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Determining the socially optimal recycling rate

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ABSTRACT

What municipal recycling rate is socially optimal? One credible answer would consider the recycling rate that minimizes the overall social costs of managing municipal waste. Such social costs are comprised of all budgetary costs and revenues associated with operating municipal waste and recycling programs, all costs to recycling households associated with preparing and storing recyclable materials for collection, all external disposal costs associated with waste disposed at landfills or incinerators, and all external benefits associated with the provision of recycled materials that foster environmentally efficient production processes. This paper discusses how to estimate these four components of social cost to then estimate the optimal recycling rate.

1. Introduction

Growing populations, rising incomes, and changes in consumption habits over the past half-century have increased the quantity of municipal solid waste produced in many developed and developing countries. In some cases, regional sanitary landfills and modern incinerators have been developed to manage the waste, while in other regions of the world open dumping remains a popular but unfortunate management option. But because of the perceived environmental threats associated with not only open dumping, but sanitary landfilling and incineration as well, many countries have considered recycling as a method to reduce the volume of waste designated for disposal. Recycling may not only reduce external costs at dumps, landfills, and incinerators, but the recycled materials may also serve as an environmentally efficient substitute for non-renewable virgin materials whose mining processes often involve costs to the environment.

To encourage the recycling of municipal solid waste, the governments of many developed countries have set targets for the percentage of all waste that should be recycled. In Europe, the Packaging Directive as last amended in 2005 has set of recycling target of between 55% and 80% for all European Union member countries to have been achieved by the beginning of 2009. Japan passed in 1997 The Law for the Promotion of Sorted Collection and Recycling of Containers and Packaging that established a recycling target at 24%. Recycling targets in the United States are set at the state level and vary across states. For example, California set a recycling target of 75% to be achieved by 2020 while Texas set a recycling target of 40%.

But are these recycling rates socially optimal? In other words, are these targets consistent with the recycling rate that minimizes the social costs of managing municipal solid waste? The lack of research on the social costs and benefits of waste disposal and recycling suggests the answer is largely unknown. To help fill this void, this paper (1) first defines the social costs and benefits associated with managing municipal waste by disposal or recycling, (2) provides estimates of these costs and benefits from the published literature, (3) discusses the data necessary to determine the optimal recycling rate within any given country, and (4) summarizes the results of one recent cost/benefit study that finds the optimal recycling rate is 36%.

2. The social costs of disposing municipal solid waste

The optimal recycling rate minimizes all social costs associated with managing waste. Assume the social costs of waste management are comprised of (1) all costs to municipalities to collect, process, and transport all waste and recyclable materials, (2) all costs to recycling households to separate and store all waste and recyclable materials, (3) all external costs associated with waste disposal arising at both landfills and incinerators, and (4) all external benefits associated with recycling attributable to environmentally efficient production processes. The objective of the social planner is to select a recycling rate that minimizes the sum of these four sources of costs. This section separately introduces these four sources of social costs. The next section describes how data on each component can be obtained.

Economic costs can be differentiated between costs that are private or internalized and those that are external or externalized.

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Throughout this paper private costs will be defined as those costs associated with waste management that are internalized by municipal governments. External costs are those costs that remain – waste management costs that are born by society at large and not internalized by municipal governments.

2.1. Municipal collection and disposal costs

Disposing municipal solid waste in an open dump, a sanitary landfill, or an incinerator involves both private and external costs. The private costs include the value of economic resources employed to collect the waste from households and small businesses, to transport the waste to a disposal site, to finally dispose the waste, and to administer the collection and disposal program. Carroll (1995), Callan and Thomas (2001), Bohm et al. (2010), and Cruz et al. (2012) estimate private municipal costs as functions of waste and recycling quantities. These private costs can be expected to vary across collection and disposal methods. Waste collection can be made convenient to households by increasing the frequency of collection, moving the location of collection closer to the door of the dwelling, and providing carts for waste collection. Transportation costs vary with the distance to the disposal facility, and can include the costs of truck transportation, transfer stations, and possible rail or barge transportation to the final disposal site. The majority of these collection and transportation costs are paid by municipal governments or by private collectors that have signed a franchise agreement with the municipal government. The municipal government or private firm may then charge households for waste collection services. These charges can be fixed in nature, such as monthly fees, or may vary with the quantity of waste collected by using special bags, tags, or stickers.

Private costs of disposal vary widely with the mode of disposal. Incineration is likely the most costly disposal option, followed by sanitary landfilling and then open dumping. Incinerators require land, vast quantities of physical capital to burn the waste and then treat the airborne pollutants, engineers and technicians to operate the facility and resolve technical difficulties as they arise, and fossil fuels to inject to keep the burning temperatures sufficiently high. Incineration can also produce private benefits. The resulting heat can be used to generate electricity or power district heating systems thereby reducing demand for fossil fuels.

The private costs of sanitary landfills, although often less than those associated with incineration, can still be substantial. Sanitary landfills require a large expanse of suitable land. Impermeable bases must be created using clay or several layers of plastic. As the waste is disposed, plumbing systems are installed to catch leachate and methane (both byproduct of decomposing solid waste in an oxygen starved environment). The leachate must be treated using reverse osmosis or other methods before the liquid can be released into the environment. In many developed countries the waste must be covered daily to mitigate odor and the attraction of unwelcome birds and rodents. Groundwater monitoring takes place along the boundaries of the landfill. Breaches, if detected, must be repaired. A potential private benefit associated with sanitary landfilling arises when the captured methane can be burned to generate electricity thereby offsetting the use of fossil fuels.

If tipping fees paid for disposal are competitively set, then future user costs associated with converting land to disposal facilities may be internalized by waste-generating municipalities. Competitive landfills can be expected to levy a tipping fee that reflects not only all current marginal costs of operation, but reductions in land value attributable to converting land to a disposal site. Municipally-owned landfill may charge low tipping fees that do not reflect the value of the land to either the present or to future generations.

Open dumping also requires a large expanse of land. But private costs are relatively small compared to the other two disposal options discussed above – modest ground preparation and the construction of a basic access road may suffice. If property rights for land are poorly defined and enforced, then the private disposal costs to municipalities may essentially be zero.

Recycling systems also require economic resources to operate and can generate private benefits to the economy. Private costs internalized by many municipalities include the value of the additional economic resources necessary to collect separate streams of recyclable materials from households such as paper, metals, plastic, and a host of other possible materials. These materials may also require staging and processing before being transported to separate markets. These costs are internalized into many municipal budgets.

If the separated recyclable materials have value to the economy, then recycling produces private benefits. Recycled materials can serve as inputs to production to numerous goods in the economy. These benefits are internalized by municipal governments if markets for recycled materials are sufficiently competitive, as the competitive sales price received by the municipality generates revenue to the municipal budget.

2.2. Household recycling costs

The second component of social waste management costs is all household resources employed to separate, prepare, and store recycled materials for separate collection. Households may also be required to transport their recyclable materials to neighborhood drop-off recycling centers. These costs may not be internalized by municipal governments unless household preferences over recycling efforts influence the municipal political process.

2.3. External disposal costs

External costs are associated with landfilling, incineration, and open dumping. Sanitary landfills can threaten area groundwater supplies, can produce odor, may be unsightly, and may depress neighboring property values. Incinerators can generate air pollution that is dangerous to human health and to ecosystems. The ash remaining from the incineration can include heavy metals and may be hazardous to the environment when landfilled. The external costs of open dumping include all of the above plus threats to human health, water supplies, and the natural environment all originating from the open decomposition of waste.

2.4. External recycling benefits

Recycling generates external benefits if they replace virgin materials in manufacturing. Life cycle assessment models suggest the use of recyclable materials over virgin materials reduces air and water pollutants, energy use, and the release of toxic substances harmful to human health and the natural environment. These benefits of recycling are not likely internalized by municipal governments or the manufacturers using the recycled materials.

The optimal recycling rate is defined as that rate that minimizes the total of all of these private and external costs associated with managing municipal waste and recycled materials. Increasing the recycling rate reduces private and external costs of collecting and disposing waste, increases costs to collect, process, store, and transport recyclable materials to markets, increases recycling costs to households, and reduces external costs associated with manufacturing some goods and services. If the reductions to social costs exceed the increases, then increasing the recycling rate is socially efficient. Given the differences in collection and disposal technologies and practices and differences in household consumption habits, tastes, and preferences, the optimal recycling rate is likely to vary across countries and even across municipalities within each country. The next section provides the data necessary to estimate the four components of social waste management costs.

3. Data necessary for estimating the optimal recycling rate

3.1. Municipal collection and disposal costs

To estimate the optimal recycling rate within a country, data representing the total budgetary costs associated with both waste and recycling are needed. These costs should ideally include all costs associated with collecting waste and recyclable materials from households, the costs of operating transfer stations and recycling storage and processing plants, all transportation costs, and all disposal costs associated with incineration, landfilling and/or dumping. If competitive incinerators or landfills are utilized for municipal disposal, then the tipping fee should reflect private disposal costs including the value of land and therefore disposal costs should be included in the municipal budgetary costs. If the municipal cost data omits any of the costs described above, perhaps full disposal costs, then these costs must be separately estimated and then added to municipal cost data.

A study by Kinnaman et al. (2012) used municipal cost data from Japan. The average municipality in Japan paid 6,989,848 thousand yen per year to collect, process and dispose all waste and recyclable materials. Such municipal cost data are not known to be generally available in the United States. Data utilized by existing students were gathered by the authors or exist only within a single state. For example, Bohm et al. (2010) use a 1996 sample of municipality cost data collected via mailed questionnaires in the United States, Carroll (1995) gather cost data from a sample of municipalities in Wisconsin, and Callan and Thomas (2001) obtain cost data from a sample of municipalities in Massachusetts. Although municipal waste and recycling cost data may be available in some developed countries in Europe, such data is not existent in the United Kingdom.

3.2. Household recycling costs

The literature is thin on estimating the recycling costs to participating households. Any comprehensive study estimating such costs may not be applicable to other countries since household tastes and preferences and possibly disposal technologies may vary across countries. Thus, these costs may be best estimated within the country of interest.

Two methods are available for estimating recycling costs to households. The first relies on surveys of a random sample of households. These surveys include questions that allow each household to identify the amount of time allocated to recycling activities and the opportunity cost of each household's time. This method of estimating recycling costs to households is based on stated behaviors rather than revealed behaviors any may therefore suffer from systematic errors in household responses that could potentially bias estimates of household recycling costs.

A second method available to estimate household recycling costs is available if a group of municipalities within any given country have implemented unit-based pricing programs. These programs require households to pay a marginal fee for each unit of waste disposed at the curb for collection. Revealed household disposal behavior under such programs allows for the estimation of the costs of preparing materials for recycling. Households facing rising marginal costs of recycling their waste will rationally increase recycle as long as the marginal cost of doing so is less than the per-unit fee for waste collection.

This logic is illustrated in Fig. 1, where the quantity of material recycled by a representative household is measured along the horizontal axis. MC denotes the household's marginal cost of recycling each unit of waste, and P is the unit-price of disposing that waste. Notice that the marginal cost curve intersects the horizontal axis at some level of recycling that is greater than zero to allow for the possibility of autonomous recycling at no cost to the household. Autonomous recycling can be facilitated by municipal efforts that make household recycling easy or household direct utility gain from the recycling process. But any recycling level beyond this autonomous level is costly to the household. These costs could include efforts to clean the materials, store the materials, and transport the materials to drop-off facilities. The presumption is that these marginal costs rise as households dig deeper into their waste to separate and prepare materials for recycling.

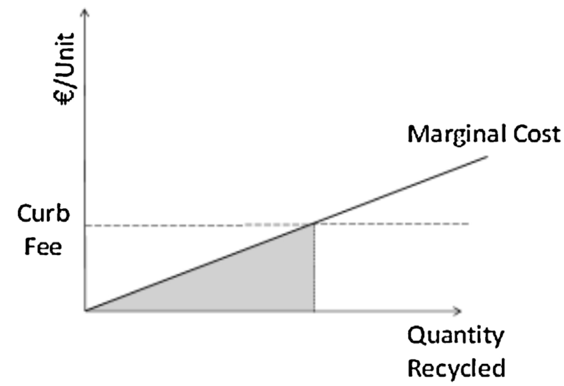

Fig. 1. Household recycling costs.

Returning to Fig. 1, the rational household facing a unit-price of P for waste collection will choose to recycle Q* units. The total cost to the household of recycling this amount is denoted by the area under the marginal cost curve between the origin and Q*. This area can be estimated by first estimating the per-capita quantity of recycling observed in each municipality as functions of a constant (an estimate of the autonomous recycling level) and the unit-price of waste. Other exogenous variables correlated with both observed recycling levels and the unit-price of waste (perhaps tastes for the natural environment) should be included in the estimation to prevent biased estimates. Or if a pooled panel data are available, then estimation techniques can control for these variables assuming they remain constant over time. Various functional forms can be employed in the estimation to allow for linear, log-linear, or non-linear estimates of the marginal recycling cost curve. Although the data demands associated with these methods are substantial, the use of revealed household behavior rather than stated behavior obtained via surveying may increase the accuracy of the recycling costs to households.

This process of estimating household recycling costs was employed by Kinnaman et al. (2012) using pooled panel data from Japan. Many Japanese municipalities had implemented unit-based pricing allowing the effect of price on recycling quantities to be estimated. The per-capita weight of recycled materials was regressed on a constant and the unit price of waste collection (this price took on a value of zero if the municipality did not implement unit-based pricing). Results are summarized in Fig. 2. Households in Japan are estimated to generate 1.32 kg per person per week of autonomous recycling. For every one euro increase in the unit-based price of waste, recycling is estimated to increase by 0.13 kg per person per week (the slope of the marginal cost curve is assumed constant). Based upon these estimates, households in Japan are estimated to incur costs of about 5.4 euros per person per year to recycle. This estimated cost represents about 5.6% of the total waste costs paid by municipalities suggesting that household recycling costs are relatively small.

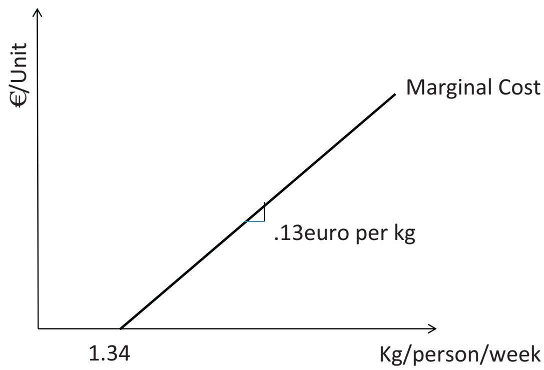

Fig. 2. Estimated recycling costs.

3.3. External disposal costs

Data are also needed on the external costs of waste disposal. These external costs can also be expected to vary across countries with respect to differences in disposal technologies and tastes for the natural environment. The external costs would ideally be estimated within each country of interest. Unfortunately, such estimates are not easy to obtain. Hedonic methods are helpful for determining how waste disposal facilities affect neighboring property values due to odor, unsightliness, and threats to local air and water quality. Hedonic methods may also be helpful for estimating the external cost of transporting waste along local roadways. But housing price and attribute data necessary to employ such hedonic methods may be difficult to obtain. In terms of climate change, the marginal external cost of generating a unit of methane or carbon dioxide has been estimated in the literature, and these results can be applied to emissions of these gasses by landfills.

A few studies have estimated the external cost of waste disposal. Davies and Doble (2004) use data in the United Kingdom to estimate the external costs of the climate change emissions and transportation from sanitary landfill disposal at 3.85 euros per ton of waste disposed. DEFRA (2004) survey the global hedonic literature to estimate each ton of waste disposed in a sanitary landfill generates 3.40 euros of external costs to neighboring properties. Adding these two effects together suggests the external costs of transportation and disposal to local properties and the climate amount to 7.15 euros per ton. These estimates, gathered primary in the United Kingdom, could be used to estimate the external costs of waste disposal in other countries if no other estimates are available and if disposal technologies are similar to those in the United Kingdom. Two less comprehensive studies suggest the external costs are 11.60 euros per ton for waste disposal (Porter, 2002), 15.45 for incineration (Porter, 2002), and 30 euros per ton for incineration (Dijkgraaf et al., 2008). These latter studies suggest the external costs associated with incineration from air quality exceed those of landfill disposals. No known study estimates the external costs of open dumps still used in many parts of the developing world.

Based on this literature, Kinnaman et al. (2012) assume the external cost of waste is 11 euros per ton for landfill disposal and 22 euros per ton for incineration. Multiplying these constants by the total quantity disposed in landfills and incinerators each year in Japan serves as a useful estimate of the external costs of waste disposal. The average municipality in Japan is estimated to generate 6.6 million euros in external disposal costs per year. In relative terms, these external costs amount to about 12.4% of municipal budget costs, which is roughly 4 times the magnitude of household recycling costs.

3.4. External recycling benefits

The next empirical estimate necessary to estimating optimal recycling rates is the external benefits associated with using recycled materials instead of virgin materials in production. A manufacturing economy that uses recyclable materials in place of virgin materials emits fewer climate change gasses, fewer acidifying compounds, fewer nitrifying compounds, less damage to the natural environment, and fewer releases of toxic substances. The engineering literature contains several life-cycle assessments that estimate the reductions in these five categories. Cleary (2009), summarizes the results of twenty such peer-reviewed papers. But very few of these studies monetize these benefits for use in an economic study. Craighill and Powell (1996) serve as one known exception using data from the United States. This study estimates that using recycled aluminum over virgin aluminum generates external benefits of 1367 euros per ton. This benefit is estimated as 145 euros per ton for glass, 175 euros per ton for paper, 184 euros per ton for steel, and slightly negative for PET, HDPE and PVC plastic (all of these estimates have been adjusted for changes in the overall price level). Recycling one ton of any of these materials will generate these external benefits only if that ton replaces a ton of virgin input. If instead recycled materials are used to expand production into new products with no subsequent reduction in virgin material, then these values overstate the external benefits of recycling. Once again, these benefits can be expected to vary across countries according to tastes and technologies and may therefore only be appropriate if the country under study is similar to that of the United States.

The Japanese data include the specific quantity recycled of each of the materials listed above for each municipality in the sample. Multiplying these quantities by the constant values provided in the last paragraph provides one estimate of the external benefits of the recycled materials generated by any municipality. The average municipality in the Japanese data set generated 22.7 million euros of benefit from its recycling efforts. In relative terms, these benefits amount to about 35% of municipal budgetary costs. Of the three external components of social costs discussed above, the external benefits of recycling appear to be the most substantial.

Thus, the data necessary from each municipality to estimate the social cost of waste disposal include the budgetary costs to the municipality to operate both waste and recycling programs, the quantity of waste disposed at landfills, incinerators, and possibly open dumps, the quantity generated of each recycled materials, and the value of a possible unit-based pricing program (or questionnaire data). The costs of labor, capital, and necessary resources such as fuel should also be included in the cost function. The next section discusses issues related to the estimation of social costs as a function of the recycling rate and other exogenous variables.

4. Estimating the social waste management costs as a function of the recycling rate

Given the above data, the social cost of managing waste can be calculated by simply summing all private municipal budgetary costs with estimated recycling costs to households and estimated external costs of waste disposal and then subtracting the estimated external benefits of generating recyclable materials. The optimal recycling rate can be estimated by regressing these social costs on the recycling rate and other variables such as the quantity of total waste generated, factor costs such as fuel, labor, and capital costs, land values, and variables describing the municipal recycling program. See Kinnaman et al. (2012) for an example of this regression process. A flexible functional form is necessary to identify the optimal recycling rate. One such flexible functional form involves

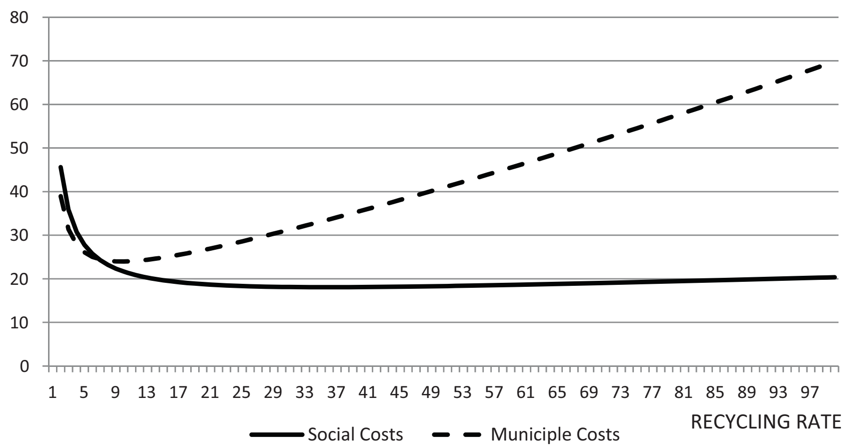

Fig. 3. Recycling costs (billion yen).

regressing the log of social cost on the log of the recycling rate and its squared term (with other exogenous variable). If the estimated coefficient on the log of the recycling rate is negative and the estimated coefficient on its squared term is positive, then the estimated total cost curve with respect to the recycling rate will take a u-shaped form. The recycling rate at the minimum of this u-shaped curve would be consistent with the social cost-minimizing recycling rate.

Pooled panel data sets, where annual observations of all of the important variables are provided across time, can allow for fixed or random effects regression models. These models control for all unobserved variables that are not expected to vary over time. If such unobserved variables are correlated with both the recycling rate and the social costs of waste, then their emission from the model would bias results. This list could be sizeable if it were to include specific attributes of municipal recycling programs such as the frequency of collection or the number of materials collected. Such attributes could increase both the recycling rate and the social costs. Household preferences for environmental quality could also bias results if such preferences result in both high recycling rates and high external costs of waste disposal. To the extent that these household preferences and program attribute variables remain constant over time, pooled panel data are important for obtaining unbiased estimates.

One potential estimation problem to consider is the possibility of a simultaneous equations bias in the relationship between the recycling rate and social costs. Assuming the recycling rate is exogenously determined allows for the simple regression methods described above. But if social costs also affect the recycling rate, then simple regression methods will result in biased estimates of the coefficients. If for example, an unobserved variable such as the natural terrain of the land causes municipal budgetary costs of recycling to be large, then that municipality may chose a low recycling rate. The simultaneous equations bias can be cured using Two Stage Least Squares (2SLS) or other econometric methods.

The data used by Kinnaman et al. (2012) include a 6-year pooled panel data set on Japanese municipalities. In addition to the basic variables described above, the data included only the cost of labor, the cost of fuel, and the number of separate materials collected by each municipal recycling program. Thus, results are unbiased if other unobserved program-specific variables or household preference variables are constant across the duration of the sample. Two fixed-effects estimations were conducted. First, the natural log of just the municipal costs were regressed on the natural log of the recycling rate, its squared term, the natural log of the total quantity of waste disposed, the wage rate, and the number of materials collected. Second, the full social costs were regressed on the same set of variables. Both regressions estimate a negative coefficient on the recycling rate and a positive coefficient on the squared term of the recycling rate. In combination, these two estimated coefficients give rise to a u-shaped estimate of the costs of waste with respect to changes in the recycling rate. Fig. 3 presents these estimates, where all other variables are held constant at their mean levels.

Notice that the recycling rate that minimizes the municipal (private) cost of waste is roughly 10%. Recall, that these costs do not include external costs of waste, costs to households, or external benefits of recycling. Therefore, if municipalities are devising recycling practices and policies to minimize their own costs, then the recycling rate chosen will be inefficiently low. The socially optimal recycling rate is 36%. Increasing the recycling rate from 10% to 36% decreases the social cost of waste management by an average of 11.34 euros per person per year. But any recycling above 36% is estimated to increase social costs and is therefore inefficient. The recycling rate of 48%, the highest observed recycling rate in the sample increase per-capita social costs by an estimated 18.8 euros per person per year.

Given that the estimates of the external costs and benefits were estimated in the United States and the United Kingdom and may therefore be prove inappropriate for use in Japan, sensitivity analyses can be performed on the results. Each of the three components of external cost can be separately doubled and halved. The four recalculated social costs can then be regressed on the recycling rate to determine the whether the results are robust or not. If the optimal recycling rate is found to be sensitive to changes in the magnitude of any of the three external cost components, then additional attention may be necessary to ascertaining accurate estimates of the relevant cost. If, on the other hand, the optimal recycling rate is robust to these changes, then any concern with the precision of the estimated external costs can be relaxed. For example, in Kinnaman et al. (2012), the optimal recycling rate of 36% was found to be robust to changes in the external costs of waste disposal and to changes in the household recycling costs, but the optimal recycling rate was found to be sensitive to changes in the external benefits of recycling. These results might suggest that careful attention be paid to estimating the external benefits of recycling.

Recall that to estimate the external benefits of recycling, the data available must contain the quantity recycled of individual recyclable materials. These data can also be utilized to estimate how the recycling of each specific material might influence social costs. Simply remove the aggregate recycling rate (and its squared term) from the regression and add the recycling rate of each individual material. Results could inform future recycling policy by targeting which recyclable materials reduce social costs and which might increase social costs. For example, in Kinnaman et al. (2012) the recycling of paper and metals were estimate to reduce social costs but the recycling of PET and a category of "all other" materials was found to increase social costs. Paper and glass recycling neither increased nor decreased social costs.

5. Conclusion

This paper outlined a process to follow to solve for the optimal recycling rate within any given country. Data important to the analysis include the municipal costs to the municipality, the quantity of waste disposed, and the quantity recycled. Recycling quantities of individual materials is needed to estimate external benefits and to estimate optimal recycling of each material. Other variables may be necessary if panel data are not available to prevent biased results. Estimates of the external costs of waste disposal, the external benefit of recycling, and the costs to recycling households are also needed, and if not available within the country the sources cited in this paper can serve as a reference. Sensitivity analysis could be performed to determine whether changes in these measures would affect the optimal recycling rate. Using such data from Japan with external costs and benefits estimates from the U.S. and Europe, Kinnaman et al. (2012) estimate an optimal recycling rate of 36%. Sensitivity analysis suggested this result is sensitive to changes in the external benefits of recycling, but not to the external costs of waste or the costs to recycling households.

Another consideration of the analysis is the social costs of varying from the optimal recycling rate. If social costs are estimated to rise sharply with either small decreases or increases in the recycling rate from the optimum, then policy should focus on that optimum recycling rate. But if social costs change only modestly with small errors in the recycling rate, then a broad range of recycling rates may be deemed efficient.

Certain weaknesses are inherent to this process of estimating the optimal recycling rate. First, this process did not consider source reduction efforts by households and municipalities. Through educational programs and other efforts, municipal governments or environmental groups can encourage citizens to reduce the amount of material requiring either disposal or recycling. If such measures are costly to the municipality and also correlated with the recycling rate, then this omitted variable may bias the results. If source reduction efforts are constant across time, the fixed effects model eliminates this source of bias.

Second, credible estimates of external disposal costs may not exist in many developing countries, where even recycling rates may be non-existent. All available estimates of the external costs of waste and external benefits originate from developed countries. Thus, additional research on these factors may be necessary to estimate the optimal recycling rate in developing countries.

A third weakness arises from the assumption that all external cost of waste disposal and external benefits of recycling are constant. A more realistic position would likely involve rising external marginal costs of waste disposal and falling external benefits of recycling. Using household responses to unit-based pricing allows for non-constant linear costs to households, but other external factors are constant given the current state of research.

Finally, this framework for estimating the optimal recycling grate does not consider the distributional effects of various recycling rates. High recycling rates would benefit households surrounding landfills, households surrounding manufacturing regions, and of course the recycling industry but would impose costs on municipal taxpayers and recycling households. Changes in the recycling rates may transfer costs and benefits across these groups. This approach considers the aggregate costs with the eye toward minimizing total social costs.

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