1-1-2010

The Optimal Recycling Rate

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The Socially Optimal Recycling Rate[1]

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September 30, 2010

Abstract:
After experiencing nearly 20 years of increases in national recycling rates, the recycling rates in some developed countries have leveled off at between 20% and 30% over the past decade. If recycling rates have reached some sort of steady state, then the relevant policy question is whether the observed steady state is socially optimal. Data obtained both in the United States and Japan suggest that the net social costs of recycling either remain constant (in Japan) or fall with increases in the recycling rate above 8% (in the United States). Policies that serve to increase the recycling rate over existing levels would therefore be socially beneficial. Results also suggest that the net private costs of recycling – those costs internalized by municipal governments– also fall with increases in the recycling rate for all recycling rates over 25%. It is not immediately evident, then, why municipal governments have not continued to increase their recycling rates and reduced their own costs in the process.

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1. Introduction

The recycling of household solid waste has become increasingly common across the globe over the past 25 years. The emergence of residential recycling was unlikely the consequence of market forces, as rarely was offering curbside recycling services the brainchild of some private waste collection firm interested in reducing disposal costs or capturing revenue from the recovery and sale of recyclable materials. Instead, the growth can be attributable largely to state and federal government mandates. The Resource Conservation and Recovery Act in the United States indirectly resulted in over 82 million Americans having access to curbside collection of their recyclable waste (Jenkins at al., 2008). The Landfill Directive has made recycling a national priority in many member countries of the European Union, and the Law for the Promotion of Sorted Collection and Recycling of Containers and Packaging has had a similar impact in Japan.

But after steady increases in the recycling rates over much of the 19990's, the percentage of residential waste recycled has remained rather steady over the past 10 years. The percentage of residential waste recycled in the United States has grown from 29.0% in 2000 to just 33.2% in 2008 (U.S. E.P.A., 2008). The recycling rate in Japan was roughly the same in 2007 (20.5%) as it was in 2002 (19.9%). It appears recycling rates have reached some sort of steady state. The relevant policy question is whether the steady state is socially optimal.

It is not immediately evident why the growth in recycling rates has slowed. Although an assortment of other environmental policies have faced increased public scrutiny over the past decade, the public rhetoric on recycling remains favorable. Instead of public criticisms, we begin to hear calls for a zero waste society. Caroline Spelman, the Secretary of State for Communities and Local Government (a cabinet position within the United Kingdom government) has asked each local council to develop a strategy to achieve zero residential solid waste. Scotland has approved a national goal to become the world's first zero-waste country by 2025.

Perhaps the reasons for the steady recycling rates are economic in nature. Microeconomic theory might suggest that recovering recyclable materials from the residential waste stream, like any other production process, may confront diminishing returns to scale and therefore rising marginal costs. Municipal governments interested in increasing the recycling rate may find the available options too expensive. And because state or federal laws do not require further increases in the recycling rate, many municipal governments may have adopted a strategy of sustaining a constant recycling rate. But if the social marginal costs of increasing the recycling rate fall even as private marginal costs rise, then municipal decisions may not be efficient.

This paper examines data available for the United States and Japan to estimate both the net private and net social costs of recycling. The estimated socially optimal recycling rate is defined as the rate that minimizes the net social costs of managing residential solid waste. If the optimal recycling rate is estimated to be more/less than the current observed recycling rates, then state policy requiring recycling could be strengthened/relaxed. The next section of this paper provides a theoretical context for why state and federal governments find it necessary to promote household recycling. External costs associated with waste disposal and external benefits associated with supplying recycled materials form the core of this argument. Section 3 then uses data available for the United States to estimate the effectiveness of past municipal strategies for increasing the recycling rate. The section provides some understanding for how we have achieved current recycle rates and why they might have stalled. The socially optimal recycling rate in the United States and Japan is estimated in Section 4. Section 5 concludes the paper with a few policy implications.

2. Asking the Correct Policy Question

What percentage of solid waste should be recycled? Is it none? Is it all? Or is some share in the middle optimal? The answer is unlikely zero because private firms have traditionally found recycling profitable for centuries. If, for example, the market price of scrap aluminum is sufficient to cover the resource costs necessary to disassemble old tractor trailers to recover the aluminum siding, then the market will certainly do so. The question must then be restated. How much of the otherwise unwanted waste material that, by definition, will cost more to collect and process than is valued by society should society recycle? If the disposal of recyclable materials did not harm the environment or generate other external costs or benefits and if markets are sufficiently competitive, then the free market internalizes all social benefits and costs of recycling and will find the optimal quantity (Baumol, 1977). But waste disposal facilities have been estimated to generate external costs. Neighborhood property values decline, climate change gasses escape from both landfills and incinerators, and landfills threaten local groundwater quality. Using recyclable materials rather than their virgin counterparts in industrial production have also been estimated to reduce air and water pollution. Recycling therefore generates external benefits, and we must therefore abandon the free market recycling level and wonder what recycling rate is optimal once the external costs of waste disposal and external benefits of recycling are considered.

Economists have devoted very little attention to answering this question. Not because the question is not a good one, but because, given the nature of the external costs of waste disposal and uncertainties in household and municipal costs to recycle, there is a better one. If the costs to the economy to abate solid waste through recycling or other means were perfectly known to policymakers, then determining the optimal quantity to recycle would not be difficult regardless of the nature of the external costs. The recycling rate should increase until the rising marginal cost of doing so equals the marginal external benefit of reducing solid waste. But the costs to households and firms to collect, process and transport materials for recycling can vary widely across regions of the country and are largely unknown to policy makers.

In this case, the better question to ask is not what quantity to recycling but what should be the optimal price of waste disposal. The optimal price should equal to the external cost of waste disposal, making the choice of price especially easy if otherwise recyclable solid waste is a pollutant whose incremental effect on the environment is constant. Marginal external costs are constant if the first unit of solid waste disposed in a landfill is as nasty to the environment as, say, the 100th unit or the 1,000,000th unit. Each unit disposed is damaging, but equally damaging as the others. The 100th unit of waste disposed does not somehow mix with the other 99 units to create some new environmental problem. Toxic or hazardous waste associated with the disposal of computers, televisions, and cell phones (such as lead oxide, cadmium, and mercury imbedded in these products) are not likely to generate constant external costs. For toxic waste, a threshold can be reached where incremental increases in waste disposal can mix with existing waste to form new hazards to human health and the natural environment.

The optimal price of waste disposal should therefore equal the social marginal cost of waste disposal. Assuming sufficient competition, market prices for waste disposal reflect only the private marginal costs. The socially optimal price is established by assessing a disposal tax equal to the constant external marginal cost of waste disposal. Individual households, firms, and municipalities that know their own costs to recycle (even if policy makers do not) will recycle until their own marginal cost is equal to the after tax price set equal to the social cost of disposal. By choosing the best price, quantities can go where they may, and any resulting quantity will be economically efficient.[6] Thus a good strategy for reaching efficient levels of solid waste and recycling is to set a tax equal to the constant external marginal cost of waste disposal.

A related question in the economic literature is where along the waste stream to assess the tax. One option is to assess a curbside per-bag fee paid by households (Porter, 2002). Concerns have risen over the likelihood of illegal dumping and the high administrative costs of assessing the tax at the curb (Kinnaman, 2006). The tax could instead be assessed at the landfill, thus leaving to the municipality the decision over local policy for how best to abate the waste. A third option is to increase the private cost of disposal by subsidizing an alternative such as recycling. Deposit-refund programs are one such example of subsidies paid for recyclable materials (Palmer and Walls, 1997).

Public policy at the municipal level has evolved within this framework. Nearly all municipalities have avoided mandating recycling quantities from households, perhaps due to uncertainties and differences in costs to recycling households. Instead, many municipalities tax waste at the curb by requiring households to purchase special stickers, tags, or bags. Many more municipalities offer free access to curbside or drop-off municipal recycling services – in essence subsidizing the household recycling process. But policy at the state and national level is often based on setting quantity targets. In response the subtitle D of the Resource and Conservation Recovery Act (RCRA), state governments established an assortment of recycling quantity targets. Thirty-seven states in the United States have enacted goals for the recycling rate. California, New Jersey and Oregon have the authority to penalize local governments that do not achieve the recycling

[6] The nature of external costs (constant or rising) is also informing the optimal policy for mitigating climate change. Carbon taxes would be appropriate if external costs are constant, but cap and trade measures (a "quantity" policy) are preferred if carbon dioxide emissions involve rising marginal costs.

goal, while Florida cannot penalize but can use grant money as an incentive. Only Arkansas and Virginia have met the recycling goal, while Alabama, Florida, Missouri, Pennsylvania and South Carolina are within 5% of achieving their targeted recycling rate (Simmons, 2006). Although several states have also levied landfill disposal taxes, these taxes are frequently well below the estimated per-ton external marginal cost of waste as estimated in the economics literature and discussed below.

The European Union followed a similar regulatory approach by managing waste and recycling quantities rather than establishing optimal prices. The 1999 Landfill Directive requires all member countries of the European Union to reduce waste by 25% by 2006, 50% by 2009, and 65% by 2016 from 1995 base levels. The United Kingdom also serves as an interesting case study for the comparison between quantity and price-based policy. Britain first attempted to set efficient landfill prices via the use of a landfill tax, but soon had to raise the tax to levels well above external costs when it became apparent that the existing prices would not reduce waste by levels necessary to satisfy the EU landfill directive. Arbitrary targets seemed to trump efficient pricing. The Japanese government set recycling targets in 1997. Each municipality in Japan is expected to reduce waste generation by 10%, increase the recycling rate from 11% to 24%, and reduce waste incineration by 50%. Each municipality in Japan is required to submit a plan to the Ministry of the Environment outlining plans for obtaining these three goals.

The repeated theme across much of the developed world is the regulatory reliance on mandated quantity measures for waste and recycling rather than setting optimal prices as is argued by economic theory. How have municipalities historically increased their recycling rates? The next section of this paper uses municipal-level data gathered in the United States to estimate the recycling rate as a function of household demographic variables and municipal policy measures.

3. Municipal Strategies Employed to Increase the Recycling Rate

Several strategies have been utilized by municipal governments to increase the recycling rate. Municipalities can implement drop-off centers, implement curbside recycling, make recycling mandatory, set up a composting program, and charge a per-bag fee for household waste collection. This section summarizes the results of an empirical model (specified in the Appendix) that estimates the recycling rate as a function of these policy variables. The model is estimated using data gathered in the United States as described in Folz (1999). 5,044 municipalities that offered solid waste recycling services to its households were identified. Surveys were mailed to a randomly selected sample of 2,096 of these municipalities and were returned by 1,021 (a 48.7% response rate). Many of these surveys were incomplete perhaps due to incomplete information on the part of the municipal responders resulting in a usable sample of 398 municipalities.

Several variables that municipal governments have little control over are estimated to play a role in determining the recycling rate. Most important of these is the population of the municipality and thus the total amount of solid waste a municipality must manage. Holding all other variables constant, a one percent increase in the total quantity of solid waste generated is estimated to decrease the recycling rate by .33%. Thus, if a small municipality recycles 20%, then an otherwise identical municipality with identical policies but with twice the population will recycle only 14% of its waste. Efforts needed to achieve any given level of recycling must therefore be more substantial in large cities than in small towns. Perhaps social norms supporting recycling behavior are stronger in small towns than in large cities.

The demographic composition of citizens in the municipality is also estimated to play a role in determining recycling rates. Tastes for the environment are first among these. The survey asked the municipal respondent to rate (5 options from very weak to very strong) the local resident's level of support for the recycling program. Twenty percent of municipalities rated very strong, another 47% rated "strong" and 26% indicated "moderate". A one point increase in this assessment of residents' tastes for recycling is estimated to increases the recycling rate by 17.8%. A municipality with "strong" resident support for recycling would therefore experience a 3.5% greater recycling rate relative to a base recycling rate of 20%. Controlling for these environmental tastes, other demographic differences such as education level, median age, percentage of owner occupied residences, household size, ethnic origin, and gender played no significant role in determining differences in recycling rates across municipalities. The per-capita income of municipal residents does make a difference – a $1,000 increase in per-capita income is estimated to increase the recycling rate by 5.0%.

Recycling rates are also a function of policy decisions of the municipal government. Recall that all municipalities in the sample run some type of recycling program. The most basic municipal program could involve developing a non-mandatory unstaffed drop-off center for residents to deposit recyclable materials. Imagine a site in a municipal parking lot or near other municipal property with several containers set up to receive various categories of recyclable materials. According to the model, the recycling rate increases by 10.4% for each material added. The average number of materials collected for recycling in the sample is 9.23. The age of this unstaffed drop-off recycling program is also estimated to make a difference. Each year that passes from the introduction of drop-off recycling services increases the recycling rate by roughly 1.9%. Experience allows residents to become aware of the recycling opportunity, to develop strategies to separate, store, and transport materials to this facility, and possibly to adjust consumption habits to favor recycling over waste. A municipality with mean levels of all income and demographic variables described above, and managing the median level of waste, accepting the median number of materials for recycling, and with nothing but a non-mandatory drop-off facility with vintage of 8 years (the mean in the sample) is predicted by the model to recycle only 4.98% of its total waste.

What strategies are available to municipal governments to increase this baseline recycling rate? First, the municipality could staff the drop-off facility. A staffed drop off facility usually increases exposure, reduces the theft of valuable metals, and ensures that materials are not corrupted necessitating disposal in a landfill. Such an initiative is predicted to increase recycling rate from 4.98% to 6.51%. If the municipality takes the next step and implements curbside recycling, then the recycling rate is estimated to increase to 10.67%. If participation in the recycling program is made mandatory, then the recycling rate is estimated to increases again to 14.84% of all waste. The mandatory participation laws are rarely enforced, but may alter social norms in favor of recycling. Adding a municipal composting program will increase the recycling rate again to an estimated 18.39%.

Municipal governments having made the decision to adopt curbside recycling have a variety of program options from which to choose. According to the data, most of these options do not significantly affect the recycling rate. For example, municipal governments can (1) collect recyclable materials on the same day as waste collection or on a different day, (2) provide recycling containers to households or require households to place recyclable materials, and (3) either require households to separate materials into separate containers or require collectors to sort through a single mixed recycling container to separate materials. None of these three options is estimated to affects the recycling rate. These options shift the cost of recycling from the household to the municipality. Choosing among these options might therefore be based on who best can bear the burden of the costs. Some municipal governments levy an extra recycling fee paid by households for the right to participate in the curbside recycling program. These fees are not estimated to affect the recycling rate – thus they do not appear to discourage households from participating in the recycling program. One program attribute that *is* estimated to affect recycling rates is frequency of collection. Among municipalities with curbside recycling, increasing the number of collections from once per month to once per week is estimated to increase the recycling rate from 18.39% to roughly 24.42%.

One final option available to the municipality is the implementation of a user fee for waste collection. Under this program, each household must pay an added fee for each unit of waste presented at the curb for collection. The implementation of a user fee (of unobserved value) is estimated to increase the recycling rate by 21.3% - thereby increasing the recycling rate for the median municipality from 24.4% to an estimated 29.6%. This is the highest predicted recycling rate available to the municipality with median values of income and demographic variables. Relative to this median municipality, the predicted recycling rate could increase for municipalities with smaller populations, higher incomes, or citizens with stronger tastes for the environment.

Recall from above that, other things constant, program maturity is estimated to increase the recycling rate by 2% per year. This estimated is based on differences in program maturities observed in 1996, in the midst of a decade when recycling rates were increasing this estimated effect of program maturity is not likely applicable today as recycling rates have leveled off in recent years. But if we apply this coefficient, then recycling rates are predicted to have grown by 23.9% over the past 14 years. The estimated recycling rate in 2010 for the median municipality would therefore be 36.7% rather than 26.9%. The municipality could also add more materials to the mix of items households can present for recycling – recall that each additional materials increases the recycling rate by an average of 10.4%.

Thus, by setting policy municipal governments have demonstrated partial control over their own recycling rates. The remaining questions are why recycling rates have leveled off and what recycling rate is socially optimal. The next section addresses these questions.

4. The Socially Optimal Recycling Rate

Section 2 made clear that the policy focus across much of the developed world relies at least partially upon setting recycling targets. Yet, nothing is known about what rate of recycling is socially optimal. The optimal recycling rate minimizes the net social costs of waste management. The net social cost of municipal waste management includes first the sum of the budgetary costs to the municipality to operate both a municipal solid waste collection and disposal program and a municipal recycling program. These programs require labor, trucks, machinery, land, and administrative services. The recycling program could involve curbside collection, drop-off recycling facilities, or both. With either program, recycled materials need to be stored, processed, and transported to markets that demand recycled materials. These budgetary costs to the municipality form the private total costs of waste management.

Any recycling materials generated by the municipal waste program serve as inputs to production to a variety of manufacturing industries. Recycled aluminum, metal, paper, glass, and some plastics have economic value. With sufficient competition, the revenue earned on the sale of recycled materials to these industries approximates the economic value of providing recycled materials.[7] This private benefit of recycling is subtracted from the private total cost of waste management to obtain the *net* private costs of waste management.

The disposal of residential solid waste has been estimated to generate external costs and the use of recycled materials over virgin materials in industrial production has been estimated to generate external benefits. External costs of waste disposal are

[7] To the extent that competition is imperfect in markets for recycled materials – the revenues overestimate (monopoly) or understate (monopsony) the value of these materials.

associated with the nuisance to neighbors of a landfill or incinerator, pollution and congestion from garbage trucks, and the emissions of climate gasses. The economics literature has quantified these external costs to be as high as $4.96 per ton for only greenhouse emissions and waste transportation externalities (Davies and Doble, 2004), $4.39 per ton for only neighborhood nuisances (Defra, 2004), and $8.76 per ton (Kinnaman, 2006) and $15 per ton (Porter, 2002) for all external costs. The external costs of incineration have been measured to be as high as $20 per ton (Porter, 2002) and $39 per ton (Dijkgraaf, 2008). Based on this literature, this study will assume the external costs are $10 per ton for landfill disposal and $40 per ton for incineration. These per-unit external costs are multiplied by the total quantity of waste landfilled or incinerated to derive the external total costs of waste disposal.

Generating recycled materials allows manufacturing industries to utilize recycled materials in production rather than virgin materials. Craighill and Powell (1996) apply a full life-cycle assessment to estimate the external costs associated with each step of both the waste disposal and recycling processes. Even after accounting for the extra efforts necessary to collect and process recyclable materials, using those materials for production is estimated to reduce both air and water pollution. These external benefits are estimated at $1,771 per ton of aluminum recycled, $189.96 per ton of glass, $228.42 per ton of paper, $240.26 per ton of steel, and slightly negative for PET, HDPE, and PVC plastics. Multiplying these estimates by the quantity of each material supplied by each municipal recycling program allows for the total external benefit of recycling to be calculated. The net social cost of waste management is therefore equal to net private costs of waste management plus the external costs of waste disposal less the external benefits of providing recycling materials to industry. The socially optimal recycling rate is that rate that minimizes this net social cost of waste management.[8]

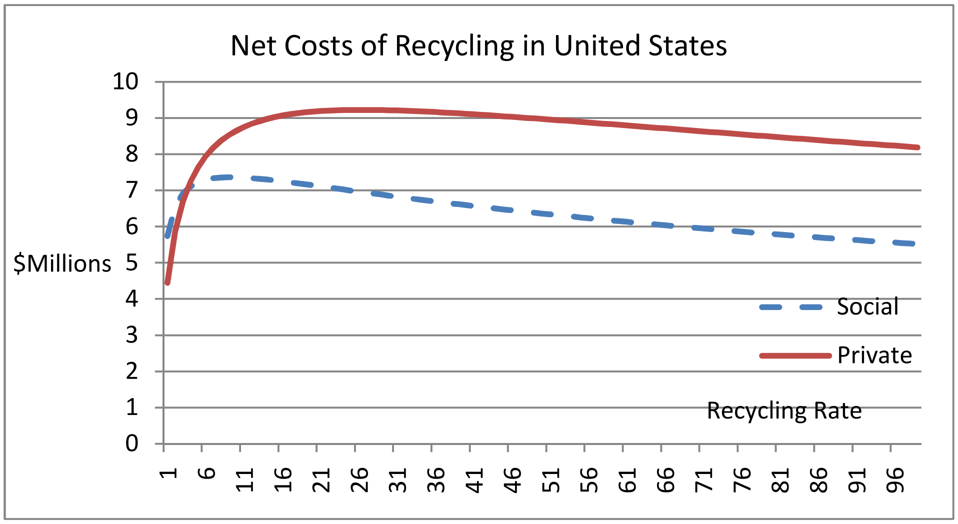
Estimating the Socially Optimal Recycling Rate in the United States

[8] Note that any state subsidies received by municipalities from state governments are not included in the analysis since these subsidies reflect transfers from state taxpayers. These subsidies can be substantial. The most common method of funding state programs is solid waste disposal fees/landfill surcharges, followed by budget appropriations.

The data made available by Folz (1999) are once again useful to calculating the net social cost of waste management in the United States. Although the survey included 38 questions, only a few are relevant to the net social costs of waste management. The important survey questions included, "What was the total collection and disposal cost for all non-recycled municipal solid wastes in 1996?" and "What was the total cost of just the city's recycling program in 1996?" The survey goes on to ask, "About how much total revenue, if any, was obtained from the sale of recycled materials collected in your city in 1996?" Subtracting this latter amount from the sum of the first two amounts provide the net private costs of waste management. Another question asked each municipality to provide the "Total tons of municipal solid waste disposed or incinerated in 1996?" The amounts provided are multiplied by \$10 (for landfill disposal) and \$40 (for incineration) to estimate the external costs of waste disposal. Finally, the survey asked municipalities, "For the materials in your recycling program, about how many tons of each was collected in 1996?" Respondents indicated tons of aluminum, newspaper, glass, and all types of plastics. These reported quantities are multiplied by the corresponding estimated external marginal cost of recycling each material (as reported above) to estimate the overall external benefits of recycling. The sample contains a wide variety of municipalities – the minimum population is just 39 persons and the maximum is 8.57 million. The average calculated net social cost is just over \$5.86 million, but varies widely with a standard deviation of \$48.8 million.

The question at hand is estimating which recycling rate minimizes the net social costs of waste. The recycling rate varies in the sample between 1% and 81% with a mean of 16.7%. Increases in the recycling rate could require additional labor and capital, but reduces the use of the landfill, provides resources to manufacturers, and the use of those resources on net reduces air and water pollution. If the latter measures exceed the first, then the increase in the recycling rate would decrease the net social costs associated with managing residential solid waste. A flexible functional form econometric model is utilized to estimate how the net social costs of waste management are affected by changes in the recycling rate. The details of all regressions are described in the Appendix.

Based on the results of the econometric estimation, the best-fit lines associating the recycling rate to both the net private and net social costs of managing household are provided in Figure 1.



The estimated best-fit line suggests the net private costs of waste management increase with the recycling rate up to a rate of about 25% and then decreases with additional increases of the recycling rate. Rather than facing increasing marginal costs to recycle attributable to diminishing marginal returns to recycling inputs, it appears that economies to scale are very prominent in residential recycling. Callan and Thomas (2001) and Bohm et al. (2010) also estimate economies to scale in the provision of municipal recycling. Particularly troubling is the observation that the observed steady state recycling rate in the United States, at about 28%, is near the top of the estimated net private cost curve. Municipal governments internalize only the private costs and benefits of recycling, yet appear to be *maximizing* their costs. Municipal (net private) costs could decrease by either increasing the recycling rate by taking advantage of economies of scale, or decreasing the recycling rate and reducing costs of resources.

The recycling rate that minimizes the net social costs of recycling is estimated to be zero. The economic value of municipal resources necessary to recycle even a small percentage of the waste stream is estimated to exceed the savings in waste disposal (private and external) and the value of producing recycled materials (private and external). According to the graph above, the social cost of recycling 28% of the waste stream increase net social costs from about $5.7 million to $6.9 million (for a municipality that manages roughly 137,000 tons of waste – the mean in the sample). If the average household of 2.25 persons generates 50 pounds of waste per week, then 137,000 tons is consistent with a human population of about 237,000 persons. The estimated increase in net social costs of waste management for a variety of municipality sizes is listed in the Table below.

Persons	Waste (tons)	TSC at zero (millions)	TSC at 28% (millions)	Increase (millions)	Per-capital Increase ($)
50,000	29,000	$1.34	$1.62	$0.28	$5.60
237,000	137,000	$5.73	$6.94	$1.21	$5.11
1,000,000	578,000	$22.04	$26.68	$4.64	$4.64
5,000,000	2,890,000	$99.36	$120.26	$20.90	$4.18
10,000,000	5,780,000	$190.03	$230.01	$39.98	$4.00

Thus, a municipal recycling program serving one million persons that achieves a recycling rate of 28% increases the social total costs of waste management by roughly $4.64 per person per year over the socially optimal recycling rate of zero. On average, a family of four incurs an additional $18.56 in social costs for its municipality to achieve a 28% recycling rate (the U.S. average). This amount is certainly not going to break the family budget. Perhaps the take away message from this estimation is that net social costs of waste management are rather constant across the recycling rate spectrum.

But that the estimated net social cost of recycling falls, albeit slightly, with all increases in the recycling rates above 10% is an important result. If society is committed to a positive level of municipal recycling, then net social costs can be minimized by maximizing the rate of recycling – perhaps to 100%. If municipal governments do not internalize all costs and benefits of waste management, then mandates set at state or national levels may be necessary to increase the recycling rate. This conclusion is especially true for municipalities recycling less than 25% of waste. These municipalities face rising net private costs of increasing the recycling rate even as net social costs decrease.

The regression controls for other variables expected to affect the net social cost of waste management. Most of these variables are not estimated to significantly affect the net social cost, but two play a role. First, the use of curbside recycling rather than the establishment of drop-off sites is estimated to increase the net social costs of waste management by 39% for any given recycling rate. Second, every $10 increase in the tipping fee, the per-ton cost to dispose waste in a landfill or incinerator, is estimated to increase the net social costs by 5.7% for any given recycling rate. Other economic variables such as the wage rate, the interest rate, and the price of fuel had no significant effect on net social costs.

Estimating the Socially Optimal Recycling Rate in Japan

Japan stands out among perhaps every other country in the world in terms of making available for public consumption high quality data on residential solid waste and recycling. Beginning in 1979, the Ministry of Environment in Japan organized a centralized data gathering process whereby each of the 1,700 Japanese municipalities submitted waste management data to its prefecture government (a prefecture government is similar to a state government in the U.S.). Each prefecture compiles and submits the municipal data to the Ministry of the Environment, which then makes the data available for public consumption. This hierarchical data gathering process is used in many areas of Japanese government including employment, agriculture, manufacturing, and education. In recent years the data gathering process has been performed electronically.[9] Included in the municipal data are quantities of waste generation, recycling, costs of waste management and recycling, and a multitude of specific program variables such as the number of trucks utilized and salaries paid to waste management workers. Data on market prices of each recyclable material necessary to calculate private benefits of recycling were also obtained from the Ministry of the Environment.

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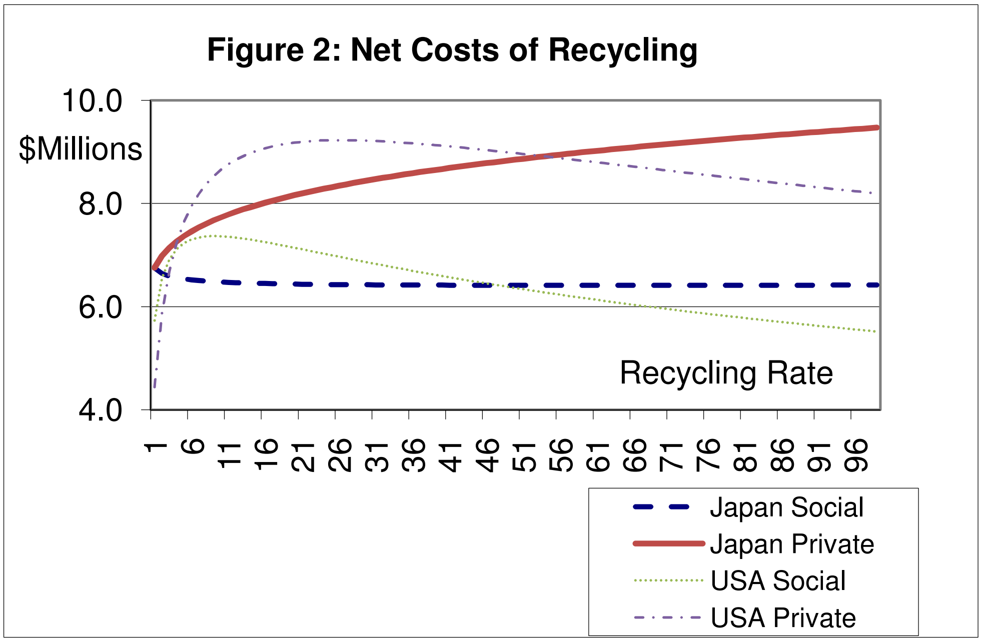
[9] For the latest survey result, please see http://www.env.go.jp/recycle/waste_tech/ippan/h20/index.html.

Data are obtained for every Japanese municipality over an eight year period (2001-2008). The panel nature of this data allow for the use of econometric methods that eliminate potential biases resulting from unobserved municipal variables that may affect recycling rates and costs but do not vary across time. That the data are available for the population of Japanese municipalities eliminates any self-selection bias that might occur in a sample. Finally, the Japanese data are more recent than that obtained in the United States (1996).

United States and Japan share much in common in regards to solid waste management. Matsuto and Ham (1990) examine the contents of actual waste generated by a sample of households in Madison, Wisconsin and Sapporo, Japan. The average individual in Madison generated 1,016.4 grams of waste per day. Compared to 866 grams generated by the average household each day in Sapporo – about 17% more. The average individual in Madison recycled 22% of waste, compared to 21% in Sapporo. The average individual in the Madison generated slightly more paper, metal, and slightly less glass, textiles, and food waste when compared to the average individual in Sapporo. The quantity of plastics and bulky waste are estimated to be about equal across the two municipalities. Although disposal patterns are not identical, these data suggest that managing waste in these two municipalities share many similarities. Two differences can be identified. First, population densities are much higher in Japanese municipalities relative to U.S. municipalities. Increasing the recycling rate by adding new households may be less costly if collection occurs in densely populated apartment building districts rather than sprawling suburban neighborhoods as is more common in the United States. Japan is also more likely to use incineration than landfilling.

The net social costs of managing waste in Japan is calculated, once again, by summing the (1) private costs to collect waste, (2) private costs to collect and process recycled materials, and (3) the external costs of waste disposal ($10 per ton for land disposal or $40 per ton for incineration). The revenue gained from the sale of recyclable materials and the external benefits of supplying recycled materials are then subtracted to arrive at the net social costs of waste management. The relationship between the net social cost and the recycling rate was estimated using the same flexible functional form model as used above for the United States data. The estimated best-fit relationship is illustrated below in Figure 2, where the quantity of waste managed, the wage, and the number of materials collected is held constant at the same levels as above. The best-fit private net cost curves for the United States are also added to provide perspective for comparing costs across the two countries.



A few differences arise when comparing the estimated best fit lines for Japan with those of the Unites States. Over much of the range of recycling rates, the net private costs of managing waste in Japan are less than for the United States. Perhaps high urban population densities in Japan make collecting waste less costly. Also notice that the optimal recycling rate is Japan is not zero. Increases in the recycling rate are estimated to have no statistical effect on the net social costs of waste management – the best fit line is essentially flat.[10]

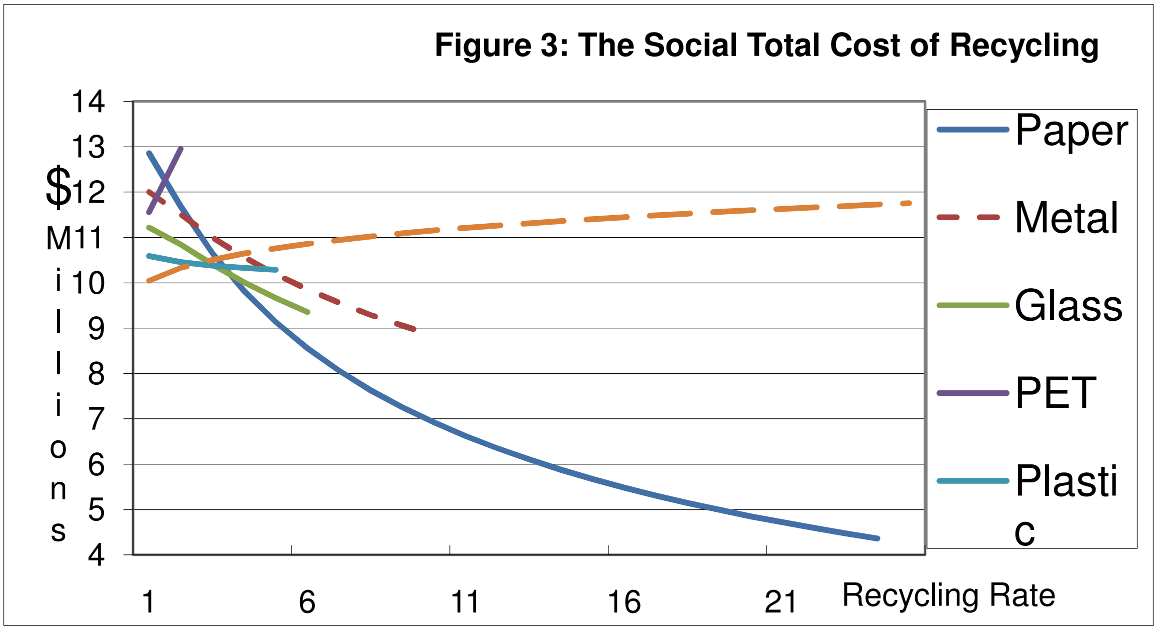
Also of interest is the minimal difference between the best fit lines for these two countries. If the statistical relationship between the net social costs of recycling and the recycling rate is similar across all developed countries, and if that statistical relationship

[10] The estimated coefficients on the recycling rate and its squared terms had small standard errors, but because the coefficient estimates are themselves very close to zero, we are unable to reject the null hypothesis of no statistical relationship between the recycling rate and the SNC. Municipal recycling services in Japan are costless in a social sense.

suggests that recycling plays very little role in determining net social costs, then global recycling efforts have not implication on net social costs. Nations are free to enact recycling regulations as rigid or lax as they wish without demonstrably affecting net social costs. The similarities in the best fit lines also suggest that omitted variables bias in the United States data do not significantly affect results. Recall that the fixed-effects econometric models for the Japanese data eliminate bias from unobserved variables that are constant across time.

The Japanese data also allow for the estimation of how recycling each specific material affects the net social costs of waste management. Each municipality in Japan reports the quantity recycled of each of six categories of materials (metal, paper, glass, PET plastic, other plastics, and other materials). Holding constant the quantity of other materials at their mean levels, Figure 3 illustrates how the net social costs change with increases from zero for each of these six specific materials. The length of each best-fit line reflects the observed recycling rates. No municipality in Japan, for example, recycles more that 2% of its overall waste in the form of PET plastic.

Examining these best fit lines suggests that recycling PET plastic and "other" materials increases the net social costs of waste management. Municipalities or national governments interested in reducing social costs could eliminate these materials from the waste steam. But recycling metal (aluminum cans and bi-metal cans comprised mostly of steel), glass, paper, and plastic serves to reduce the net social costs of waste management.



5. Conclusions and Policy Implications

Data obtained both in the United States and Japan suggest that the net social costs of recycling either remain constant (in Japan) or fall with increases in the recycling rate above 8% (in the United States). Policies in the United States that serve to increase the recycling rate over existing levels would therefore be socially beneficial. But recycling rates in both counties have remained relatively constant or grown only slightly over the past decade. One possible reason could be the rising costs faced my municipal governments. But results here also suggest that the net private costs of recycling – those costs internalized by municipal governments– also fall with increases in the recycling rate for all recycling rates over 25%. It is not immediately evident, then, why municipalities do not continue to increase their recycling rates and reduce their own costs in the process.

One possible reason, not considered in this paper, is that costs to recycling households may increase with their won recycling levels. If household costs to prepare, separate, and store, materials increase with their own recycling rate, then households may rationally choose a recycling rate for less than what might be optimal for a municipal or societal perspective. Municipalities stand ready to accept all materials presented by households for recycling, but might be out of policy options to increase recycling quantities. Enforcing mandatory recycling ordinances might be costly and politically offensive. Sharp increases in curbside taxes necessary to change household behavior might encourage illegal dumping of waste. Offering large recycling subsidies for recyclable materials might also be costly.

State and national governments could play some role in indirectly promoting household recycling efforts. The difference between net social costs and net private costs for the median municipality of 237,000 people is estimated to be almost 3 million dollars per year both in the United States and Japan (by inspection of Figure 2). This estimate justifies the use of state or federal grants designed to promote household recycling. If instead state and national governments wish to target waste and recycling prices rather than their quantities, as is suggested by economic theory, then setting state or national waste taxes at roughly $10 (for landfill disposal) and $40 (for incineration) as well as per-ton subsidies of amounts estimated by Craighill et al. (1995) would alter municipal incentives.

Finally, results here are somewhat supportive of a zero-waste society as defined recently in Scotland and other parts of the world. Although only a few municipalities have sustained recycling rates in excess of 50%, the trend line estimated by the full data set suggest the net social costs of waste decrease with increases in the recycling rate. The estimated net social costs of recycling 100% of waste in the United States are X – compared to Y for zero. In Japan its Z compared to A.

Appendix

Let y_i denote the recycling rate and let $\mathbf{z_i}$ represent a vector of (k) municipal level household demographic characteristics and waste policy variables in municipality i. Assume, $\ln(y_i) = a + b_k\mathbf{z_i} + u_i$, where u_i represents unobserved variable that affect the recycling rate in municipality i. Ordinary Least Squares estimates of the parameters a and b_k are provided in Table 1. These coefficients are discussed in Section 3 of the paper.

Table 1: Determinants of the Recycling Rate (Dependent variable = Ln(Rec Rate))

Variable	Coefficient	Standard Error	Significance
CONSTANT	3.773	1.830	5% level
Ln (Total Waste)	-0.332	0.082	1% level
Environmental Tastes	0.186	0.066	1% level
Percent Female	-0.005	0.008	-
Percent White	0.005	0.005	-
Household Size	-0.245	0.446	-
Percent Owner Occupied	-0.005	0.008	-
Household Income	0.0000499	0.0000204	5% level
White Collar Employment	0.006	0.010	-
Percent College Graduate	-0.004	0.005	-
Median Age of Residents	-0.024	0.016	-
Age of Recycling Program	0.017	0.010	10% level
Number of Materials	0.104	.0035	1% level
Staffed Drop-Off Facility	0.268	0.102	1% level
Curbside Collection	0.495	0.172	1% level
Mandatory Participation	0.330	0.089	1% level
Compost Program	0.214	0.117	1% level
Curbside Fee for Waste	0.495	0.172	1% level
Curbside Per-Bag Tax	0.213	0.103	5% level
N = 398; R^2 = 0.484			

Next, let y_i denote net private costs of waste management, let x_i denote the recycling rate, and $\mathbf{z_i}$ represent a vector of k other exogenous variables in municipality i. A non-linear flexible functional form relating y_i to x_i is given by $\ln(y_i) = a + b_1 \ln(x_i) + b_2 [\ln(x_i]^2 + g_k\mathbf{z_i} + u_i$, where u_i represents unobserved variable that affect the net private costs in municipality i. Ordinary Least Squares estimates of the parameter are provided in Table 2. The same model is applied to the data from Japan. Fixed-effects estimates of the parameters for Japan also appear in Table 2. These estimated coefficients are used to generate the best fit lines illustrated in Figures 1 and 2.

Table 2: The Net Private Costs of Recycling (independent variable is LN(PC))

	United States		Japan	
Variable	OLS Estimates	Robust Standard Errors	Fixed Effects Estimates	Standard Errors
LN(recycle rate)	0.446***	0.106	0.044*	0.024
[LN(recycle rate)]^2	-0.068***	0.025	0.006	0.004
LN(total waste)	0.903***	0.028	0.450***	0.020
Number of Materials	0.013	0.024	0.004***	0.001
Ln(wage)	0.841***	0.297	0.045***	0.005
Constant	2.391***	0.880	10.267***	0.188
N = 372; R^2 = 0.810			N = 10.275; R^2 = 0.08 (within), 0.90 (between), and 0.89 (overall)	

Table 3: The Net Social Costs of Recycling (independent variable is LN(SC))

	United States		Japan	
Variable	OLS Estimates	Robust Standard Errors	Fixed Effects Estimates	Standard Errors
LN(recycle rate)	0.226**	0.072	-0.025	0.029
[LN(recycle rate)]^2	-0.051*	0.020	0.003	0.006
LN(total waste)	0.936**	0.032	0.420**	0.025
Number of Materials	-0.0003	0.028	0.005**	0.001
Ln(wage)	0.399	0.331	0.055**	0.007
Constant	3.647**	0.880	10.623**	0.238
N = 345; R^2 = 0.774			N = 10.260; R^2 = 0.04 (within), 0.88 (between), and 0.86 (overall)	

The model was then expanded for the Japanese case by eliminating the two "recycling rate" variables and adding variables (log and log squared) on each of many recycled materials including paper, metal, glass, PET plastic, other plastics, and other materials. Because natural logs are used, municipalities with 0 levels of recycling any of the materials were dropped from the data. Results are given in Table 4, and best-fit lines are illustrated in Figure 3.

Table 3: The Social Total Cost of Recycling in Japan
(independent variable is LN(STC))

Variable	Fixed Effects Estimate (B)	Robust Standard Errors	Significance Level
LN(paper recycle rate)	-0.081	0.021	1% level
[LN(paper recycle rate)]^2	-0.001	0.006	-
LN(metal recycle rate)	-0.030	0.020	-
[LN(metal recycle rate)]^2	-0.045	0.009	1% level
LN(glass recycle rate)	-0.016	0.023	-
[LN(glass recycle rate)]^2	-0.048	0.012	1% level
LN(PET recycle rate)	0.141	0.031	1% level
[LN(PET recycle rate)]^2	0.035	0.009	1% level
LN(plastic recycle rate)	-0.018	0.008	5% level
[LN(plastic recycle rate)]^2	0.000	0.002	-
LN(other recycle rate)	0.037	0.006	1% level
[LN(other recycle rate)]^2	0.004	0.002	5% level
LN(total waste)	0.386	0.047	1% level
Number of Materials	-0.001	0.002	-
Ln(wage)	0.090	0.010	1% level
Constant	11.457	0.456	1% level
N = 4,736; R^2 (within) = 0.122; R^2 (between) = 0.866; R^2 (overall) = 0.866			

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