September, 2010

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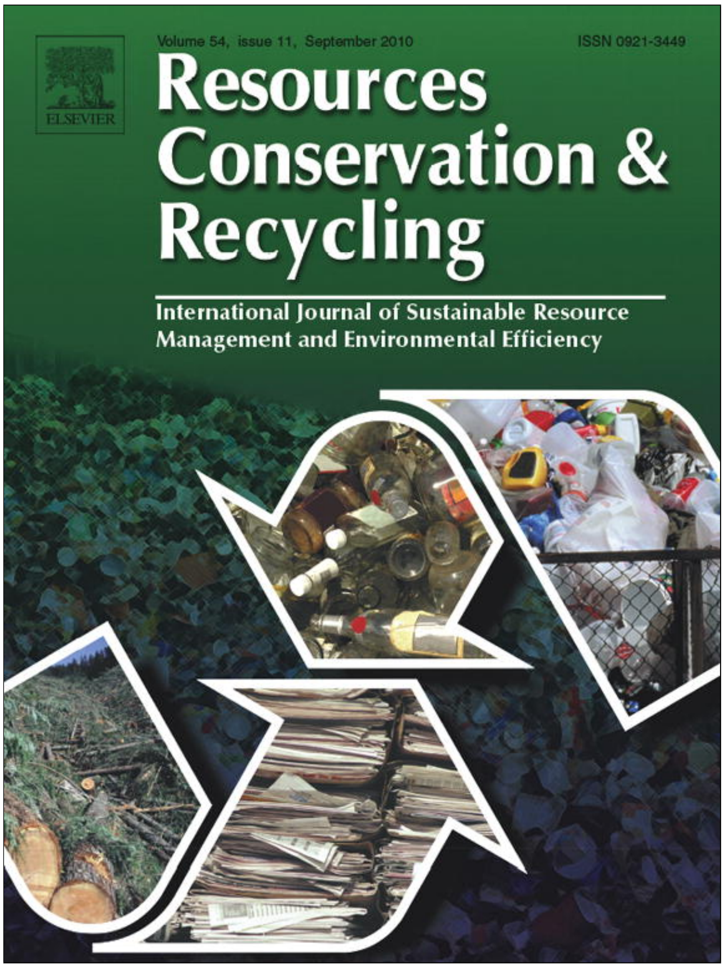
Volume 54, issue 11, September 2010
ISSN 0921-3449
ELSEVIER
Resources Conservation & Recycling
International Journal of Sustainable Resource Management and Environmental Efficiency

Resources, Conservation and Recycling 54 (2010) 864–871

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

The costs of municipal waste and recycling programs☆

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ARTICLE INFO

Article history:
Received 30 April 2009
Received in revised form 12 January 2010
Accepted 12 January 2010

Keywords:
Solid waste
Recycling
Cost functions

ABSTRACT

This paper estimates cost functions for both municipal solid waste collection and disposal services and curbside recycling programs. Cost data are obtained from a national survey of randomly selected municipalities. Results suggest, perhaps unsurprisingly, that both marginal and average costs of recycling systems exceed those of waste collection and disposal systems. Economies of scale are estimated for all observed quantities of waste collection and disposal. Economies of scale for recycling disappear at high levels of recycling—marginal and average cost curves for recycling take on the usual U-shape. Waste and recycling costs are also estimated as functions of factor costs and program attributes.

1. Introduction

The percentage of municipal solid waste (MSW) recycled in the United States increased from 6.4% in 1960 to 32.5% in 2006 (US EPA).[1] The nearly 82 million tons of materials recycled in 2006 can be attributed to 8817 municipal curbside recycling programs serving 51% of the United States population, to 10,500 drop-off programs, and to 3260 yard waste composting programs (US EPA). This growth in curbside recycling programs peaked between 1994 and 2000 when 6108 programs were initiated. Even though waste disposal costs (known as tipping fees) increased between 1980 and 2000 as landfills satisfied new state and federal guidelines, and market prices for recycled materials spiked sharply in 1995 and 1996, the empirical literature has found no causal link between these economic variables and the municipality's decision to implement curbside recycling. Instead, the increase in curbside recycling has been attributed to state mandates and local preferences for curbside recycling services (Kinnaman, 2005). The growth in curbside recycling has presumably evolved independently of costs and, perhaps for this reason, the economics literature is largely silent (with a few important exceptions) on understanding the costs of municipal waste and recycling services. Data limitations may have also hampered investigations into costs.

But both waste and recycling services are costly and require financing from local taxpayers and/or state governments to operate. This paper uses a national sample of municipal-level data to estimate the costs of municipal waste and curbside recycling services. Results suggest, perhaps unsurprisingly, that the costs to collect, separate, process, market, and transport recyclable household materials exceed the costs to collect and dispose the material as waste. Economies of scale are estimated across all observed waste quantities. But for recycling, economies of scale are estimated for only low quantities—the marginal and average cost curves for recycling take on the common U-shaped appearance.

Not all municipal waste and recycling programs are identical. The data also contain observations on local economic factor costs and program attributes. Economic variables include market prices for labor, capital, fuel, and tipping (disposal) fees. Program attributes include whether recyclable materials are separated by households prior to collection or later in a central facility, whether recycling systems are operated by municipal governments or by private firms, the size of the collection crews, the frequency of collection, and a host of other specific program attributes. Results estimate how each of these variables affect the costs of municipal waste and recycling services.

These results could help local policymakers estimate the costs and benefits of increasing or decreasing the quantity of recycled materials—where the benefits of increasing recycling include reductions in waste collection and disposal costs. Cost estimates could also be useful to a broader policymaking community interested in knowing the costs of waste and recycling services.

☆ The authors wish to acknowledge assistance from the following individuals and organizations: Alexandra Ellis, Matt Murray, Amy Ando, John Mayo, Jean Peretz, Bruce Tonn, Marcia Prewitt, Jonathon Bricker, The University of Tennessee Waste Management Research and Education Institute, The Joint Institute for Energy and Environment, Knoxville, TN and the U.S. Environmental Protection Agency. None of these individuals or organizations are responsible for the views expressed by the authors in this paper.
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[1] These percentages include materials recovered and composted.

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doi:10.1016/j.resconrec.2010.01.005

Confusion over the private marginal cost of waste collection and disposal contributed to a recent dispute published in the Comments section of the *Journal of Economic Perspectives*, where researchers debated whether the private marginal cost of recycling was $80 per ton or $209 per ton (Dijkgraaf et al., 2008). Results here suggest marginal costs vary with quantity, but achieve a minimum at about $75 per ton.

2. The empirical literature on waste and recycling services

This paper contributes to two literatures—one estimating the costs of waste collection and the other estimating the costs of recycling. The literature estimating the costs of waste disposal services originated nearly 50 years ago. Early studies lacked appropriate data and therefore employed proxy variables for the quantity of waste collected and disposed. Proxies included the number of garbage trucks in operation (Hirsch, 1965; Kemper and Quigley, 1976; Collins and Downes, 1977; Petrovic and Jaffee, 1978) and the municipal population (Kitchen, 1976). These papers estimated economies of scale in waste collection and disposal services differed on whether such returns to scale were decreasing or constant.

As waste quantity data became available following the Resource and Conservation Recovery Act of 1976, Stevens (1978), Tickner and McDavid (1986) and Dubin and Navarro (1988) expanded the literature estimating waste collection and disposal costs by using observed solid waste quantity measures. All find evidence of economies of scale in the collection and disposal of municipal solid waste. Other variables found to increase costs include an increase in the frequency of waste collection, the use of backdoor collection service rather than curbside or alley service, and the use of municipal resources in collection rather than contracting with a private collector. This paper expands upon this literature by using national data.

Empirical research on the economics of recycling can be divided into three main areas of inquiry. The first is multi-disciplinary in nature and focuses on estimating household participation in municipal recycling programs. Variables found to influence household participation rates include income (Saltzman et al., 1993; Feiock and West, 1996), education (DeYoung, 1990), the convenience of the recycling program (Feiock and West, 1996; Judge and Becker, 1993; Jenkins et al., 2003), citizen involvement in program design (Folz, 1991), and social and personal standards (Hopper and Neilson, 1991). Studies have also linked household participation rates to bag/tag unit pricing for waste disposal (Reschovsky and Stone, 1994; Hong et al., 1993; Miranda et al., 1994; Fullerton and Kinnaman, 1996; Podolsky and Spiegel, 1999; Kinnaman and Fullerton, 2000; Folz and Giles, 2002), and subscription-based volume pricing programs (Repetto et al., 1992; Reschovsky and Stone, 1994; Callan and Thomas, 1997; Podolsky and Spiegel, 1999; Jenkins et al., 2003). Jakus et al. (1996) and Tiller et al. (1997) estimate costs and benefits of drop-off recycling among rural households. The role of social norms in household recycling behavior is explored by Bruvoll and Nyborg (2004), Berglund (2006) and most recently by Halvorsen (2008).

A second branch of the economics literature estimates the demand for recycled materials. Nestor (1992), for example, examines the demand for recycled newsprint by the paper industry. Berglund and Soderholm (2003) compare utilization rates across 49 countries. Hervani (2005) considers the effect of oligopsony on the demand for recycled newspapers.

This research contributes most directly to the third branch of the literature on recycling. Only two studies are known to estimate the costs of collecting recyclable materials at the curb, but both use data from a single state. Carroll (1995) initiated the literature by estimating recycling costs with 1992 data from 57 municipalities in Wisconsin. Carroll found no economies of scale in those data. Callan and Thomas (2001) use 1996–1997 data on 101 municipalities in Massachusetts and are the first to estimate economies of scale in curbside recycling. In a related body of literature, Criner et al. (1995), Steuteville (1996) and Renkow and Rubin (1998) estimate the costs of municipal composting programs. Criner et al. (1995) estimate composting is worthwhile for landfill disposal fees between $75 and $115 per ton. Renkow and Rubin (1998) examined 19 cases to find composting preferred to landfilling when disposal costs are high.

3. Solid waste and recycling cost functions

Let Q_i^G be the quantity of solid waste collected and disposed in municipality i and TC_i^G be the total cost of collecting and disposing municipal solid waste. A flexible functional form for a simple cost function is given by

$$\ln(TC_i^G) = \alpha^G + \beta_1^G \ \ln(Q_i^G) + \beta_2^G[\ln(Q_i^G)]^2 + \mu_i^G \quad (1)$$

where α^G, β_1^G, and β_2^G are parameters to be estimated and μ_i^G represents all unobserved variables affecting the total cost of waste collection and disposal with mean zero and variance $(\sigma^2)^G$. The quadratic term in log output allows for a non-linear relationship between quantity and both marginal and average costs of waste collection and disposal. This cost equation will be expanded in Section 4 below to include other exogenous variables.

The corresponding total cost function for the collection of recyclable materials is

$$\ln(TC_i^R) = \alpha^R + \beta_1^R \ \ln(Q_i^R) + \beta_2^R[\ln(Q_i^R)]^2 + \mu_i^R \quad (2)$$

where Q_i^R represents the tons of materials recycled, TC_i^R represents the total cost of collecting recyclable materials, and μ_i^R represents unobserved variables thought to affect costs with mean zero and constant variance. This cost equation will also be expanded in Section 4 below to include economic and program attribute variables.

Even though the assumptions made for each individual equation satisfy the conditions necessary for ordinary least-squares estimates of the coefficients to be unbiased and efficient, the equations collectively exhibit serial correlation if unobserved variables affecting the cost of waste disposal also affect the cost of recycling. Owing to the many similarities between municipal waste and recycling processes, ordinary least squares of the two seemingly unrelated equations would be inefficient if the independent variables differ across the two equations. Efficient estimates of the parameters in Eqs. (1) and (2) are instead obtained with the seemingly unrelated regression (SUR) model developed by Zellner (1962) using Generalized Least Squares (GLS).

The data available to estimate costs are derived from a national survey of municipal recycling programs conducted in 1997 and described by Folz (1999a,b).[2] The data gathering process first identified all municipalities in the United States that maintained "at least some operational control of solid waste recycling services." From this population of 5044 municipalities, a stratified random sampling procedure produced a sample of 2096 municipalities. Each of the municipalities in the sample received a survey, and 1021 survey responses were obtained (a 48.7% response rate). Contact with each municipality consisted of an initial mailing, two follow-up mailings, and telephone conversations on matters of

[2] The survey was funded by a grant from the University of Tennessee Waste Management Research and Education Institute. The survey instrument was comprised of 38 questions and expanded upon the survey developed by Folz (1991). Modifications to the initial survey were made to enhance the specificity of queries concerning type and amount of materials collected, program costs and costs related to program characteristics.

Table 1
Quantity and cost variables.

Variable	N	Minimum	Maximum	Mean	Median	Std. deviation
Tons of solid waste collected in 1996 (Q^G)	428	40	1,389,000	36,610	7312	110,968
Total cost (in $s) to collect and dispose solid waste in 1996 (TC^G)	428	5407	92,913,000	2,290,700	513,763	6,882,700
Tons of recyclable materials collected in 1996 (Q^R)	428	3	70,000	3232	1200	6808
Total cost (in $s) of curbside recycling program in 1996 (TC^R)	428	300	6,230,000	371,060	110,000	782,271

Table 2
Waste collection and disposal costs (dependent variable = ln(TC^G)).

Variable	Coefficient	Standard error	Significance
Constant	$\alpha^G = 4.4576$	0.8080	1% level
$\ln(Q_i^G)$	$\beta_1^G = 1.1302$	0.1808	1% level
$(\ln(Q_i^G))^2$	$\beta_2^G = -0.0169$	0.0099	5% level
$N = 428$; $R^2 = 0.7154$			

Table 3
Curbside recycling costs (dependent variable = ln(TC^R)).

Variable	Coefficient	Standard error	Significance
Constant	$\alpha^R = 7.2926$	0.4705	1% level
$\ln(Q_i^R)$	$\beta_1^R = 0.3736$	0.1453	1% level
$(\ln(Q_i^R))^2$	$\beta_2^R = 0.0330$	0.0111	1% level
$N = 428$; $R^2 = 0.6378$			

clarification. Although these data have been used by Folz (1999a,b, 2004), Folz and Giles (2002) and Folz et al. (2005), the data have not been used by economists to estimate costs functions.

Each variable defined above is defined and summarized in Table 1. Perhaps due to imperfect information on the part of the survey responders, not all questions were answered by the 1028 responding communities. Only 428 communities reported total costs and quantities for both solid waste and recycling. If the reasons for imperfect information are uncorrelated with observed quantities and costs, then using the smaller sample will not introduce bias to the estimated coefficients.

The sample is comprised of a broad range of municipality sizes. As is summarized in Table 1, the quantity of municipal sold waste collected and disposed or incinerated (Q^G) varies between 40 tons and 1,389,000 tons. For TC^G, each municipality reported "the total collection and disposal cost for all non-recycled municipal solid wastes". These annual costs vary in the sample between $5407 and $92,913,000. That the median of all variables in Table 1 are less than their mean suggests the sample is comprised of a large number of small municipalities relative to the number of large cities—perhaps consistent with the overall distribution of municipal sizes in the United States.

GLS estimates of the parameters in (1) are provided in Table 2. All estimated coefficients are statistically significant at the 5% level. The value of R^2 (0.7154) suggests a large portion of the variation in cost data can be explained by the quantity variables—perhaps not surprising given the large range of quantity and cost data observed in the sample. These results can be used to estimate the marginal and average total cost curves for waste collection and disposal. These curves are illustrated in Fig. 1. The marginal cost of collecting and disposing the 40th ton of solid waste (the minimum in the sample) is estimated at $111.40. This marginal cost is estimated to

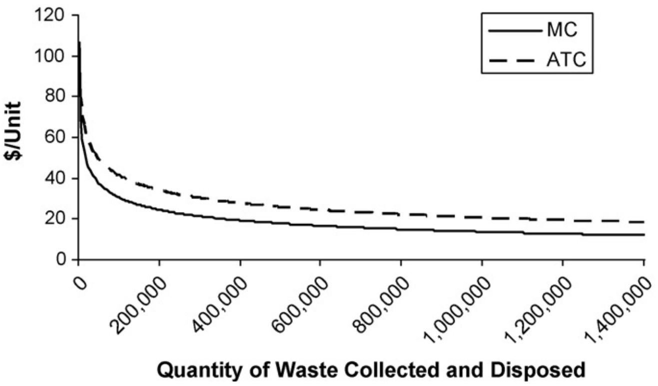

Fig. 1. Estimated costs of solid waste collection and disposal.

decrease to $59.70 and $40.54 for the municipality collecting the median (7312 tons) and mean (36,610) quantity of waste. The estimated marginal cost of collecting and disposing the 1,389,000th ton of waste (the maximum in the sample) is $12.19.

These estimated cost curves are long run in the sense that they are obtained by comparing the total costs of municipalities with varying levels of physical capital and administrative overhead. The costs to set up a solid waste collection system necessary to collect and dispose just 1 ton of waste (roughly two 20-pound bags of garbage per week) are small and perhaps consist only of the cost for the occasional use of a pick-up truck. Costs increase with expanding waste collection and disposal services due to purchases of additional collection trucks, establishing transfer stations, paying disposal (tipping) fees and creating the necessary administrative structure.

As illustrated in Fig. 1, economies of scale in waste collection and disposal are estimated for all observed quantities of waste in the sample. Both marginal and average total costs decrease with quantity. Increasing waste quantities may allow for the division of factor resources into specialized tasks. Stevens (1978) and Tickner and McDavid (1986) also find evidence of economies of scale in the provision of waste collection and disposal services.[3] In contrast, Callan and Thomas (2001) estimate constant returns to scale in waste collection and disposal with constant marginal cost of $77.82 per ton.

Variables used to estimate the recycling cost equation (Eq. (2)) are also defined and summarized in Table 1. According to the survey, the recycling quantity variable (Q^R) represents the total tons of "non-composted, recyclable materials recovered or collected as part of the local recycling program." This variable includes both materials collected at the curb and materials recovered at drop-off facilities. Recycling quantities varied between 3 tons and 70,000 tons across the municipalities in the sample with a mean of 3232 tons. The total cost of recycling (TC_i^R) represents "all direct and indirect costs and any payments made to contractors" and "excludes revenue earned from the sale of recyclable materials." The sample captured a broad range of program sizes, as recycling costs varied between $300 and $6,230,000 across the sample with a mean of $371,060.

GLS estimation results for the recycling equation are provided in Table 3. All three parameters are significant at the 1% level. Marginal and average total costs curves based upon the GLS estimates of the parameters from Eq. (2) are illustrated in Fig. 2. The marginal cost of recycling the 3rd ton of material (the minimum amount recycled in

[3] Stevens (1978) finds constant returns to scale among municipalities with populations in excess of 50,000.

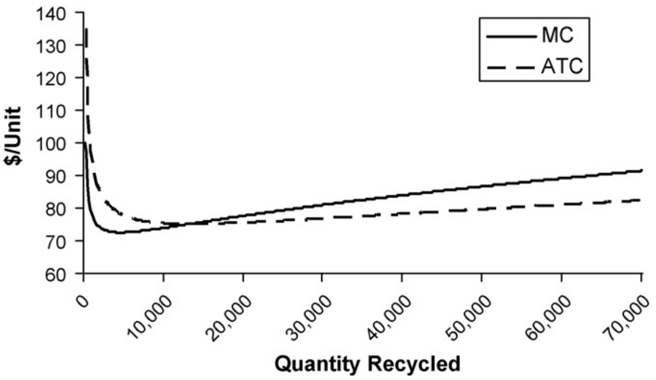

Fig. 2. Estimated costs of curbside recycling.

the sample) is estimated at $342.80. The marginal costs of recycling the 1200th ton and the 3232nd ton – the median and mean in the sample – are estimated at $76.53 and $72.81, respectively. As illustrated in Fig. 2, the marginal cost of recycling initially decreases at low quantities but eventually increases. Factor specialization and utilization reduces marginal costs at low quantity levels, but diminishing returns to recycling factors may cause marginal costs to then rise at high quantity levels. The marginal cost of recycling reaches a minimum of $72.57 at the 4600th ton recycled. Average total costs are minimized at a value of $75.18 at the 13,200th ton recycled. Examining the raw data, municipalities in the sample that recycle an amount close to 13,200 tons of materials have populations of about 80,000 persons.

These estimates suggest economies of scale are present in the curbside collection only for quantity levels below 13,200 tons per year. Callan and Thomas (2001) also found economies of scale for recycling using a sample with an annual mean of 11,098 tons of recyclable materials. Callan and Thomas (2001) also estimate the marginal cost of recycling at $13.55 per ton—in stark difference to the range of estimates reported above. Carroll (1995) estimated constant returns to scale in recycling using a sample of 57 municipalities averaging 4468 tons per year.

These results are useful to any municipality contemplating an expansion or contraction of their recycling program. Consider a municipality collecting and disposing the median quantity of waste (7312 tons) and recycling the median quantity of materials (1200 tons). By recycling one additional ton of waste that would have otherwise been disposed, the municipality would save an estimated $59.70 in collection and disposal costs but incur $76.53 in added recycling costs. This extra cost is reduced by any revenues gained from selling the recyclable materials. The municipality can then compare the expected change in costs with the expected gain in environmental quality attributable to the reduction in waste disposal or increase in recycling.

Household source reduction efforts presumably complement recycling practices. Households that increase recycling may simultaneously seek ways to reduce the use of shopping bags and beverage containers. If source reduction indeed accompanies recycling, then the 1 ton increase in recycling discussed above could lead to more than a 1 ton decrease in waste quantity. If a municipality that increases recycling by 1 ton experiences a 1.28 ton reduction in solid waste due to source reduction, then the marginal cost of the additional recycling ($76.53) would equal the marginal benefit of lower waste collection and disposal costs (also $76.53).

4. Specific determinants of the costs of curbside recycling and waste collection

Cost functions for both waste and recycling can be expanded to include other variables thought to affect the long-run marginal cost of collecting and disposing solid waste or operating a curbside recycling program. Let $Z_{i1}, Z_{i2}, \ldots, Z_{iK}$ denote variables potentially influencing the marginal cost of operating waste or recycling systems in municipality i. The total cost function in Eq. (1) or (2) can be expanded to

$$\ln(\mathrm{TC}_i) = \alpha + \beta_1 \ln(Q_i) + \beta_2[\ln(Q_i)]^2 + \gamma_1 Z_{i1} + \gamma_2 Z_{i2} + \ldots + \gamma_K Z_{iK} + \mu_i \quad (3)$$

Each γ determines how a change in each of the corresponding Z variables affects costs. Once again the seemingly unrelated regression (SUR) econometric model is used to estimate the coefficients in (3).

Economic variables expected to affect the costs of municipal waste and recycling services include costs for labor, capital, and fuel. Because the survey does not contain detailed budget information, data on these variables are derived from outside sources. WAGE is the 1996 average hourly earnings of production workers in each Bureau of Labor Statistics labor market area. INTEREST represents the municipality's opportunity cost of acquiring physical capital based on Moody's full faith and credit bond rating. FUEL is the prevailing local price of regular gasoline in 1996, obtained from United States Department of Energy. In terms of program attributes, *all* variables obtained from the survey that might potentially affect the cost of waste collection and disposal and/or the cost of recycling are included in the model. All economic and program attribute variables are listed in Table 4. Descriptive statistics are summarized in Table 5. Also in Table 5 is an indication of which cost model the variable belongs to (garbage—G, and/or recycling—R). Because the survey was designed to gather data primarily on recycling programs, the amount of variables available to the recycling equation far exceeds the number available to waste. Due to missing value in the new variables, the number of usable observations decreased from 428 to 284.

4.1. *The costs of waste collection and disposal*

SUR estimates of the coefficients for the waste equation are listed in Table 6. The coefficient on the log of quantity (β_1) and its squared term (β_2) do not change substantially by adding the extra variables. The coefficient on the factor cost for fuel is positive and significant in the waste equation. A 1% increase in the price of gasoline is estimated to increase waste collection and disposal costs by 1.653%. Labor costs (WAGE) and capital costs (INTEREST) are also estimated to increase waste collection and disposal costs, but not with statistical significance. A 1% increase in disposal costs (TIPFEE) is estimated to increase costs by 0.17%.

20% of the municipalities in the sample levy per-bag user fees to finance a portion of solid waste collection and disposal costs. Such programs require municipal resources to print and distribute special tags, stickers, or bags required for households to dispose of each bag of waste. Holding the quantity of waste constant, such efforts are estimated to increase the overall costs of waste collection and disposal by 18.1%, but this estimate is not statistically significant.

Collecting waste on the same day as recyclables (SAMEDAY) is estimated to decrease the marginal cost of waste collection and disposal by an insignificant 12.6%. Callan and Thomas (2001) suggest that municipalities share resources across the two collection programs. Finally, DENSITY, obtained from the U.S. Census (*City and County Data Book*) represents the density of the population in persons per square mile. A 1% increase in the population density is estimated to increase waste costs by 0.092%. Waste generated in high-density municipalities may incur high costs to transport waste to remote landfills for disposal.

Table 4
Variables affecting the costs of solid waste or recycling.

Factor costs	
WAGE	Average hourly earnings of production workers in 1996 (Bureau of Labor Statistics)
INTEREST	Opportunity cost of capital based upon Moody's bond rating
FUEL	Price of regular gas
TIPFEE	Cost of waste disposal ($ per ton)
Scope of services	
MFAM	Recyclables are collected from multi-family dwellings
FREQUENCY	Number of curbside recycling collections per month
STAFFDROP	Community offers staffed facility for households to drop-off recyclable materials
UNSTAFFDROP	Community offers un-staffed facility for households to drop-off recyclable materials
PARTICIPATE	The percentage of eligible households participating in curbside recycling
Collection practices	
BINSTOHHS	Recycling containers provided to households
COLLSEP	Recyclable materials are separated by collectors
CENTSEP	Recycled materials are separated in a centralized facility
VARFEE	Municipality levies a variable fee for waste collection
CREW	Size of collection crew for recyclable materials
SAMEDAY	Recyclables collected on the same day as solid waste collection
CITYCOLL	City crews collect recyclable materials using city trucks
CITYPROC	City owned and operated materials recovery facility processes recyclables
RECTRUCK	Specialized recycling truck used to collect materials
Exogenous variables	
DENSITY	Population density of municipality (persons per square mile)
STMANDATE	State mandate or recycling goal is very significant for continuation of recycling
VINTAGE	Number of years a community recycling program has been in operation (as of 1996)

4.2. The costs of recycling

Variables expected to affect the costs of operating a curbside recycling program are listed in Table 4, and descriptive statistics for each variable are summarized in Table 5. Results suggest a 1% increase in interest rates increases recycling costs by an estimated 21.903%. That INTEREST, the cost of capital, is positive in the recycling equation but insignificant in the waste equation could suggest recycling systems are more capital intensive than waste systems. Perhaps trucks are the only capital necessary to most waste collection and disposal systems (land being the other important input). Capitalized processing facilities in addition to collection trucks may be necessary inputs to recycling systems.

Labor and fuel costs are not significant predictors of recycling costs. Wages were also insignificant in the waste equation—apparently neither of these systems is labor intensive. But the cost of fuel was significant and positive in the waste equation. Perhaps waste is transported over long distances to reach remote waste disposal facilities. The distance to recycling facilities may be comparatively small.

Several program-specific attributes could potentially affect recycling costs. The first is a binary variable that indicates whether multi-family residents are included in the curbside recycling program. As summarized in Table 5, 79% of municipal recycling programs collect materials from multi-family residences such as apartment buildings (MFAM = 1). Residents in multi-family dwellings might individually transport their recycled materials to a single on-premise depot, making municipal collection from these households easier than for single-family dwellings. But this coefficient is not statistically different from zero.

The frequency of curbside service (FREQUENCY) varied in the sample from as few as one collection per month to as many as two

Table 5
Descriptive statistics of variables affecting costs.

	N	Model	Minimum	Maximum	Mean	Std. deviation
WAGE	284	G and R	9.80	18.32	12.84	1.62
INTEREST	284	G and R	5.10	5.34	5.24	0.04
FUEL	284	G and R	1.07	1.56	1.26	0.10
TIPFEE	284	G	0	110	38.86	18.68
MFAM	284	R	0	1	0.79	0.41
FREQUENCY	284	R	1	8	3.44	1.01
STAFFDROP	284	R	0	1	0.30	0.46
UNSTAFFDROP	284	R	0	1	0.31	0.46
PARTICIPATE	284	R	1	100	70.98	22.41
BINSTOHHS	284	R	0	1	0.81	0.40
COLLSEP	284	R	0	1	0.32	0.47
CENTSEP	284	R	0	1	0.44	0.50
VARFEE	284	G	0	1	0.20	0.40
CREW	284	R	1	5	1.63	.76
SAMEDAY	284	G and R	0	1	0.80	.40
CITYCOLL	284	R	0	1	0.44	.50
CITYPROC	284	R	0	1	0.13	0.34
RECTRUCK	284	R	0	1	0.43	.50
DENSITY	284	G and R	8	4397	944.31	751.05
STMANDATE	284	R	0	1	0.48	0.50
VINTAGE	284	R	1	28	8.16	4.43

Table 6
The costs of waste collection (dependent variable = ln(TC^G)).

Variable	Coefficient	Standard error	Significance
CONSTANT	−5.944	9.522	–
ln(Q^G)	1.098	0.228	1% level
[ln (Q^G)]^2	−0.016	0.012	–
ln(WAGE)	0.225	0.271	–
ln(INTEREST)	4.057	5.745	–
ln(FUEL)	1.653	0.669	5% level
ln(TIPFEE)	0.170	0.086	5% level
VARFEE	0.166	0.116	–
SAMEDAY	−0.119	0.119	–
ln(DENSITY)	0.092	0.051	10% level
N = 284; R^2 = 0.775			

collections per week. More frequent service holding constant the quantity collected would presumably increase costs. The estimated coefficient is positive, as expected (costs are estimated to increase by 3.6% with each additional pick-up per month), but insignificant. Callan and Thomas (2001) estimate average costs increase with frequency, while Carroll (1995) finds no connection between frequency of collection and total costs.

As summarized in Table 5, 30% of responding communities reported a staffed drop-off facility (STAFFDROP = 1) and 31% reported an un-staffed drop-off facility (UNSTAFFDROP = 1). The model controls for the presence of either a staffed or un-staffed drop-off facility when estimating costs because the quantity variable, Q^R, includes all materials recovered via curbside collection and at drop-off facilities. The marginal cost is expected to fall to the extent the municipality's recycling costs decreases when households rather than collection crews transport materials to recycling facilities. Results do not confirm this prediction. Neither variable is statistically different from zero.

The data also include the estimated participation rate among eligible households in each municipality (PARTICIPATE).[4] Holding the quantity of material collected constant, an increase in the participation rate might increase the cost of collecting material—collecting a lot of material from a few households is presumably cheaper than collecting a little material from many households. These data confirm the suggestion, every 1% increase in the reported participation rate increases costs by 0.50%.

Just over 81% of the municipalities in the sample provide recycling bins, bags, or carts at no costs to participating residents (BINSSTOHH = 1). Costs of recycling rise with the costs of purchasing, storing, and delivering these bins to households and fall to the extent these bins make collection more efficient. Results suggest the two affects could offset each other—the overall affect of providing bins to households on recycling costs is not statistically different from zero.

Roughly 32% of municipalities in the sample allow households to co-mingle all recyclable materials in a single container. The collectors then separate the materials at the time of collection (COLLSEP = 1). The marginal cost of recycling increases to the extent these separating services increase the time necessary to complete a collection route. But the data suggest the marginal cost is unaffected by this option. Collection crews do not appear advantaged by the pre-separated materials, as they may still have to deposit each material into separate sections of the recycling truck. Thus, if separating materials are costly to households, then a program with collectors separating recyclable materials may be welfare improving.

About 44% of the sample also collects co-mingled recyclables from households and then separates the materials at a centralized facility (CENTSEP = 1). The municipality must allocate resources to operate the separating facility, but this practice could ease the collection process as collection crews simply dump all co-mingled recyclable materials at once into a single truck for subsequent separation. Results suggest the costs of recycling decreases by 36.3% per ton. This result suggests centralized separating facilities reduce costs, especially if requiring households to pre-separate recycled materials is costly to households.[5]

Municipalities vary with respect to the size of crews sent out to collect recyclable materials from households (CREW). As few as one and as many as four workers comprise a collection crew in the sample. The average crew size is 1.63 members. The marginal cost of recycling can be expected to rise with the additional labor costs incurred with larger crews and fall as additional crew members allow for specialization and the division of labor in collection. The data suggest changes in the crew size do not affect marginal costs, perhaps suggesting that these two forces negate each other.

79% of municipalities in the sample collect recyclable materials on the same day as regular waste collection (SAMEDAY = 1), perhaps to make recycling more convenient to households. The marginal cost of collecting recyclable materials does not statistically change for municipalities with same-day service.

CITYCOLL is a binary variable that indicates whether curbside recycling is conducted by municipal employees or by a private contracted company. 44% of municipalities in the sample utilize municipal employees. The marginal cost of recycling is estimated to rise by 26.6% with municipal employees relative to a private contracted collector. Carroll (1995) also found costs increase with municipal provision, but Callan and Thomas (2001) find no effect. Kemper and Quigley (1976) estimate that competitive markets are 25–36% more expensive than a single collector, and that contract or franchise agreements reduce costs over municipal collections by another 13–30% (depending on the level of service). Stevens (1978) estimates that the contract or franchise agreements reduce costs by 26–48% below that of a competitive private market and by 27–37% below that of municipal provision (for cities with populations over 50,000). Costs could increase with public provisions if wage payments to municipal workers exceed those to workers of the private marketplace or if the municipality lacks competitive pressure to minimize costs.

Similarly, 14% of municipalities in the sample feature a municipally run processing facility (CITYPROC = 1). Other municipalities rely upon private companies, a non-profit association, or other governmental unit to process the recycled materials. A city-operated processing facility is estimated here to have no statistical affect on costs.

Another variable that could affect the long-run marginal cost of recycling is the type of vehicle used to collect materials at the curb. Low-cost options could include ordinary refuse trucks, pick-up trucks, or dump trucks. Alternatively, a municipality could purchase a designated recycling truck with individual compartments engineered for each material (RECTRUCK = 1). 43% of the sample made such a choice. The presence of such a truck is estimated to increase recycling costs by 6.4%, but this variable is not statistically significant.

[4] The survey asked municipalities how they estimated participation rates. Each municipality could select "all that apply" from a list of 7 options. Only 10% utilize actual sign-ups or subscriptions to recycling programs to observe participation. About half of the municipalities indicated their estimate was based upon subjective "field observations."

[5] The remaining option to COLLSEP and CENTSEP is to require households to separate materials into different recycling bins or bags. Because this variable is omitted to avoid colinearity with the constant term, the coefficients on COLLSEP and CENTSEP are interpreted as cost differences relative to having households pre-separate the material.

Table 7
The costs of recycling (dependent variable = $\ln(TC^R)$).

Variable	Coefficient	Standard error	Significance
CONSTANT	−24.775	11.480	5% level
$\ln(Q^R)$	0.321	0.195	10% level
$\ln(Q^R)^2$	0.033	0.014	5% level
ln(WAGE)	−0.483	0.332	–
ln(INTEREST)	21.903	6.847	1% level
ln(FUEL)	−0.502	0.868	–
MFAM	0.025	0.138	–
FREQUENCY	0.035	0.057	–
STAFFDROP	−0.051	0.127	–
UNSTAFFDROP	−0.009	0.123	–
PARTICIPATE	0.005	0.003	10% level
BINSTOHHS	0.205	0.146	–
COLLSEP	−0.057	0.145	–
CENTSEP	−0.310	0.132	5% level
CREW	0.092	0.077	–
SAMEDAY	0.201	0.147	–
CITYCOLL	0.236	0.134	10% level
CITYPROC	0.059	0.180	–
RECTRUCK	0.062	0.114	–
ln(DENSITY)	0.086	0.064	–
STMANDATE	0.051	0.112	–
VINTAGE	−0.011	0.013	–
$N = 284$; $R^2 = 0.678$			

Three additional variables have been identified that could potentially explain differences in the costs of operating a curbside recycling program. DENSITY reflects the space a program must cover to collect materials from a given population. The density of the population has no statistical affect on the costs of recycling. Carroll (1995) found densities decrease average costs, but Callan and Thomas (2001) found no such relationship in recycling collection.

The variable STMANDATE indicates a state mandate or state waste reduction goal was significant to the municipality's decision to sustain the recycling program. Such mandates have been imposed in 22 states, comprising 48% of the municipalities in the sample. The coefficient on this variable suggests costs do not differ between programs initiated voluntarily by the municipality and programs required by state law.

Finally, the VINTAGE variable represents the number of years the curbside recycling program has been in operation. This variable captures reductions in costs from learning and experience as a program matures. The sign of VINTAGE is negative as expected, but is not statistically significant.

5. Summary and conclusions

This paper extends two empirical literatures measuring the costs of two municipal solid waste services by utilizing a data set of randomly selected municipalities from across the United States. Results suggest waste collection and disposal costs exceed the costs of recycling, perhaps owing to the cost of additional economic resources necessary to separate and process recyclable materials. Results also suggest economies of scale are present in both waste collection and disposal and curbside recycling, but disappear at high levels of recycling. Average total costs of recycling are minimized at $75.18 by a municipality recycling 13,200 tons of materials per year. This quantity was produced by municipalities with populations of about 80,000 persons.

The data also feature economic variables and specific program attributes previously unmeasured in the literature. Municipal recycling programs that contact to private collecting companies rather than using public employees and recycling systems that feature centralized separation rather than curbside separation enjoy lower costs. These results could prove useful to municipal officials interested in implementing changes in these approaches to recycling (Table 7).

Note, finally, that results as depicted in Table 3 and Fig. 2 might mistakenly be interpreted to suggest that all municipalities can minimize average recycling costs by selecting the quantity that minimizes long-run average total costs (13,200 tons). But the total quantity of waste material available for recycling (G + R) is largely determined by local populations and income levels, factors that are exogenous to the municipal government. A very small municipality, for example, is obviously unable to achieve this minimum average cost if the total quantity of household material available for recycling (G + R) is less than 13,200. These results could prove useful to municipalities interested in estimating the marginal cost of increasing or decreasing the quantity of materials recycled. Results could also inform adjoining municipalities that are interested in the cost implications of combing recycling programs.

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