The Costs of Municipal Curbside Recycling and Waste Collection

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The costs of municipal waste and recycling programs

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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). 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.
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., 2001), 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)

3. Solid waste and recycling cost functions

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

\[
\ln(TCG_i) = \alpha + \beta_1 \ln(Q_i) + \beta_2 \ln(Q_i)^2 + \mu_i
\]

where \( \alpha, \beta_1, \beta_2, \) and \( \mu_i \) are parameters to be estimated and \( \mu_i \) represents all unobserved variables affecting the total cost of waste collection and disposal with mean zero and variance \( \sigma^2 \). The quadratic term in log output allows for a non-linear relationship between quantity and 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

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

where \( Q_i^R \) represents the tons of materials recycled, \( TCR_i \) represents the total cost of collecting recyclable materials, and \( \mu_i^R \) 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). 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...
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 solid waste collected and disposed or incinerated ($Q^w_i$) varies between 40 tons and 1,389,000 tons. For $TC^w_i$, each municipality reported “the total cost of collecting and disposing the 40th ton of solid waste (the minimum in the sample)” for the occasional use of a pick-up truck. Costs increase 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 structure.

Fig. 1. Estimated costs of solid waste collection and disposal.
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 $Z_{1i}, Z_{2i}, \ldots, Z_{K_i}$ 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

$$\ln(TC_i) = \alpha + \beta_1 \ln(Q_i) + \beta_2 [\ln(Q_i)]^2 + \gamma_1 Z_{1i} + \gamma_2 Z_{2i} + \ldots + \gamma_K Z_{Ki} + \mu_i$$

Each $\gamma$ 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 collection equation are listed in Table 6. The coefficient on the log of quantity ($\beta_1$) and its squared term ($\beta_2$) 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 0.082%. Waste generated in high-density municipalities may incur high costs to transport waste to remote landfills for disposal.
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 (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.
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. Carroll and Thomas (2001) estimate average costs increase by 3.6% with each additional pick-up per month), but insignificant. 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, 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), 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 retrieved materials is costly to households.

Municipalities vary with respect to the size of crew 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.

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 6

| Variable Coefficient Standard error Significance |
|-----------------|-----------------|-----------------|
| CONSTANT | -0.944 | 0.522 | - |
| ln(Q) | 1.089 | 0.012 | 1% level |
| ln(Q)^2 | -0.016 | 0.012 | - |
| ln(WAGE) | 0.225 | 0.271 | - |
| ln(INTEREST) | 0.057 | 0.271 | - |
| 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
The population has no statistical affect on the costs of recycling. Tom and Thomas (2001) found no such relationship in recycling collection programs that contact to private collecting companies rather than municipal regulations of about 80,000 persons.

Average total costs of recycling are minimized when waste collection and disposal costs exceed the costs of two municipal solid waste services by utilizing a data set of over 5,000 municipalities. The sign of VINTAGE is negative as expected, and the VINTAGE variable represents the number of years a program matures. The sign of VINTAGE is negative as expected, but is not statistically significant.

Table 7

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard error</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
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<td>11.480</td>
<td>5% level</td>
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<tr>
<td>ln(\theta)</td>
<td>0.321</td>
<td>0.195</td>
<td>10% level</td>
</tr>
<tr>
<td>ln(\theta^2)</td>
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<td>0.014</td>
<td>5% level</td>
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<td>ln(WAGE)</td>
<td>-0.483</td>
<td>0.332</td>
<td>–</td>
</tr>
<tr>
<td>ln(NINTEREST)</td>
<td>21.903</td>
<td>6.847</td>
<td>1% level</td>
</tr>
<tr>
<td>ln(FUEL)</td>
<td>-0.502</td>
<td>0.868</td>
<td>–</td>
</tr>
<tr>
<td>MFAM</td>
<td>0.025</td>
<td>0.138</td>
<td>–</td>
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<td>FREQUENCY</td>
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<td>–</td>
</tr>
<tr>
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</tr>
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<td>BINSTOHHS</td>
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<td>ln(DENSITY)</td>
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<tr>
<td>VINTAGE</td>
<td>-0.011</td>
<td>0.013</td>
<td>–</td>
</tr>
</tbody>
</table>

N = 284; R^2 = 0.678

Three additional variables have been identified that could potentially explain differences in the costs of operating a curb-side recycling program. DENSIFY 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 programs.

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 curb-side 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 curb-side 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 curb-side 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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