of municipal solid waste vary widely across countries, generally in accord with the nature of the waste stream and key environmental and economic features. The least efficient practices tend to be found in developing countries, creating serious threats to local environmental quality and public health. Although considerable evidence indicates that the generation and management of waste is sensitive to income and price variables, natural incentives to overuse common property and the presence of intergenerational externalities both suggest that private economic behavior will not yield socially optimal outcomes in this area. Community intervention may be needed to promote the social good, with evidence accumulating in support of arrangements involving the participation of private firms. The authors' calculations also suggest that improvements made now in the handling of hazardous waste will be far less expensive in discounted terms than undoing in the future the damage being caused by current practices. Addressing these issues from a rational societal perspective will become increasingly urgent in the future, especially in the developing countries, where the authors project that municipal solid waste will increase at an annual rate of 2.7 percent through the year 2010.

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The United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992 focused world attention on the undesirable environmental side effects of population growth and economic advancement. The two problems that garnered the most attention were climate change, caused by the accumulation of greenhouse gases, and depletion of the ozone layer, caused by the emission of chlorofluorocarbons. Yet, to the extent that these problems are understood in scientific terms, both appear to be developing slowly and are not expected to unfold significantly until well into the future.

By contrast, increased levels of municipal solid waste (MSW) may not have the catastrophic potential of either global warming or stratospheric ozone depletion, but they have long posed threats to environmental quality and human health that are reasonably well understood and typically of great local and immediate concern. This article therefore explores through the lens of economics the implications for the future of current trends, practices, and policies in the generation and management of municipal solid waste. Although our analysis focuses mainly on developing countries, we also devote attention to the example of the United States, for which relevant data are more readily available.

Using economic reasoning, data analysis, and a review of the literature, we endeavor to make three main sets of points.

First, huge quantities of municipal solid waste are being generated around the world. Although much of it is collected and disposed of through controlled incineration or burial in sanitary landfills, a good deal of the rest continues to be burned in the open or dumped haphazardly, especially in developing countries. Such practices are putting increasing pressure on land, air, and water quality, and posing threats to human health that will be exacerbated by projected increases in total waste generation. Our calculations suggest that some improvements in the handling of hazardous wastes now would be less expensive (in discounted terms) than undoing in the future the damage to the environment and to human health caused by current handling practices.

Second, solid waste has resource value. Some of it is captured through the scavenging and recycling practiced in the informal sector throughout the developing world, and some through community-sponsored recycling systems and the conversion of waste into energy, compost, or both. Many studies are under way throughout the world to determine whether further value can be economically captured from solid waste.

Third, because the benefits of solid waste disposal extend beyond the households and firms that incur the costs, community intervention may promote the social good.

Patterns and Trends in MSW Generation

The focus of this article is on municipal solid waste generated by communities. Municipal solid waste can be divided into recycled and nonrecycled materials (see the glossary in box 1 for definitions of MSW, recycling, and other technical

Box 1. *Glossary*

Aerobic composting. A method of composting organic wastes using bacteria and other organisms that need oxygen. Requires that oxygen be diffused throughout the organic material, either by mixing the material to expose it to air or by forcing air through perforated pipes that pass through the material.

Anaerobic composting. A relatively slow method of composting organic wastes using bacteria that cannot function in the presence of oxygen.

Collection. Gathering MSW from where it is generated and transporting it to a transfer station, processing facility, or landfill to safeguard public health, limit congestion, and preclude unpleasant odors and offensive sights.

Compost. A soil amendment derived from decomposed organic wastes. Valuable in agriculture, horticulture, and land reclamation because it improves the ability of soil to retain moisture and chemical fertilizers and to resist erosion. Can also be used as a feedstock in aquaculture and as intermediate cover in MSW landfills to reduce the volume of waste and prevent waste from attracting pests or blowing away into residential neighborhoods.

Disability-adjusted life-year. A measure of the burden of disease representing the present value of future years of disability-free life that are lost because of premature deaths or cases of disability that occur in a particular year (World Bank 1993).

Disposal. Isolation and containment of the residual waste left after processing.

Landfilling. Disposal of MSW by burying it.

Leachate. Liquid that has seeped through MSW in a landfill and has accumulated possibly harmful dissolved or suspended materials.

Materials-balance analysis. A method for estimating MSW generation based on the weight of the domestic output of nondurable goods minus net exports and of discards of durable goods (based on past domestic production minus net exports and on estimated product lifetimes) adjusted for an estimate of permanent diversions from the waste stream. Examples of permanent diversions: paperboard used in construction, and sanitary papers disposed of in sewage systems.

Methane. By-product of anaerobic composting; can be used as a fuel.

Municipal solid waste (MSW). All solid wastes generated in a community except for industrial and agricultural wastes. Generally includes discarded durable and nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic debris, including household hazardous wastes and often construction and demolition debris and sludges and ashes generated by sewage treatment plants and MSW incinerators. Sources of MSW include households, commercial enterprises such as food markets and offices, and institutions such as schools, transportation terminals, and hospitals.

Processing facility. Facility that transforms the physical characteristics of MSW by recycling, composting, burning, or compacting to reduce the threat it poses to human health and ecosystems, improve its disposability, and possibly capture value from the waste.

Recycling. The act of gathering and refining the by-products of production or consumption activities for use as inputs for production activities.

Recycling facility: high-tech capital-intensive. Facility that uses automated processes to separate recyclable materials from commingled recyclable materials or raw MSW.

Recycling facility: low-tech capital-intensive. Facility at which workers hand sort commingled recyclable material as it passes by on a conveyor belt.

Residual waste. Incinerator ash, materials that are not recyclable or not worth recycling, residues from recycling and composting processes, and unprocessed MSW; generally disposed of in landfills.

(Box continues on following page.)

Box 1. *(Continued)*

Sanitary landfill. Method of disposing of MSW to minimize effects on human health and the environment. Generally consists of a pit lined with clay and plastic to prevent leachate from seeping into groundwater, drainage pipes to draw off leachate for treatment, deposits of MSW in thin layers that are frequently covered with soil or other materials to keep out water and prevent waste from blowing away or attracting pests, and a system to collect methane to prevent explosions (the methane is either flared or used as fuel).

Transfer station. A facility where MSW from collection vehicles is consolidated into larger loads that are transported by tractor trailors, railroad, barges, or other means to processing facilities or landfills.

Windrows. Piles of aerobically composting materials that are formed into rows and turned periodically to expose the materials to oxygen and to control the temperature to promote biodegradation.

Note: This glossary relies heavily on the more comprehensive glossary that appears in Kreith (1994a). Another excellent glossary appears in Tchobanoglus, Theisen, and Vigil (1993).

terms). Examples of recycled materials are discarded aluminum soft-drink cans melted down to create new cans, food and yard wastes composted and used to enhance soil fertility, and old newspapers and plastic bottles burned to produce electricity. The nonrecycled portion of MSW consists of by-products that must generally be removed from the site lest they interfere with production and consumption by attracting vermin and flies, obstructing passage, clogging drains, emitting unpleasant odors, and so on. Whether or not materials are recycled depends on the nature and cost of available production, consumption, recycling, and disposal technologies, as well as on government regulations. These can vary widely across economic settings. In developing countries, municipal solid waste is often disposed of with ash, human waste—where sewage systems do not reach substantial portions of the population (Mensah and Whitney 1991)—medical waste (Bartone, Bernstein, and Wright 1990), and industrial waste (Benavides 1992). For this reason, MSW in developing countries is sometimes more harmful to human and ecological health than it is in industrial countries.

Economic research on MSW is impeded by a lack of data and by imperfections in what data we have. Time-series data on MSW generation, recovery, and disposal rates are available for only a few countries. Like most variables used in cross-national empirical research, few country estimates of MSW are derived using common definitions, data sources, or estimation techniques. Most country estimates of MSW generation (and its composition) are based on either the sampling method or materials-balance analysis. The sampling method involves sorting and weighing samples of the MSW of individual households (see, for example, the description of the Garbage Project at the University of Arizona in Rathje and Murphy 1993) and using the results to infer MSW generation rates for a larger group of households. This method is labor intensive, and therefore prohibitively expensive in some contexts (U.S. Environmental Protection Agency 1992). By contrast, materials-balance analysis estimates MSW generation by weight as the tonnage of nondurable-goods consumption plus estimated discards of durable goods. Generation rates estimated by the Environmental Protection Agency using materials-balance analysis appear to be broadly consistent with estimates obtained using the sampling method (U.S. Environmental Protection Agency, 1992).

Putting aside questions of data quality and comparability, note that published data on the generation of MSW vary with key economic variables. Data for thirty-six countries compiled by the World Resources Institute (1993) show that daily per capita rates of MSW generation range from 0.5 kilograms for Mozambique (with a per capita gross domestic product, or GDP, of $620 in 1990) to 1.9 kilograms for Australia ($17,000 per capita GDP in 1990). On the basis of other data sources, researchers have found that the generation of per capita MSW appears to be at least 0.3 or 0.4 kilograms per day for even the poorest people.

The first column of table 1 estimates the responsiveness of MSW generation to changes in income and population. The findings show that a 1 percent increase in per capita income is associated with a 0.34 percent increase in total MSW generation, and a 1 percent increase in population is associated with a 1.04 percent increase in MSW.[1]

One might expect the generation of MSW to be relatively insensitive to variations in per capita income. Even if MSW generation were roughly proportional to consumption, empirical studies have found that consumption does not vary in equal proportion with income. Moreover, the share of services in consumption expenditure appears to rise with income, which also suggests that the generation of waste is relatively insensitive to income, because the MSW that accompanies the consumption of goods is likely to be greater than that produced by the consumption of services.

Along with the World Resources Institute data, we use the estimated measures of the responsiveness of MSW to variations in income and population, and data on per capita GDP and population in 1990 for 149 countries and territories not included in the analysis summarized in the first column of table 1, to construct an estimate of global MSW generation (see table 2). This exercise suggests that approximately 1.3 billion metric tons of MSW were generated in 1990, an average of two-thirds of a kilogram per person per day, or more than the combined global output of wheat and rice in that year (*The World Almanac 1993*).[2]

The last column of table 2 indicates that daily per capita generation of MSW in low-income countries is well below that in higher-income countries and that the latter account for a disproportionate share of MSW on a *population* basis (these countries account for less than one-sixth of the world's population but generate more than one-fourth of global MSW), while developing countries account for a disproportionate share of MSW on an *income* basis (with less than half of global GDP but nearly three-fourths of global MSW).

Assuming that national GDP growth rates for the 1980s hold steady, that population growth proceeds according to World Bank (1992) projections,[3] and that the statistical relationship reported in the first column of table 1 remains stable,

Table 1. *Cross-Sectional Patterns in MSW Generation Rates*

Independent variable	Country cross-section: Unrestricted	Country cross-section: Restricted[a]	Forty-five cities in China, 1990: Unrestricted	Forty-five cities in China, 1990: Restricted[a]	Thirty-three states in the United States, 1992: Unrestricted	Thirty-three states in the United States, 1992: Restricted[a]
GDP per capita	0.34	0.34	0.26	0.29	0.62	0.60
	(0.06)	(0.06)	(0.13)	(0.12)		
Population	1.04	1.00	0.95	1.00	0.96	1.00
	(0.04)	(—)	(0.06)	(—)	(0.04)	(—)
R^2	0.96	0.96	0.87	0.87	0.94	0.94
Number of observations	36	36	45	45	33	33

— Not applicable.

a. Restricted refers to regression estimation that imposed the assumption that MSW generation per capita does not vary with population.

Note: Ordinary least squares (OLS) estimates of the covariates of MSW generation rates. Dependent variable: natural logarithm of annual MSW generation by weight. Standard errors in parentheses. Though not reported, each regression model was specified with a constant term. Chinese city regressions are based on per capita GDP for each city. U.S. state regressions are based on average personal income in each state. Eighteen states whose waste included construction and demolition debris, sewage sludge, and industrial wastes were dropped from the analysis.

Source: For MSW generation rates: World Resources Institute 1993; for GDP per capita and population estimates: World Bank 1992; for data on Chinese cities: State Statistical Bureau of the People's Republic of China 1991; for data on U.S. states: Steuteville and Goldstein 1993, U.S. Bureau of the Census 1993, and U.S. Bureau of Economic Analysis 1994.

global MSW generation is projected to double between 1990 and 2019 (that is, an average annual growth rate of about 2.4 percent). The per capita MSW generation rate will not double until 2049, however. In all likelihood these doubling times will be even longer because of substitution (using aluminum and plastic instead of steel and glass in containers and packaging, for example) and because of technological innovations, such as new containers that use less material (Rathje and Murphy 1993; Alexander 1993).

The same trends and patterns that are evident across countries exist across jurisdictions in China and the United States (see table 1). That is, per capita MSW does not vary with population (holding per capita income constant), and total MSW is positively related but relatively insensitive to variations in per capita income.

Trends and patterns can also be explored using available time-series data for Taiwan (China) and the United States (table 3). For Taiwan (China) the estimated sensitivity of MSW generation to variation in income is 0.59, and its sensitivity to variations in population is 1.63. If one assumes that MSW generation per capita does not vary with population among countries with comparable per

Table 2. *Estimated World MSW Generation and Selected Characteristics by Income Classification of Economies, 1990*

Income classification[a]	*Total MSW generation*[b] *Billions of metric tons a year*	*Percentage of world total*	*Population size* *Millions of people*	*Percentage of world total*	*Percentage of world total GDP*[c]	*Kilograms of MSW per capita per day*
Low	0.598	46.3	3,091	58.5	18.7	0.53
Lower-middle	0.145	11.2	629	11.9	9.9	0.63
Upper-middle	0.193	14.9	748	14.2	16.5	0.71
High	0.357	27.6	816	15.4	54.9	1.20
All economies	1.293	100.0	5,284	100.0	100.0	0.67

a. Classification is based on estimates of GNP per capita: low-income economies, $600 or less in 1990; lower-middle-income economies, $630 to $2,490; upper-middle-income economies, $2,490 to $7,050; high-income economies, $9,550 and above.

b. Regression coefficient estimates were used to calculate fitted values for MSW generation for countries with no published MSW data. Fitted values (and the published MSW data if available) were then summed across the countries to arrive at global estimate of MSW generation.

c. International Comparison Project of the United Nations (ICP) estimates of GDP. ICP GDP is adjusted for purchasing power differences. GNP per capita estimates for countries with populations of less than 1 million if these were available. For countries for which data on GDP or GNP per capita were not available, averages (weighted by population) of the ICP estimates of GDP per capita for countries within the income classifications used in World Bank 1992 were computed. Cuba and the People's Democratic Republic of Korea were classified as low-income countries. Per capita income in the former U.S.S.R. was estimated by computing the average (weighted by population) 1991 estimated GDP per capita of the countries that constituted the former U.S.S.R., using estimates from World Bank 1993.

Source: For population, GDP per capita, and income classifications: World Bank 1992; for GDP per capita for former Soviet republics, World Bank 1993.

Table 3. *Time-Series Patterns in MSW Generation Rates*

Independent variable	*Taiwan (China) 1980–91*[a] *Unrestricted*	*Restricted*	*United States 1970–88*[b] *Unrestricted*	*Restricted*
GDP per capita	0.59	0.72	0.86	0.63
	(0.21)	(0.04)	(0.16)	(0.05)
Population	1.63	1.00	0.63	1.00
	(1.02)	(—)	(0.25)	(—)
R^2	0.98	0.97	0.98	0.92
Durbin-Watson statistic	1.73	1.90	1.61	1.69
Number of observations	12	12	19	19

— Not applicable.

Note: Standard errors in parentheses. Ordinary least squares(OLS) estimates of the covariates of MSW generation rates. Dependent variable: natural logarithm of annual MSW generation by weight. Though not reported, each regression model was specified with a constant term. Taiwan exchange rate based on 1986 average of 39.88 Taiwan dollars to the U.S. dollar.

Source: For Taiwan (China): (Taiwan) (China) 1992 and authors' calculations; for the United States: Council of Economic Advisers 1993; U.S. Bureau of Census 1978, 1983, 1990; and U.S. Environmental Protection Agency 1990, 1992.

capita income, the estimated income sensitivity of MSW generation rises to 0.72 but remains significantly less than 1.0. For the United States the estimated income sensitivity of total MSW generation is 0.86, and the population sensitivity is 0.63. If one assumes that per capita MSW generation does not vary with population (holding income per capita constant), the sensitivity of total MSW to income falls to 0.63 and is significantly less than 1.0 and very close to the cross-state income responsiveness shown in table 1. These estimates suggest that MSW is more responsive to income per capita than the cross-country estimates noted earlier. Nevertheless, MSW generation appears to be positively related but relatively insensitive to variations in per capita income, and per capita amounts do not vary with respect to population among countries with comparable income per capita.[4]

Cost-Benefit Considerations in Managing MSW

Most systems for managing MSW have three basic components: collection and transport, processing, and disposal. The purpose of collection and transport is to gather and remove MSW from its point of generation to safeguard public health, limit congestion, and preclude unpleasant odors and aesthetically offensive sights. The purpose of processing is to transform the physical characteristics of MSW by recycling, composting, burning, or compacting in order to reduce the threat it poses to human health and ecosystems, improve its disposability, and possibly capture value from the waste. The purpose of disposal is to isolate and contain the residual waste that is left after processing. Some MSW management systems ignore or incompletely implement one or more of these key components. For example, typically only 50 to 70 percent of MSW is collected in the cities of developing countries (Cointreau-Levine 1994).

Ideally, cost-benefit comparisons will guide choices among the range of options available for each component of MSW management. Such comparisons will reflect a variety of technical parameters that define the physical characteristics of specific waste streams and local geography, such as climate, suburbanization, and transportation infrastructure. They will also reflect key economic parameters, such as the relative prices of labor, plant and equipment, materials, energy, and land, which can vary considerably both within and between countries.

The valuation is relatively clear cut for some costs and benefits of management options, such as out-of-pocket collection and transport expenses and revenues from the sale of recyclable materials, compost, and energy. Other, less obvious, costs and benefits must also be accounted for, however, such as the opportunity costs of land (for transfer stations, processing facilities, or landfills) and household labor (especially if households are expected to sort their waste or transport it to a central collection point) and savings from disposal costs avoided by new technologies. Further complexities arise in valuing outcomes that are not easily expressed in pecuniary terms, such as changes in public health or in the aesthetic quality of air, water, or land. Cost-benefit comparisons must reflect complementarities among options for MSW management; for example, the cost of producing agricultural-quality compost may fall sharply if households separate their compostable and noncompostable waste. The comparisons must also account for the time value of resources, which requires choosing a discount rate, often a controversial issue.

Although estimating reliable monetary values for all costs and benefits is often not feasible, the framework of cost-benefit analysis can nonetheless provide guidance for decisionmaking and evaluation. Four factors generally weigh heavily in cost-benefit comparisons of alternative options for MSW management: the relative costs of labor and other production factors, the physical characteristics of the waste, efficient scales of operation, and nonpecuniary costs and benefits.

Relative Costs of Labor and Other Production Factors

Compared with industrial countries, in developing countries unskilled labor is abundant, skilled labor and physical capital are scarce, and infrastructure is often limited. As a consequence, the cost of unskilled labor relative to skilled labor, land, and capital is generally lower. Although capital-intensive waste-management techniques, which are typically intensive in human capital and infrastructure as well, may be economically efficient in industrial countries, they are not likely to be so in developing countries.

Labor-intensive collection and processing of recyclable materials are found throughout the developing world. Households bring their recyclables to redemption centers (Cointreau and others 1984). Small-scale entrepreneurs go door to door to purchase recyclables. (The Zabbaleen in Cairo, for example, provide collection services in exchange for the opportunity to extract recyclable materials and food waste for resale.) Collection workers and scavengers rummage through household waste put out for collection. The proportion of official work time that collection workers take to sort recyclables ranges from 10 percent in Mexico City to 40 percent in Bangkok. In Manila collection workers routinely take with them on their routes scavengers who pick out and sell recyclable materials and share the proceeds with the collection workers. Scavengers sift through waste at transfer stations and final dumpsites. It is estimated that about 7,000 scavengers are working at the MSW dumps in Manila, 8,000 in Jakarta, and 10,000 in Mexico City (Cointreau-Levine 1994).

Often the privately run businesses that purchase, clean, sort, and sell recyclables in bulk to other middlemen or directly to factories are also highly labor intensive. (See Bennett and others 1993 and Sicular 1992 for descriptions of the recycling industry in Jakarta.) The practice of scavenging may also have implications for the adoption of other waste-management techniques, as in Jakarta, where scavengers were observed regularly tearing apart waste that had been machine-compacted and baled by the city government's MSW sanitation agency (Bartone, Bernstein, and Wright 1990).

By contrast, the collection and processing of recyclable materials in industrial countries are considerably more capital-intensive. Nevertheless, there is a broad range of capital intensities of recycling activities within the United States and presumably within other industrial countries.[5] The most capital-intensive method is mixed MSW collection, in which MSW is collected and delivered to a facility using complex equipment to extract recyclable materials, the remainder often being used to make fuels for electricity-generating incinerators.

A somewhat less capital-intensive system for recycling is the collection of old newspapers and commingled glass, metal, and plastic materials. Generally, this method requires special trucks that have two compartments, one for newspapers and the other for the rest of the recyclable materials. Households and firms perform the initial separation of recyclable materials, and the process is refined at materials-recovery facilities.

Here again the range of capital intensities is broad. Some recovery facilities use highly automated systems with magnets to extract ferrous metals, air classifiers with blowers to separate light materials, such as plastics, by weight, and eddy-current separators with magnets above a conveyor belt that induce an opposing magnetic field in aluminum on the belt and push it off into a separate bin. Others use a "low-tech" conveyor belt that transports recyclable materials past workers who pick and sort the materials.

Among the least capital-intensive, and hence most labor-intensive, recycling systems in use in industrial countries is one in which either households sort and separate each type of recyclable material (paper, aluminum, steel cans, different types of plastic, glass by color, lawn and compostable food wastes) or workers sort commingled recyclable materials as they collect them and place each type of waste in its own compartment in the collection truck. Sometimes households must transport separated recyclable materials to drop-off centers—containers scattered throughout a community or staffed facilities—or to bottle buy-back centers, in the case of beverage-container deposit systems. To reduce transport costs, all capital-intensive recycling systems require that materials be shredded, baled, or pulverized.

Labor-intensive aerobic composting facilities may be more appropriate in developing countries than the highly automated aerobic or anaerobic facilities typical of industrial countries. In the most extreme cases, workers may use only simple hand tools to handsort nonrecyclable biodegradable materials from noncompostable materials, build and turn windrows, and screen and bag finished compost. (See Bennett and others 1993 for details of a project in Jakarta that developed a highly labor-intensive composting technique. To avoid the labor-intensive process of turning windrows, researchers experimented with a more capital-intensive forced-aeration static-pile technique but quickly rejected it as economically inefficient.) Capital-intensive composting projects in developing countries often fail, as in Lagos (Cointreau-Levine 1994: 29), or they may be converted to relatively more labor-intensive facilities, as in Jakarta and a number of cities in India.

Substituting labor for capital in the management of MSW has its limits, however. Singapore's Environment Ministry claims that recycling materials other than paper and metal cans is impractical and that capital-intensive incineration to produce energy, conserve landfill space, and recover some metals is more cost-effective (*The Straits Times* 1994). Landfill disposal in developing countries usually involves discarding the waste in open dumps (Bartone and Bernstein 1993). This practice is insufficiently capital-intensive, because siting landfills in areas with a high water table or constructing them without clay liners may lead to the formation of leachate that can seep out of the landfill and pollute groundwater and surface water. To the extent that hazardous waste is present in the MSW stream, leachate could seriously contaminate the water supply, which could adversely affect agriculture, with costly health implications for current and future generations.

Public cleansing of streets and open areas is critically important in areas where waste is indiscriminately dumped alongside roads. Inefficient collection techniques exacerbate this problem. In the old quarters of Moroccan cities, for example, residents discard food waste in the streets, and the following morning, when crews sweep it up into wicker baskets, some of it spills back onto the streets (Ohnesorgen 1993). In Shanghai, uncovered collection trucks also spill some of their loads back onto the streets (Ward and Li 1993). In developing countries, the cost per metric ton of cleaning waste off the streets is estimated to be between two and three times the cost of collection (Cointreau-Levine 1994), so covered trucks or other more costly collection equipment that reduces spillage would probably be more efficient.

Composition and Physical Characteristics of MSW

The composition and physical characteristics of MSW affect the economics of collecting, processing, and residual disposal.

Table 4 reports data on the average composition by weight of MSW for several cities in developing countries and for the United States. Food waste is the largest component in the cities of developing countries but is a relatively small component in the United States. This difference reflects relatively high consumption of unprocessed vegetables, fruits, and meats in the developing countries, which leads to more discarding of peel, bones, and other food wastes. A comparative study of MSW in Mexico City and the United States, for example, found that Mexican households consumed less processed and packaged foods and discarded higher amounts of food waste. An estimated $1.4 million worth of food (in 1980 dollars) was discarded each day in Mexico City in 1980. The high figure is attributable to poor refrigeration and storage facilities in low-income Mexican households and to the low cost of food staples because of heavy government subsidies (Rathje, Reilly, and Hughes 1985). In the United States, factories that

Table 4. *Composition and Physical Characteristics of Municipal Solid Waste, Selected Locations and Years*

Category	*Bangkok*[a] *1989*	*Dar es Salaam 1988*	*Jakarta 1989*	*Mexico City 1980*	*United States 1990*
Composition of MSW (percentage by weight)					
Food waste	39.2	62.5	60	43.1	8.1
Glass	3.2	0.3	2	8.4	6.5
Paper	12.4	6.2	2	19.2	32.3
Plastic	9.4	0.3	2	5.0	9.8
Leather, rubber	1.9	n.a.	n.a.	n.a.	2.7
Metals	1.7	1.2	2	3.7	7.7
Textiles	3.2	1.8	n.a.	5.7	3.3
Miscellaneous	29.0[b]	27.7	32	14.9[c]	29.6[c]
Characteristic					
Discard rate (kilograms per capita per day)[d]	0.9	0.7–0.9	0.5[e]	1.0	1.6
Landfill density (kilograms per cubic meter)[f]	615	980	1,000	640	460
Potential landfill utilization rate (cubic meters per capita per year)[g]	0.5	0.3	0.2	0.6	1.3
Percentage biodegradable (by weight)[h]	67	69	62	66	67
Moisture content of biodegradable portion of MSW (percent)	31	44	42	34	20
C/N ratio of biodegradable portion of MSW	88:1	32:1	24:1	49:1	90:1
Energy content of MSW (kilojoules per kilogram)	11,300	6,300	6,000	8,900	12,900

n.a. Not available.

Note: C/N is carbon to nitrogen. 1 kilojoule = 0.948 British thermal unit (BTU).

a. Estimates are for residential MSW from low-income-housing areas.

b. Wood and grass constitute 15.2 percent of total MSW discards and are included under "Miscellaneous" in the table but counted separately as yard wastes to compute average physical characteristics of MSW.

c. Yard wastes (grass and shrub trimmings) constitute 4.1 percent of total MSW discards for Mexico City and 26.3 percent for the United States. They are included under "Miscellaneous" in the table but counted separately to compute average physical characteristics of MSW.

d. For the United States, discards equal MSW net of materials recovered for recycling or composting. For other countries, discards by households and firms are MSW net of materials recovered by them, by scavengers, or by collection workers.

e. Based on estimated total daily MSW generation rate of 5,000 metric tons per day and estimated population of 9,882,000 in 1991.

f. The landfill density estimates for each material were based on experimental compaction of each material to simulate landfill conditions in the United States (U.S. Environmental Protection Agency 1992). These densities were used to estimate landfill density of MSW in the cities of developing countries.

g. Based on the landfill densities of MSW components, these are upper-bound estimates, because when the materials in MSW are intermingled, there tends to be less void space than if only one material were deposited in the landfill.

h. The sum of shares of paper, wood, yard wastes, and food wastes.

Source: For Bangkok: Muttamara, Visvanathan, and Alwis 1992/93; for Dar es Salaam: Yhdego 1991; for Jakarta: Bennett and others 1993, *The World Almanac 1993*, and Yhdego 1991; for Mexico City: Rathje, Reilly, and Hughes 1985; for the United States: U.S. Environmental Protection Agency 1992. For data on characteristics: Tchobanoglous, Theisen, and Vigil 1993.

produce packaged foods generally recycle food preparation wastes into animal feed or incinerate them to produce energy.

By contrast, paper accounts for a much smaller share of MSW in the cities of developing countries than in the United States, reflecting lower per capita consumption of packaged goods, office paper, newspapers, and magazines. A study using data from twenty-seven countries found a negative and statistically significant correlation between packaging waste and food waste: an additional kilogram of plastic packaging was associated with 1.1 fewer kilograms of food waste, and an additional kilogram of paper packaging with 0.7 fewer kilograms of food waste (Alter 1989). The higher food-waste content of MSW in cities of the developing countries is more or less offset by the lower paper content, resulting in comparable biodegradable content.

Key characteristics of MSW affecting collection, composting, and disposal include density, biodegradable content, moisture content of the biodegradable portion, the carbon-to-nitrogen (C/N) ratio of the biodegradable portion, and energy content.

Density affects landfill capacity and equipment requirements for collection and transport. Biodegradable content is important because biodegradable materials can be converted through microbial activity either into compost or into methane, which can be captured and used as a fuel. Such conversion may be economical in the northeast United States, where landfill tipping fees run as high as $110 a metric ton. Worldwide, the only commercial venture that converts waste into transport fuels is operating in Italy. The process is likely to yield less fuel in developing countries, where MSW contains less paper and wood and more moisture than in industrial countries. Tipping fees are likely to be lower as well, making these processes less economically efficient (Chen 1995).

The moisture content of biodegradable MSW affects collection, composting, and incineration. Compacting trucks designed in the United States often perform poorly when loaded with the high-moisture waste typically found in many developing countries (Bartone, Bernstein, and Wright 1990). High-moisture waste also tends to clog windrow aeration machines, reducing the efficiency of the equipment.

With respect to composting, the moisture content needed to achieve the most rapid conversion into compost is 50 to 60 percent (Tchobanoglous, Theisen, and Vigil 1993). This exceeds the moisture content of biodegradable MSW for every location reported in table 4 (although moisture content can vary considerably by season). Maintaining moisture content at a level that reduces composting time may keep average production costs down, but it may make composting prohibitively costly in arid regions and in areas with water contaminated by salt, heavy metals, or other nonbiodegradable pollutants. Arid regions can conserve water by using compost in agriculture; thus there is a tradeoff in deciding how best to use scarce water resources in these regions.

With respect to incineration, the energy content of MSW in developing countries is generally much lower than in the United States, as table 4 indicates, mainly because of high moisture content. Incineration to reduce volume (which lowers landfill costs) and perhaps to generate energy is impeded by moisture. This problem is generally dealt with by adding fuel, which increases the capital intensity of incineration and reduces its cost-effectiveness (Elkington and Shopley 1989).

The C/N ratio of the biodegradable portion of MSW is another important determinant of the speed (and therefore the cost) of composting. The optimal C/N ratio of 25:1 is substantially exceeded for all the locations reported in table 4 except Jakarta and Dar es Salaam. Lower C/N ratios can be achieved, although at a cost, by blending waste with sewage sludge or certain animal manures, such as chicken or cow, that have relatively low C/N ratios (Tchobanoglous, Theisen, and Vigil 1993). But if the primary goal is to recover energy by anaerobic digestion of organic materials, too low a C/N ratio can lead to excessive generation of ammonia. A C/N ratio of less than 10:1 kills the anaerobic bacteria that generate methane (Tchobanoglous, Theisen, and Vigil 1993).

Efficient Scale of Operations

Because the average cost per ton of collecting, processing, or disposing of MSW generally varies with the amount of waste being handled, the scale of operations may be crucial to the selection of cost-effective management options. Average management costs per ton of MSW may decline as the scale of operations increases, for several reasons. First, MSW management facilities have certain costs that are relatively invariant to the amount of waste dealt with at the facility, within a specified range. These fixed costs include (a) compensation for workers in such overhead occupations as administrator, engineer, technician, mechanic, and salesperson, and (b) the cost of plant and equipment, access roads to facilities, water and electricity hookups, and siting and licensing. For example, a study of 340 MSW collection operations in the United States found that average collection costs per ton declined as the scale of operations increased to service for 50,000 persons and remained unchanged when the service population exceeded 50,000 (Stevens 1977). Management alternatives that are intensive in unskilled labor will tend to achieve their minimum average costs per ton at lower levels of capacity than alternatives that are intensive in physical and human capital.

Second, average costs of MSW management may decline as the amount of waste handled rises and more specialized workers or machines are used. For example, a relatively small but capital-intensive composting facility may use a single bulldozer or bucket loader for forming and turning windrows and for consolidating and moving composted material from the windrow area of the facility to the curing area. These are not the most efficient machines for turning windrows, however, because they compact the material and do not accomplish much mixing or aeration. Specialized windrow-turning equipment may be more cost-effective at large-capacity (more than a few metric tons per day), capital-intensive facilities (Diaz, Savage, and Golueke 1994).

The geographical characteristics of metropolitan areas may affect the degree to which there are economies of scale in waste management. Households in rural areas are typically able to dispose of MSW in ways that do not adversely affect their neighbors. For example, rural households may dump their MSW in nearby fields or wooded areas; they may burn their MSW; or they may compost organic substances. Urban households that cannot exercise these options require frequent and reliable MSW collection.

Although urbanization raises the concentration per square meter of MSW, which may lower the average cost of collection, urbanization may also increase the cost of MSW management because low-income urban areas often have narrow or congested streets that cannot support large collection trucks (Cointreau-Levine 1994). Given such infrastructure, it may be cost-effective to use communal containers to which residents bring their MSW. Waste-management systems in Egypt, India, Indonesia, and the Philippines use handcarts for door-to-door MSW collection in low-income neighborhoods. The MSW is often delivered to neighborhood bins or mini-transfer stations (Bartone, Bernstein, and Wright 1990); the waste is collected by larger trucks for transport to processing or disposal facilities. Because handcart collection requires relatively little capital investment compared with motorized vehicle collection, the minimum efficient scale of handcart collection is relatively small. If urbanization outpaces the development of transportation infrastructure, the average cost of MSW management will tend to rise.

Suburbanization can raise the costs per ton of collection and transport.[6] First, insofar as it is associated with rising land costs at the fringes of metropolitan areas, suburbanization may raise the cost of establishing new MSW management facilities. Taiwan (China), for example, is increasingly turning to incineration, presumably because of prohibitively high land-acquisition costs for landfills. Second, suburbanization may increase the average distance that collection vehicles must travel from one collection site to the next. Greater travel distances increase the likelihood that a system of transfer stations would be cost-beneficial. If hauling distances to MSW processing or disposal facilities are greater than fifteen to twenty kilometers or travel time exceeds thirty minutes, delivering collected MSW to transfer stations where it can be consolidated into large loads that can be transported by tractor-trailer trucks, rail cars, or barges to large-scale management facilities is generally less expensive than transporting the same amount of MSW in smaller vehicles (Bartone and Bernstein 1993).

These efficiencies occur because vehicle operators, fuel, and container requirements are relatively unresponsive to increases in truck capacity. Cointreau-Levine (1994) suggests that there may be considerable economies of scale in transfer stations, especially if compaction devices are used to fill tractor-trailer trucks, as in Bogotá, Colombia (Tchobanoglous, Theisen, and Vigil 1993). Building enough capacity to cut down the time that collection vehicles must wait to unload can reduce transportation costs. Locating transfer stations near MSW generators and near major transportation routes also helps to lower hauling costs per ton of MSW, but these savings must be traded off against community and environmental protests. Objections may be appeased by designing enclosed transfer stations to reduce odors and the possibility that wind may blow trash out of the facility and by careful monitoring to ensure that waste does not accumulate at the facility for more than several hours (Tchobanoglous, Theisen, and Vigil 1993). World Bank projects in Calcutta and Lagos encountered difficulties and delays in acquiring land with economic, environmental, and political features suitable for transfer station sites (Bartone, Bernstein, and Wright 1990). The cost of siting these facilities probably is not responsive to the level of throughput capacity, so higher costs for sites may lead to fewer but larger facilities.

In developing countries, informal-sector recycling enterprises are generally extremely labor intensive and hence do not show economies of scale. Low-technology capital intensive recycling facilities appear to show weak economies of scale, and high-technology capital-intensive recycling facilities actually appear to exhibit diseconomies of scale (Kreith 1994b).

There appear to be economies of scale in high-technology incineration facilities. This conclusion is based on statistical analyses of the association between operating and maintenance costs (excluding collection costs) and plant capacity for facilities that burn largely unprocessed MSW, generate both steam and electricity, and range in capacity from 90 metric tons to 1,100 metric tons a day. The economies of scale, however, do not appear to extend to mass burn facilities that generate only electricity, which operate on an even larger scale (average capacity of 1,100 metric tons of MSW a day) (Kreith 1994b). The installed capital cost per ton of MSW capacity of incinerator emission-control systems appears to decline sharply as the daily capacity of facilities rises from about 500 metric tons to 1,000 metric tons, leveling off for facilities with greater than 1,500 metric tons a day (Teller 1994). In the United States the economies arise partly because of the difficulty of siting and obtaining regulatory permits and because of the high cost of air pollution control devices (see, for example, Bailey 1993a and 1993b).

Evidence for the United States also suggests that the average cost of operating sanitary landfills declines by about 70 percent as their capacity increases from 227 metric tons to 2,700 metric tons a day (DeLong 1994). Recently issued U.S. Environmental Protection Agency regulations for site preparation and management to prevent groundwater contamination appear to impose even higher fixed costs on MSW landfills, creating even greater regulation-driven economies of scale.

In sum, the limited economies of scale available in collection of MSW and the greater economies of scale associated with transfer stations, landfills, and other MSW management facilities suggest that collection services are best provided on a decentralized basis, whereas it may be more cost-effective for disposal and treatment facilities to be consolidated at a regional or metropolitan area level (Bartone and Bernstein 1993).

Nonpecuniary Costs and Benefits

Decisionmakers must take into account the implications of MSW management alternatives for public health and environmental quality. Poor collection or disposal practices attract and promote the breeding of insects, rodents, and pathogens that can cause and transmit diseases, particularly several of the diseases in the tropical cluster: schistosomiasis, South American trypanosomiasis, and Bancroftian filariasis. The World Bank estimates the burden to developing countries from these diseases alone was 8 million disability-adjusted life-years in 1990, or about two life-years per 1,000 population. An estimated 25 percent of these might have been averted through "feasible interventions" (World Bank 1993), such as covering the waste delivered to a dumpsite with fifteen to thirty centimeters of soil at the end of each day. (Doing so sacrifices landfill capacity, but this cost could be lessened by using relatively low-quality composted MSW as the daily cover; see Tchobanoglous, Theisen, and Vigil 1993.)

Although the direct contribution of inadequate management of MSW to the burden of disease in developing countries is modest, the indirect contribution is larger. For example, waste may clog open drains, creating breeding grounds for malaria- and dengue-transmitting mosquitos (Mensah and Whitney 1991), or causing floods in rainy seasons, which may increase human contact with pathogen-infected feces contained in the waste.

Cleaning up MSW landfills contaminated by hazardous waste appears to be substantially more costly than placing the waste in specially designed hazardous waste landfills at the outset. The experience of the United States is instructive. Closed MSW landfills in the United States account for a large share of hazardous-waste sites that have been targeted for cleanup under the 1980 Comprehensive Environmental Response, Compensation and Liability Act, also known as Superfund (U.S. Congress 1989). Soil contaminated by hazardous wastes may include not only the remnants of waste deposited on the site in the past, but also neighboring soil that has soaked up leachate from the waste. In the United States, household hazardous waste accounts for less than 1 percent of MSW by weight, suggesting that industrial and commercial hazardous wastes were the main contaminants at old landfills. (More recently, regulations that restrict the disposal of hazardous waste in MSW landfills have led to lower concentrations of harmful compounds in leachate in new landfills; see Tchobanoglous, Theisen, and Vigil 1993.)

There are two major methods for cleaning up the contaminated soil after it is excavated. One method is to deposit it in licensed hazardous-waste landfills, which have double plastic linings, high-technology leachate collection systems, and rigorous management. In the United States, these landfills charge tipping fees between $220 a metric ton and $550 a metric ton of contaminated soil (Schneider 1994). The other method is to incinerate the soil in special kilns at high temperatures (Bowen and Lambe 1994), also at high cost.

A simple calculation suggests that disposing of hazardous waste in hazardous-waste landfills or incinerators instead of in ordinary MSW landfills is highly cost-beneficial. Consider, for example, a landfill with a fifteen-year capacity at the present pace of accepting MSW. Suppose 10 percent of the waste discarded at the dump is hazardous. Suppose further that shortly after the landfill reaches its capacity, a decision is made that for public safety the entire dumpsite must be excavated and the wastes transferred to a landfill or incinerator specifically designed for hazardous materials. Assume the disposal cost at the hazardous-waste treatment and disposal facility is seven times the cost at the MSW landfill (the average MSW landfill disposal fee in the United States was $31 a metric ton in 1993, according to Bailey 1993a). The cleanup option would have a positive net present value only if the discount rate were in excess of 28 percent, which is far above even upper-bound estimates of the social discount rate. If the cleanup is instead deferred for another ten years, the break-even discount rate will be about 14 percent, which is close to typical estimates of the social discount rate. The true break-even discount rate may be even higher: the costs of excavating and transporting the waste from the MSW landfill to the hazardous-waste treatment and disposal facility were not included in the calculation, and the hazardous proportion of waste deposited in MSW landfills is likely to be less than 10 percent. To the extent that not only the waste deposited in the landfill but also the neighboring soil, perhaps contaminated by toxic leachate, must be excavated and transported to a hazardous waste treatment and disposal facility, the break-even discount rate would be higher still. The length of the deferral period for cleaning up the landfill may depend in part on the time it takes for leachates to contaminate ground and surface waters.

Landfills may also contribute to the accumulation of greenhouse gases in the atmosphere. The Intergovernmental Panel on Climate Change estimates that between 20 million metric tons and 70 million metric tons of methane (about 6 percent of estimated global annual methane emissions) are emitted annually by the anaerobic decomposition of organic waste at landfills worldwide (U.S. Department of Energy 1993). Developing countries contribute relatively little to global methane emissions, but that could change with a shift toward sanitary landfill practices. (The accumulation of greenhouse gases could be reduced if the methane were collected and flared or used as fuel; an estimated 940,000 metric tons of methane were recovered for fuel use in the United States in 1990; see U.S. Department of Energy 1993).

Incineration releases several pollutants into the atmosphere, including particulate matter and incomplete-combustion products such as carbon monoxide, nitrogen oxides, chlorinated and other hydrocarbons, acid gases, and mercury and lead (U.S. Congress 1989). Modern incinerators in industrial countries generally use a combination of furnace temperatures of 1,800 degrees Fahrenheit for complete combustion, electrostatic precipitators or fabric filters to remove particulate matter and metals, and scrubbers to remove acid gases. Although these measures eliminate most of the air pollutants, continuing controversy about the risks of air emissions to human and ecosystem health often make the siting of new facilities difficult (U.S. Congress 1989). In many developing countries, MSW is burned with few or no emission controls and therefore is likely to pose a greater threat to the environment per ton incinerated than if burned in state-of-the-art incinerators. Still, the use of coal, wood, or dried animal dung as fuel and the rapidly increasing vehicular emissions and industrial pollution are together far more important sources of morbidity and mortality than smoke from MSW landfills (although perhaps not for MSW landfill workers and scavengers and residents of nearby communities).

Attaching a monetary value to changes in health and environmental quality is a classic economic problem. It is typically addressed by attempting to estimate through surveys or more indirect means the willingness of individuals to pay for the benefits of environmental quality. Even this method may provide only a lower-bound valuation, because it does not take into account the preferences of future generations or of individuals outside the local community who have an interest in these issues. An example of how economists use indirect methods to value environmental quality can be found in Nelson, Genereux, and Genereux (1992). Using data on prices and other characteristics of houses located near a MSW landfill in the United States, this study estimated that, other factors held constant, housing values rise with distance from a landfill (an average of 6.2 percent a mile within a two-mile radius of the landfill), presumably because the environmental and aesthetic problems of living near a landfill diminish as distance from it increases.[7]

Contingent-valuation surveys are another way for economists to estimate the willingness of individuals to pay for improvements in their environment. Contingent-valuation surveys describe a program, for example, an enhanced waste collection and street-cleaning program, and its likely environmental consequences. Questions are then designed to elicit truthful and consistent information from respondents about their willingness to pay for the program. Surveys must be carefully designed and administered to ensure that respondents fully understand the proposed program, which can often be very technical, that they do not try to give answers they hope will influence policy decisions rather than provide accurate reflections of the value they attach to the program, and that their answers focus on the question at hand and not on broader environmental issues (Portney 1994).[8] Households in cities of developing countries generally report little willingness to pay for improved MSW services, either because they place little value on improved management or because they do not believe that the supposed levels of service will be achieved.

Selected Economic Issues

The generation of MSW, its physical characteristics, and its management are all influenced by household income and a variety of price variables. For a number of reasons, however, private economic behavior is unlikely to yield socially optimal outcomes with respect to the generation and management of MSW. Government intervention in a variety of forms may therefore be needed to overcome these market failures.

The Role of Private Economic Behavior

Both the cross-country and time-series data in tables 1 and 3 indicate that the generation of MSW is positively related to average income. Presumably, this result captures the net impact of several underlying mechanisms, including the effects of income on consumption, on the distribution of consumption between goods and services, and on the demand for environmental quality. Environmental quality is probably like most goods: high-income households are likely to demand more of it than low-income households and are willing to pay more for it. In addition, the complexity and distance (in time or space) of the health and aesthetic implications of low-quality air, land, and water make it likely that better-educated households have stronger preferences for environmental quality. This reinforces the effect of income on the demand for environmental quality because higher incomes are associated with higher levels of education (Baumol and Oates 1988).

The positive association of income and MSW generation may also reflect the net effect of higher wages on the amount of waste produced by household activities. Higher wages are normally associated with a higher valuation of time and therefore with greater purchases of prepared foods, which generate more packaging waste and less food-scrap waste, less use of ash-generating coal or wood for home heating and cooking and more reliance on electricity or methane, and less effort devoted to recycling waste for personal pecuniary gain. Thus, higher wages affect not only the quantity of MSW that is generated but also its composition and the degree to which households process it before discarding the residue.

A number of price variables also influence behaviors that affect the generation, composition, and management of MSW. All else being equal, higher market prices offered for recyclables provide incentives for households and firms to gather, clean, and transport materials extracted from waste for sale and reuse. The price that must be paid for the disposal of waste also affects the actions of households and firms. For example, the residents of Seattle, Wash., pay a fee for each uniform-sized garbage can of trash they put out for collection. This has led to the "Seattle stomp," as residents try to compress as much trash in a can as possible to minimize collection fees (Richards 1993). In developing countries, the least costly options for disposal of waste—dumping it in public spaces or burning it openly—are often the most popular (Bartone and Bernstein 1993). Although inexpensive in terms of out-of-pocket costs and environmental effects to those who dump or burn waste, these acts may impose large costs on society. Aesthetic, environmental, and health problems may result, especially in densely populated urban areas. The contamination of the water supply caused by dumping waste in unlined and unsealed pits and the air pollution produced by burning waste at dumpsites or in crude incinerators may also cause urgent health and cleanup problems, particularly if the MSW contains hazardous materials. Without reimbursement, individual households are unlikely to choose a more costly but less socially damaging way to dispose of waste. It is very difficult to collect voluntary payments from other households that benefit from better disposal methods, because the private regulation of the use of common property is hard to monitor and enforce. Moreover, even if the market for management services reflected the willingness of persons living today to pay for environmental quality, it would not reflect the preferences of the future generations who will be forced to bear the costs of current management practices. Households and firms left to their own devices may reap benefits from avoiding investment in environmentally sound waste disposal, but they leave a legacy of far greater damage to future generations.

The Role of Government

Common property resources and intergenerational externalities provide incentives for households and firms to underconsume services in the private market for MSW management. Because the benefits of some kinds of MSW management to households and firms fall short of the benefits to society, the optimal government interventions are those that align the private and social incentives for MSW disposal as closely as possible.[9] The government has access to a number of policy instruments.

VOLUMETRIC AND FLAT TARIFFS. Government can undertake one or more of the tasks of MSW collection, transport, processing, and disposal, charging either a volumetric tariff (a curbside charge per unit volume of waste handled) or a benefit tax (a flat amount per household). A volumetric tariff gives households and firms an incentive to reduce residual waste ("Project 88–Round II" 1991) either by changing the way they produce and consume, by recycling, or by illicitly dumping or burning waste.

In an analysis of per unit charges for curbside collection of MSW, Repetto and others (1992) estimated that environmental damage and the amount of waste households set out for collection would be substantially reduced by charging households a fee that fully reflected the costs of collection and disposal. The study used 1980–89 data on MSW collection charges and tonnage of waste collected and deposited in landfills by a sample of fourteen communities in the United States. Ten of these communities levied curbside collection charges. The results suggest that a $1.50 charge per 32-gallon container (which typically holds about 9.5 kilograms) induced households to cut the waste they put out for collection by an average of 18 percent per capita (0.2 kilograms per capita per day). When the fees were combined with a program for collecting recyclable materials from households, the average reduction increased to more than 30 percent.

A flat benefit tax charged to all households as part of their utility or property tax bill may be the most effective way for cities of developing countries to pay for MSW management, reduce the incentive to dump MSW illegally, and possibly subsidize MSW management services for poor neighborhoods. Such an arrangement has financed 100 percent of the cost of MSW management in Santiago, Chile. Santiago, Caracas, São Paulo, and Rio de Janeiro all bill households for MSW services on the basis of past MSW management costs. Because of low inflation in Chile, Santiago's MSW management fees have been in line with current MSW management costs. In the other cities, accelerating inflation has led to consistent underestimates of management costs; as a result, management fees have covered only 10 to 70 percent of program costs (Bartone and others 1991). Although benefit taxes do not provide an incentive to reduce MSW discards, in developing countries it is likely that most of the recyclable or reusable materials have been recovered by the time MSW is put out for collection.

DEPOSIT REFUND SCHEMES. Fullerton and Kinnamon (1993) present a theoretical model where illicit burning or dumping are options for MSW disposal and the resulting environmental damage is greater than from sanitary landfilling or incineration. In such circumstances, a deposit-refund scheme for recycling waste may be a more efficient policy than levying curbside charges. The clear advantage is that it encourages households and firms not to dump or burn MSW illegally. Moreover, it may be cheaper to manage a deposit-refund scheme than to monitor the disposal behavior of many small-scale illegal dumpers ("Project 88–Round II" 1991). Cyprus, Egypt, India, Lebanon, and Syria have deposit-refund systems for carbonated-beverage containers made of glass; Australia, Canada, France, Germany, Switzerland, and the United States have deposit-refund systems for various types of beverage containers; and the Scandinavian countries are considering deposit-refund systems for certain products containing mercury and cadmium, such as batteries (King, Crosson, and Shogren 1993). Whether the benefits of these programs, including aesthetic benefits, exceed the costs, including the opportunity cost of households' time, is not entirely clear (see, for example, Porter 1978).

PRICE AND TAX INCENTIVE POLICIES. Incentive policies that indirectly affect prices are also an option. Fees can be imposed on goods at the retail level to reflect expected disposal costs. This policy is less precise than curbside charges because it does not directly influence disposal decisions. It may affect consumption decisions, however, and hence the composition of MSW. If a system of curbside charges is too costly to operate, as would probably be the case in developing countries, packaging taxes may be a second-best policy ("Project 88–Round II" 1991). A related policy would be to tax the virgin-materials content of goods at the point of production to reflect their disposal costs. This policy may be easier to administer than retail charges and would give producers, and ultimately consumers, a clear incentive to favor recycled over virgin materials.

A problem with these policies is that any variations in disposal costs within the product's geographic market will mean that the tax will inaccurately reflect local disposal costs ("Project 88–Round II" 1991). Another issue is the distributional impact of retail or virgin-content disposal charges. Some evidence, at least for the United States, indicates that low-income households are more likely to purchase small sizes of packaged goods than to buy in bulk, perhaps because they lack storage space or cannot afford to tie up their limited funds in stored food. Thus, low-income households may purchase more packaging per unit of product than high-income households, which suggests that retail and virgin-materials taxes would be regressive (Rathje and Murphy 1993).

Well-intentioned government policies that influence prices may have unintended and undesirable consequences on the quality and scope of MSW management. In India, Indonesia, and other developing countries, for example, governments subsidize the production of chemical fertilizers, thereby stifling the development of agricultural markets for compost. Yet compost not only cuts down on fertilizer use, but reduces runoff pollution by enhancing the ability of soil to prevent fertilizer from leaching out after rainfall.

SITING INCENTIVES. Policymakers can create incentives that indirectly affect MSW disposal behavior. For example, policymakers in industrial countries frequently face local resistance to the siting of MSW disposal facilities. So-called NIMBY (not in my back yard) activism may also arise in developing countries even if government authorities are trying to site and construct environmentally benign facilities. Previous MSW landfills in developing countries were almost universally so poorly managed that many governments have little credibility when they claim that the new facilities will be well managed. A potential solution might be to require a locality to encourage debate and to hold a fair and binding referendum if the government or a firm proposes to build an MSW disposal facility within its borders. This would encourage the builders of the facility to choose communities whose voters would be willing to accept the smallest compensation package—those communities either least affected by the facility or most in need of the compensation ("Project 88—Round II" 1991).

For example, the province of Alberta, Canada, devised a successful process for siting a hazardous-waste treatment facility. After canvassing sites for their technical suitability, representatives of the Alberta government met with officials of the jurisdictions containing the sites. The localities had the choice of continuing to participate in or dropping out of the siting process. Once the provincial government narrowed down the remaining potential sites, each of the five remaining communities held a referendum to measure support for the proposed facility. Seventy-nine percent of the voters in Swan Lake approved of the facility, even though no fees were paid to the community as a condition for locating there. Swan Lake's economy was based on oil and gas industries, which meant that the community was familiar with hazardous operations. Moreover, the facility represented an opportunity for the town to diversify into a new industry. After the facility opened in 1987, community support remained strong, mainly because the operators of the facility were careful to remain available to answer questions from the public (LaGrega, Buckingham, and Evans 1994).

EDUCATION. Another government policy would be to educate households about the health and aesthetic implications of undesirable MSW management practices (Bartone and Bernstein 1993; Ohnesorgen 1993). In the United States in the early 1900s, for example, youth leagues were set up in many cities to educate the population about proper handling and disposal of solid waste (Melosi 1981). More sophisticated approaches to mass education might use radio, television, and school programs.

RESEARCH AND DEVELOPMENT. There may be underinvestment in the research and development of socially efficient MSW management practices. Entrepreneurs generally have no incentive to develop the small-scale, labor-intensive methods that may be most appropriate for developing countries. It is difficult to reap much of the gain from methods that are easy to imitate and inexpensive to implement. Governments can correct this problem by supporting research on the development of low-cost MSW management techniques or institutional arrangements for handling MSW in environmentally friendly ways.

Private Provision of Management Services

It may be more efficient for a city government to contract for MSW management services instead of providing the services itself. Profit-seeking firms generally have greater flexibility and incentive than government bureaucracies both to redeploy workers and physical capital quickly in response to changing circumstances and to design and implement cost-cutting innovations. The key to efficient privatization of MSW management is to promote competitive bidding by private firms (and even by public agencies). To realize the potential gains in efficiency, the government must be able to hold contractors accountable for their performance. The better able the government is to specify the tasks it seeks to accomplish, including setting standards for environmentally sound practices, the more easily it can evaluate contractor performance. And the more effective the government's mechanism for penalizing poor performance, the greater the likelihood that private provision of MSW management services will be more efficient than public provision (Donahue 1989).

Conversely, a private firm granted exclusive control over MSW management with insufficient monitoring of its performance may exercise its monopoly power to earn a higher-than-normal rate of return on its investment. A city government that fails to foster a competitive environment will find that privatization does not increase efficiency. Instead, the lure of excess profits for entrepreneurs and of above-market wages for labor unions will encourage both groups—whether through lobbying, campaign contributions, bribes, or kickbacks on the part of the entrepreneurs or strikes on the part of public waste-collection workers—to influence governments to make inefficient spending decisions (Donahue 1989). The threat of a strike by public waste-collection workers can be a particularly potent weapon. The unpleasant prospect of suspended service will lead voters to put extreme pressure on elected officials to settle labor disputes (Donahue 1989).

Empirical studies of private MSW collection services in Canada, the United Kingdom, and the United States have generally found that noncompetitive public collection services are less efficient than competitive contracting by private firms. Some of the studies found, however, that open competition—allowing free entry and exit of firms into the regulated MSW collection market—was the least efficient of the three modes of service delivery. Some evidence shows that public agencies bidding against private firms for contracts are about as efficient as their competitors; the efficiency gains from competition do not depend on the form of ownership of the collection service (Donahue 1989).

A review of private MSW services in Latin America confirms that one reason they are efficient is effective government regulation and monitoring. Unfortunately, both private and municipal collection enterprises sometimes dump MSW at open landfills instead of disposing of it at the nearly state-of-the-art, capital-intensive sanitary landfills in Buenos Aires, Caracas, and Santiago. This apparently happens because the local MSW management agencies have been unable to collect sufficient fees to pay for tipping charges at the sanitary landfills (Bartone and others 1991). A solution might be to reduce the incentive for illegal and unsafe dumping by subsidizing tipping fees.

Experiences in the United States and Developing Countries

MSW management experience in the United States has differed widely from experiences in the developing countries. These experiences illustrate the wide range of private and public factors that influence decisions on MSW management, the variety of approaches adopted to address these factors, and the quality of the results.

United States

Expenditures on MSW collection and disposal in the United States increased from $4.7 billion in 1972 to $14.5 billion in 1992 (both figures in 1987 dollars), or an average annual growth rate of 5.8 percent (Rutledge and Vogan 1994). These figures include payments by households to private collection and disposal businesses; local, state, and federal government spending on publicly provided service; and fees paid by governments to private MSW management contractors to provide services to households, government agencies, and perhaps other entities. They do not include the expenditures by enterprises and institutions other than households and governments, which account for between 35 and 45 percent of MSW generation in the United States (U.S. Environmental Protection Agency 1992). The U.S. federal government provides virtually no MSW collection and disposal services to entities other than federal agencies.

Although expenditures on collection and disposal in 1992 amounted to only 0.29 percent of GDP (up from 0.15 percent in 1972), the 5.8 percent average annual growth rate from 1972 to 1992 substantially exceeded the average annual growth rates of 1.4 percent in real GDP per capita and 1.0 in population. Given the estimated sensitivities of MSW generation to changes in GDP and population reported in table 3, this increase in expenditures suggests a sharp rise in the real per-ton cost of managing MSW. Furthermore, the increase coincided with growing employment in the MSW management sector, an increasing share of which is private. A 1975 study estimated that private firms collected the MSW of between one-third and one-half of all households in the United States (Donahue 1989). Corresponding estimates for the early 1990s range as high as 80 percent (McAdams 1994). In 1991 an estimated 343,000 people were employed in the collection, transport, and disposal of MSW, of which about two-thirds were employed by private firms (U.S. Bureau of the Census 1991, 1993).

The doubling of real per capita MSW collection, transport, and disposal costs in the United States during the past two decades resulted in part from an increase of nearly a third in daily per capita waste generation, up from 1.5 kilograms in 1970 to about 2.0 kilograms in 1990 (U.S. Environmental Protection Agency 1992).

About 66 percent of MSW is currently deposited in landfills, roughly the same share as in 1965. Nearly 15 percent is recycled, up from 6.6 percent in 1965 and 9.9 percent in 1985. Another 2.1 percent of MSW is composted, for a total of about 17 percent that is recovered before disposal. Finally, 15.2 percent is incinerated to generate energy, up sharply from 4.6 percent in 1985 (U.S. Environmental Protection Agency 1992). The rise of recycling and composting and of converting waste to energy reflects increased awareness of the potential value that resides in MSW, more ambitious state recycling goals, and possibly increased value of recyclable materials.

LANDFILL. Another reason that per capita MSW management costs have doubled has been the increasingly stringent regulations imposed by states and, more recently, the federal government. In 1993 the U.S. Environmental Protection Agency's Municipal Solid Waste Landfill Criteria took effect. These regulations

- Impose restrictions on the location of new landfills
- Require a daily cover of six inches of soil on landfills
- Require owner-operators of landfills to check for and remediate methane emission
- Largely prohibit the open burning of waste
- Mandate owner-operators to build and maintain control systems for stormwater runon-runoff

- Set maximum contaminant levels for groundwater as a basis for designing new landfills, which can be met by lining landfills with a layer of impermeable material two feet thick plus a synthetic flexible membrane barrier and a leachate collection system
- Require owner-operators to file plans for closing the landfill (including a two-foot earthen cover) and for thirty years of postclosure maintenance of the final cover, during which ground water and methane gas are monitored and leachate management is continued (U.S. Environmental Protection Agency 1993).

The U.S. Office of Technology Assessment estimates that imposing pollution controls on landfills increases the average MSW disposal cost per metric ton to $20 compared with $9 (1988 dollars) for landfills with no pollution controls (U.S. Congress 1989), although the cost of pollution controls probably varies with regional differences in hydrogeology.

Controls appear to have evolved in response to the side effects of earlier attempts to limit the environmental problems associated with landfills (Ham 1993). In the 1960s landfills began to be sited away from surface waters and wetlands to avoid surface-water contamination. In the early 1970s groundwater contamination led to requirements that landfills be located in areas with low water tables and tight soils (fine silts and clays) or be lined with clay. By the mid-1970s experts realized that these requirements led to leachate accumulation within landfills and leakage into surrounding areas, so leachate collection and treatment systems were mandated. Because these systems are costly, landfill operators tried to limit the entry of water into landfills by using clay or plastic membrane caps. Unfortunately, this practice prevented the venting of methane and posed a danger of explosion, so by the mid-1980s methane was collected for flaring or for use. Excluding all water from landfills is impossible, and some decomposition will occur anyway. Consequently, monitoring of leachate and gases must take place for many years, even after a landfill is closed, a costly process that many developing countries cannot afford.

The increasingly strict state and federal landfill regulations led to many landfill closures and a great deal of concern in the late 1980s about future landfill capacity. Some 14,000 landfills have been closed in the United States since 1978, leaving about 6,000 in operation. Many of those that were shut down were open dumps and relatively small, while the landfills still in operation are much larger (Rathje and Murphy 1993). New landfills are becoming more and more difficult to site because of local resistance, and increasing amounts of MSW must be hauled farther, adding to the cost.

RECYCLING. Much of the increase in recycling since 1985 is attributable to mandatory recycling goals or programs imposed by many states. Judging whether recycling programs are cost-beneficial is hampered by poor, incomplete, or inconsistent data (Spencer 1994). Prices for recyclable materials have climbed recently, for various reasons: new plants that are capable of recycling old newspapers and other materials have driven up demand. Government agencies are now required to use recycled paper. The global economic recovery is leading to high prices for virgin materials (Pressler 1995). Meanwhile, landfill capacity has increased considerably in the past several years, lowering disposal prices per ton and leading to declining cost savings from recycling (Bailey 1992). Furthermore, curbside collection of recyclable materials adds considerably to the overall cost of MSW collection (Kreith 1994a). Even advocates of recycling acknowledge that prices for recyclable materials have not risen to the point where curbside recycling programs are profitable. Thus the already difficult judgment of whether the benefits of recycling outweigh the costs depends on the hard-to-measure costs of environmental damage that have been avoided (Pressler 1995).

INCINERATION. A combination of factors was responsible for the sharp rise between 1985 and 1990 in the percentage of MSW being burned for energy recovery. Among these were growing concerns that landfill capacity was inadequate, regulations requiring utilities to purchase electricity from incinerators at premium rates, investment tax credits covering the construction of incinerators, and inexpensive government-backed financing for the construction of incinerators. Most of the incentives for incinerator construction were reduced or discontinued by the early 1990s, and with MSW incineration fees now roughly double the corresponding landfill fees (Bailey 1993b), the growth in incineration has moderated.

Locations in Developing Countries

Experiences in the developing countries are different from the United States experience and from each other. The character of the MSW problem differs from one location to another, depending on the physical characteristics of the solid waste and on local geography. In Bangkok and Shanghai, narrow streets make waste collection difficult. Coal, which generates substantial amounts of ash, is still widely used to heat homes in Shanghai, although ash as a percentage of the MSW stream has been decreasing since the mid-1980s. Per capita MSW generation rates are nearly 50 percent higher in the summer because of a seasonal increase in food wastes from fruits and vegetables (Ward and Li 1993).

Notwithstanding the diversity in developing countries, several generalizations emerge from a brief review of MSW management experiences in a sample of developing country locations: Bangkok, Dar es Salaam, Jakarta, Mexico City, Shanghai, and Taiwan (China).

A GROWING PROBLEM. Solid waste is not only a sizable problem throughout the developing world, but a growing one, partly because of population growth and partly because rising per capita incomes in much of the developing world have led to rising per capita generation of waste.

From 1982 to 1989, daily per capita MSW generation in Bangkok increased from 0.6 to 0.9 kilogram (Muttamara, Visvanathan, and Alwis 1992/93). Mexico City residents each generate about 1.0 kilogram of MSW a day, double the estimated rate in the 1950s, with even faster growth in per capita generation of nonbiodegradable waste (Meade 1992). Shanghai's daily per capita MSW generation of 0.80 kilogram translates into 2.50 million metric tons a year, up from 1.31 million metric tons at the beginning of the 1980s (Ward and Li 1993). In Taiwan (China), per capita MSW generation increased an average of 4.8 percent a year from 1980 to 1991 (Taiwan, China 1992).

COLLECTION AND URBANIZATION. The urban proportion of the population of developing countries increased from 25 to 46 percent between 1970 and 1991. Moreover, the annual growth rate of urban populations in developing countries has accelerated from an average of 3.7 percent in the 1970s to 6.3 percent in the 1980s (even though the much lower overall annual average rate of population growth for developing countries decelerated from 2.2 percent in the 1970s to 2.0 percent in the 1980s (World Bank 1993). These trends, combined with rising per capita income in many developing countries, have led to burgeoning concentrations of MSW in metropolitan areas. It is likely that these trends drive up the average cost of collection, processing, and disposal and strain the administrative capacities of city governments. About 20 percent of solid waste in Bangkok is believed to be dumped into the city's canals or burned (Muttamara, Visvanathan, and Alwis 1992/93). In 1988 Dar es Salaam's population of roughly 1.5 million people generated about 1,040 tons to 1,340 tons of waste a day. The city's system for handling solid waste involves collection and transport by truck to an open dumpsite about six kilometers outside the city, but the scope and effectiveness of this system are limited. Only about 180 tons of MSW are actually collected each day by the city's thirty trucks operating on a limited number of accessible streets (Yhdego 1991). In Jakarta, the city government and private companies together collect only about 60 to 80 percent of MSW. They transport it to open, unlined dumps on the outskirts of the city, where some of it is burned. Much of the remainder is burned in the open air within the city, dumped in local waterways, or left to decompose on unused plots of land. Mexico City uses 2,000 collection trucks (including street sweepers), only 60 to 65 percent of which are typically in operating condition at any time (Meade 1992). In Shanghai collection is labor intensive, and waste is transported to landfills by trucks and barges. Because only 60 percent of the trucks hauling waste are covered, much is scattered along streets and spilled into waterways in the process (Ward and Li 1993).

ADVERSE EFFECTS OF POOR PROCESSING AND DISPOSAL. Poor processing and disposal practices have serious adverse effects on the quality of air, water, and land. About 90 percent of Bangkok's collected MSW is disposed of by open dumping, and the remaining 10 percent is composted or incinerated (Muttamara, Visvanathan, and Alwis 1992/93). Most of Dar es Salaam's household waste is discarded into open pits near households, on streets, in markets, or in stormwater drainage channels (Yhdego 1991). Some is burned. Moreover, the city's main dump, which was fairly isolated when it was established in 1965, is now close to several communities and contributes leachate to the nearby Luhanga River (Yhdego 1988). Most of Shanghai's landfills rest on land with sandy soils and high water tables, causing foul odors, insect concentrations, and leachate pollution of local drinking water (Ward and Li 1993). In 1984 the Shanghai government built a simple MSW composting plant with a capacity of 300 metric tons a day, in which MSW is composted in large, closed containers for one month and then put on grates and sorted by particle size. Owing to poor quality control, however, the compost is heavily contaminated with glass, plastics, and metals and is therefore of relatively little value to local farmers (Ward and Li 1993).

WIDESPREAD INFORMAL SECTOR RECYCLING. Bangkok households typically separate newspapers, magazines, cardboard, and bottles from their solid waste to sell to door-to-door collectors. Street scavengers pick through waste in streetside containers, collection crews spend an estimated 40 percent of their time sorting through the waste for recyclable materials they can sell to supplement their incomes, and scavengers pick over the rest at the dumps. Scavengers and refuse collectors sell recyclables to small-scale recycling shops near the dumps (Muttamara, Visvanathan, and Alwis 1992/93). In Mexico City, collection workers sort through waste for recyclables they can sell to supplement their incomes. This has become increasingly difficult, however, because the quantity and value of recyclable materials declined dramatically in 1982, when the economic crisis led household help to screen the waste more carefully (Meade 1992). In Dar es Salaam, considerable scavenging, under very difficult conditions, takes place at both the main dump and throughout the city (Yhdego 1991). Some organized extraction of recyclables takes place at Shanghai's landfills (Ward and Li 1993). Throughout Jakarta an estimated 30,000 to 60,000 scavengers extract recyclable materials such as glass, paper, cardboard, metals, wood, rubber, bones, and textiles from the waste stream. They sell these materials to small-scale entrepreneurs who sort, clean, bundle, and sell them to other middlemen who specialize in particular materials, which they in turn transport and sell to recycling factories.

Conclusion

In 1992 the Gallup International Institute conducted an in-depth international survey of attitudes toward environmental quality. The survey polled large, representative samples of citizens of twenty-four countries (twelve industrial and twelve developing countries, accounting for about 40 percent of global population) in Eastern and Western Europe, North America, Latin America, Asia, and Africa, giving it the broadest coverage of any international survey on the environment to date (Dunlap, Gallup, and Gallup 1993b).

Two of the survey questions made specific reference to MSW generation and management. One asked whether people who "use more resources than they need" and who "throw away too much" contribute a "great deal" to their nation's environmental problems. About one-third to two-thirds of the respondents (54 percent on a population-weighted basis) said "yes" (Dunlap, Gallup, and Gallup 1993a). Interestingly, the affirmative response rates do not vary with per capita income.

The other question asked whether "inadequate sewage, sanitation and garbage disposal" was a "very serious" problem (Dunlap, Gallup, and Gallup 1993a). The range of affirmative response rates was wider than for the first question, between 2 and 62 percent, although the population-weighted affirmative response rate was only 37 percent. A strong negative relationship was apparent between income and concern about this problem.

The Gallup poll findings suggest that concern about MSW generation is strong in both developing and industrial countries, reflecting the large and rapidly growing burden of MSW, especially in developing countries. Between 1990 and 2010, we project a 2.7 percent annual rate of increase in MSW generation in the developing counties, nearly double the projected rate of increase in the industrial countries. The Gallup poll findings also suggest that the capacity of MSW management systems is weak in many developing countries. Nevertheless, there are encouraging signs that economic development leads to stronger institutional structures and a willingness to experiment with and invest in projects that can alleviate long-standing problems of MSW management in ways that are appropriate to a country's level of development.

For low-income countries, one option may be to remove sanctions on informal sector collection and recycling enterprises, integrate them with other MSW management strategies, and explore ways that these enterprises can economically divert more MSW from landfills.

For example, even though scavengers extract most of the readily recyclable material from Jakarta's solid waste, interest has grown in the possibility of extracting further value from the organic portion of the remainder by converting it into compost. In recent years, investigators have conducted a number of projects to explore the technical and economic feasibility of composting the biodegradable portion of nonrecycled MSW. Perhaps the most promising of these is a project sponsored by the government of Indonesia that began by establishing an experimental station in Jakarta in late 1989 to develop a composting technique appropriate for the city's waste stream, climate, and labor-surplus economy; study the cost of producing compost using that technique; and investigate the economic uses of compost and the nature and potential size of the compost market. By late 1990 the investigators had developed a technique for which preliminary technical and financial results were sufficiently encouraging to justify establishing four pilot projects. These projects, known as Enterprises for

Recycling and Composting (ERCPs), were operated by private entrepreneurs who were all former scavengers or small-scale middlemen in the recycling industry. The government supported the pilot projects by

- Providing partial start-up grants, technical assistance, worker training, and a guaranteed purchase arrangement for the compost
- Securing access to suitable land and arranging for the daily delivery of fresh MSW and the removal of noncompostable residuals and hazardous materials as they accumulated
- Providing experimental analyses of the benefits of compost in Indonesian agriculture and aquaculture.

The pilot projects served as a testing ground for solutions to problems of odor, flies, aesthetics, and community relations, all of which had to be addressed before the program could be expanded. Because the pilot projects appear to demonstrate that high-quality compost can be produced at a relatively low cost, a tenfold expansion is currently under way. Nevertheless, given government subsidization of chemical fertilizer and uncertainties about the magnitude and price sensitivity of the demand for compost, the long-term viability and expansion of the program remains an open question.

In addition to coordinating official waste-management activities with those of the informal sector, local governments in lower-middle-income countries can contract with private firms for collection. Moreover, large metropolitan areas with sufficiently strong municipal governments can take advantage of economies of scale in the operation of transfer stations and landfills by setting up metropolitan authorities to manage these facilities. For example, Mexico City recently closed seven open-air, polluted dumps, and replaced them with ten waste transfer stations and two operating landfills that meet strict environmental standards, including clay linings to prevent seepage of leachate and 0.3 meters of daily soil cover to contain orders and prevent runoff after a rain (Meade 1992).

Higher-income countries are unlikely to have a significant informal sector recycling industry and therefore may benefit from pricing policies that encourage households to recycle. For instance, a deposit-refund program for polyethylene terephthalate plastic bottles was introduced in 1989 in Taiwan (China). Initial participation levels were low because of inadequate public information programs, inconvenient dropoff locations (Taiwan, China 1992), and a low deposit of two cents a bottle (O'Connor 1993). But in 1992 the government strengthened the program by providing 13,500 collection bins in stores, opening up a toll-free telephone information line, and raising the deposit to eight cents a bottle, an amount thought to correspond more closely to the social cost of inadequate disposal (Taiwan, China 1992). By making recycling more convenient and increasing the deposit, participation levels, and presumably social welfare, improved. By contrast, recycling programs for aluminum and tin cans, glass, batteries, and tires have relatively low participation rates because these programs are not as convenient as the plastic-bottle deposit-refund program.

International experience, although not strictly transferable, offers many valuable lessons for designing and implementing innovative systems that dispose of MSW in ways that enhance environmental quality and public health. Fortunately, although rising income levels in rapidly developing countries increase waste generation, they appear to stimulate improved management as well.

Notes

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1. Shafik and Bandyopadhyay (1992) report an estimate of 0.38 for the income responsiveness of MSW (with the population responsiveness effectively constrained to equal 1.0) using a similar data set for 1985.

2. We may gain a different perspective by estimating how much land the world's annual output of MSW would occupy if it were all landfilled to a height of 100 meters, considerably less than the planned height of the Fresh Kills landfill in New York City (Rathje and Murphy 1992). The result is slightly more than twenty-eight square kilometers, if the density of the world'sdiscarded MSW is assumed to be the same as that of the United States (see table 4). In other words, it would take nearly 100 years for a landfill containing the entire planet's MSW at current generation rates (without accounting for population or per capita income growth) to cover the entire state of Rhode Island, which represents only two-thousandths of 1 percent of the world's land area. (See Wiseman 1992 for a similar calculation for the MSW generated by the United States.) Because discarded MSW is much more dense in developing countries than in the United States, our estimate may overstate global landfill land area requirements. Obviously, both the weight and the volume of discarded MSW are important determinants of the cost of collecting, transporting, and disposing it.

3. Post-1990 projections of GDP are based on average annual GDP growth rates from 1980 to 1990 (World Bank 1992). Population growth rates for 1990–2000 and population levels in 2025 are based on World Bank (1992); growth rates from 2000–2025 are assumed to hold for the years after 2025. For countries that did not report annual GDP or population growth rates, the average (weighted by population) growth rates for the relevant income group are used.

4. Because population equals the product of average household size and the number of households, we explored whether variation in these variables influences the level of MSW generation independently of population and per capita income using both the U.S. cross-section and time-series data (sufficient data were not available for other countries). From 1970 to 1990, the size of the average household in the United States declined from 3.14 to 2.63 persons, and in 1990 ranged from 2.26 persons in the District of Columbia to 3.15 persons in Utah (U.S. Bureau of the Census 1993). One might expect that declining average household size would be associated with rising per capita MSW generation, as there may be economies of scale in household consumption. In other words, comparing two economies with the same per capita income, one with 1.0 million households and an average of two people per household and the other with 0.5 million households and an average of four people per household, per capita consumption of newspapers and magazines (major components of MSW in the United States) is likely to be lower in the latter economy than in the former. We found a negative relationship between household size and MSW generation in

the cross-section analysis, but not in the time-series analysis. In both cases, however, the hypothesis that average household size exerts an influence on MSW generation that is statistically different from the influence of population can be rejected.

5. The description of recycling systems in industrial countries is based on Spencer (1994). Kreith (1994a, chap. 9) is an excellent source of information on the technology and economics of capital-intensive recycling systems.

6. Suburbanization is typically measured by the population-density gradient, or the average percentage decrease in population density per unit of distance from the urban core. A decline in the density gradient for a metropolitan area implies that suburbanization has advanced. Average density gradients have been declining in developed countries during the past century and a half, whereas the decline in developing countries became widespread only after World War II (Mills and Tan 1980).

7. Nelson, Genereux, and Genereux (1992) also provide a thoughtful review of other studies that estimate gradients in housing prices.

8. For more details on the intricacies of the contingent-valuation method, see Mitchell and Carson (1989). Two recent articles, Hanemann (1994) and Diamond and Hausman (1994), debate its strengths and weaknesses. An exhaustive bibliography of contingent-valuation studies (Carson and others 1994) indicates that the use of this technique in the context of MSW management is still in its infancy.

9. Under narrowly defined conditions (see Coase 1960), the disposal of MSW might not generate negative externalities and therefore might not require government intervention to improve social welfare. Consider two neighboring households, A and B. Suppose household A dumps its waste onto the property of household B, and suppose further that the adverse consequences of A's dumping are visited only on B. If B has well-defined legal rights as a victim of MSW dumping, B can bargain for a payment from A that compensates B for the damages caused by A's dumping. Likewise, if A has well-defined legal rights to dump its MSW on B's property, A can bargain for a payment from B that compensates A for forgoing the right to dump on B's property. In either case, an optimal result is achieved without direct government intervention. But such an outcome is unlikely to occur, for the following reasons. First, except for extremely isolated rural households, the adverse consequences of open dumping are not confined to a small area that affects only one party. As more victims and dumpers are involved, it becomes more costly to negotiate, monitor, and enforce compensatory contracts among all the parties, creating incentives for "free riding" that undermine the contracts (Baumol and Oates 1988). Second, the preferences of future generations who may be adversely affected by open dumping may not be considered when victims and dumpers negotiate compensatory payments, resulting in a suboptimal outcome.

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