Available online at www.sciencedirect.com
SCIENCE DIRECT
ACADEMIC PRESS
Journal of Environmental Economics and Management 45 (2003) 294–318
JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT
http://www.elsevier.com/locate/jeem

The determinants of household recycling: a material-specific analysis of recycling program features and unit pricing☆

Robin R. Jenkins,[a,]* Salvador A. Martinez,[b] Karen Palmer,[c] and Michael J. Podolsky[d]

[a] US Environmental Protection Agency, Office of Policy, Economics and Innovation, 1200 Pennsylvania Avenue NW MC 1809T, Washington, DC 20460, USA
[b] Department of Economics, University of Florida, USA
[c] Resources for the Future, USA
[d] School of Law, Case Western Reserve University, USA

Received 7 April 2000; revised 19 May 2001

Abstract

This paper analyzes the impact of two popular solid waste programs on the percent recycled of several different materials found in the residential solid waste stream. We examine a unique, household-level data set representing middle and upper-middle income groups in 20 metropolitan statistical areas across the country and containing information on the percent recycled of five different materials: glass bottles, plastic bottles, aluminum, newspaper, and yard waste. We find that access to curbside recycling has a significant positive effect on the percentage recycled of all five materials and that the level of this effect varies across different materials. The length of the recycling program's life also has a significant positive effect on two materials. Making recycling mandatory has an insignificant effect on all five materials. The level of the unit price is insignificant in our regressions, but the effect of unit pricing on recycling activity remains unclear.

Keywords: Solid waste; Recycling; Unit pricing; Incentives

1. Introduction

The past 15 years have been a time of dramatic change for solid waste management. Beginning in the mid-1980s, with stricter EPA requirements for landfill construction on the horizon, landfill

☆Any opinions, findings, conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the Environmental Protection Agency.

*Corresponding author.
E-mail address: jenkins.robin@epa.gov (R.R. Jenkins).

0095-0696/03/$ - see front matter © 2003 Elsevier Science (USA). All rights reserved.
doi:10.1016/S0095-0696(02)00054-2

tipping fees increased dramatically and there was a widespread impression that landfill space was growing scarce and that a landfill "crisis" was inevitable.[1] Two clear national trends in solid waste management emerged as a result of local efforts to reduce the quantities of waste being landfilled. The most pervasive was the introduction of residential curbside recycling programs. In 1988, there were approximately 1000 such programs in the US; in 1992, there were almost 5000; by 1999 the number reached just over 9000 [5]. A second, less pervasive but still important, trend during this period was the introduction of volume-based pricing, or unit pricing, of solid waste disposal services wherein households are charged for garbage collection according to the number of containers they set out. Prior to the late 1980s there were perhaps a few dozen such programs [25]. By 1992, there were approximately 2000; and by 1999, just over 4000 [17].

Though the nature of a curbside recycling program is quite different from a unit pricing program, both theoretically provide incentives for a redirection of waste quantities from disposal sites to recycling centers. A curbside program reduces a household's cost of recycling by making recycling more convenient and less time consuming. A unit pricing program increases a household's cost of discarding additional waste relative to its cost of recycling; i.e., not recycling leads to higher fees for waste collection services.[2]

Each program targets different waste management activities, which might lead to differences in the outcomes of the two programs. For example, unlike a curbside recycling program, unit pricing only gives an indirect incentive to recycle while its direct incentive is to reduce waste quantities. Unit pricing may also create incentives for households to adjust their purchasing habits to generate less solid waste. Thus, the two programs might very well have different effects on household recycling effort.

Economic principles also suggest that the two programs will have different impacts on recycling and consumption of different recyclable materials [11]. One suggestion is that volume-based unit pricing will give households an incentive to recycle bulky items that take up lots of garbage container space—such as plastic milk jugs. On the other hand, unit pricing might encourage households to avoid generating bulky wastes in the first place. Households might alter the composition of their consumption bundles so that there is less trash to discard.

A curbside recycling program also might disproportionately affect certain materials. As a substitute for drop-off recycling, curbside collection mainly reduces a household's costs of transporting recyclable materials. Compared to a household without any local recycling program, a household with a curbside program will have a much easier time recycling materials that are hard to transport, like glass bottles, which are bulky and can break.

Policy makers would benefit from a better understanding of the impact of the two programs and their features on different recyclable materials. To the municipalities that collect them, different recyclable materials have different costs of recycling as well as different values on the open market. Understanding which program features lead to greater recycling of high valued

[1] Most of the increase in tipping fees occurred during the middle and late 1980s. In 1985 the national average tipping fee in the US was approximately \$11.20 per ton; in 1990, it was approximately \$33.75. As of 1997, it remained close to \$30.00. (All values are in 1997\$.) [31].

[2] Without unit pricing, most communities finance waste disposal via general tax revenues or flat fees. From the perspective of households, this places a marginal price of zero on waste disposal. This causes them to dispose of more than the socially efficient amount of waste. A unit pricing program imposes a non-zero marginal price on waste disposal that can potentially correct this problem.

materials could improve the cost-effectiveness of a community's efforts to promote recycling. In other cases, municipalities sometimes achieve very high recycling effort directed at a few materials. In order to increase their aggregate recycling percentage in an effort to meet state-mandated recycling rate targets, municipalities must sometimes encourage households to recycle additional materials. Understanding how best to promote recycling of a broader range of materials would be beneficial. On the other hand, if the costs of adding a particular material to a curbside program exceed the waste diversion and recycling revenue benefits of doing so, then adding certain materials may not be worthwhile.

This paper analyzes a large household-level data set representing 20 metropolitan statistical areas (MSAs) across the country to study the impact of these two popular solid waste programs and their features on the percent recycled of five different materials: glass bottles, plastic bottles, aluminum, newspaper, and yard waste. All communities in the data set offer curbside recycling of at least one of the five materials; although most offer it only for a *subset* of the five. However, the data set contains detailed information on the attributes of different recycling options for all five specific materials. For example, the data indicate whether each material is collected at all through a local program and if so whether it is collected curbside or at a local drop-off facility. The data also indicate whether recycling the material is mandatory or voluntary and the age of the recycling program. Finally, the data set contains rich household level socio-economic information. We augment the household-level data with community-level information on the prices charged for disposal under a unit-pricing program where it is applicable.

The contributions of this paper are more easily understood within the context of the literature that has investigated the determinants of recycling. Thus, we start with a brief review of this literature and adopt from it a simple theoretical model. We then describe our own data and present an empirical model. We present the empirical results, note limitations of the data and in closing, discuss the relevance of our findings to policy.

2. Prior research and a conceptual framework

This paper makes two contributions to the existing economics literature on recycling. First it adds to the research on the effectiveness of curbside recycling and unit pricing at encouraging households to recycle. Several papers study various aspects of these programs, sometimes with unit pricing and curbside recycling operating together and sometimes with one program operating in isolation (e.g., [1,4,8,14,16,21,32]). However, ours is the first that analyzes data from most major US metropolitan areas and rests on a household-level unit of analysis.[3] Household-level is preferred to community-level because households are the decision-making units that are the target of recycling policies. Analyzing data from numerous MSAs located in different parts of the country is preferred to an analysis of only one region because it facilitates the identification of policies and demographic variables that are significant across regions.

[3] Several econometric studies analyze the impacts on recycling effort of one or both of these two popular programs by examining household-level data; in particular, Nestor and Podolsky [21], Fullerton and Kinnaman [4] and Hong et al. [8]. However, the data for all three of these studies are for a single region where curbside recycling and unit pricing co-exist. Several other studies are national in scope but rely on community-level data (e.g., [14,16,18,29]). (The latter two use the case study method of analysis.)

A second contribution of this paper is to extend previous research by investigating whether and how the impact of these two popular programs differs for different recyclable materials. The few existing material-specific studies have lacked the rich amount of information about both recycling and unit pricing programs contained in our data set (e.g., [23,24]). We also examine the effect of household socio-economic characteristics on recycling effort directed at different materials.

Table 1 summarizes the existing econometric literature that studies the effects of unit pricing and curbside recycling on household recycling effort. A number of papers have developed conceptual frameworks to study the impact of unit pricing (e.g., [4,11,20]). Others, including Podolsky and Spiegel [22] and Kinnaman and Fullerton [13], describe the substitution possibilities between waste disposal and recycling as part of household waste management. These papers develop models in which households maximize utility subject to a budget constraint that incorporates a unit price for waste collection. The models are the basis for solid waste disposal and recycling demand equations.

On the right-hand sides of these equations are three categories of exogenous variables: characteristics of the goods whose consumption generates waste; descriptions of the local waste management system; and socio-economic factors. The first category includes the price of consumption good i (P_i) and the amount of waste generated per unit of good i ($\boldsymbol{\beta}_i$) where ($i = 1 \ldots n$). The second category consists of the price per unit of waste disposal (P_W) and a vector of recycling program features (RP) including whether the collection occurs at the curb or at a drop-off facility, the length of life of a recycling program, and so on.[4] The third category is comprised of socio-economic characteristics (SE) such as household size, income and education.

Specifically, D and R are the optimal levels of household disposal and recycling,

$$D = f(\beta_1, \ldots, \beta_n, P_1, \ldots, P_n, P_\mathrm{W}, \mathrm{RP}, \mathrm{SE}) \tag{1}$$

$$R_j = \gamma_j(\beta_1, \ldots, \beta_n, P_1, \ldots, P_n, P_\mathrm{W}, \mathrm{RP}, \mathrm{SE}) \tag{2}$$

$$R = \Sigma\, R_{j.} \tag{3}$$

Each recycled material, j, has unique characteristics that could affect the relationship between recycling and the exogenous variables. These characteristics include factors such as bulkiness that affect the ease of recycling as well as the availability of substitutes for the material. Thus, each material (R_j) has a unique recycling demand equation as specified in (2).

Consistent with (2), we analyze material-specific recycling behavior for each of five materials. However, since we do not have data on recycling quantities, we actually estimate the effects of the exogenous variables on the intensity of recycling for each material.

[4] The price per unit of waste disposal charged to households is usually a volume-based price. For example, households in communities employing a bag/sticker purchase official program bags or stickers, which they affix to garbage bags of the mandated size. Alternatively, households in communities using a subscription can program specify a level of waste disposal per period of time in advance and are charged according to this level.

Table 1
Econometric studies of the impact of unit pricing and curbside recycling programs on recycling effort

Author(s) (year)	Dependent variable	Independent policy variables		Data	
	Aggregate or material specific recycling quantities	Unit price	Recycling program attributes[a]	National or regional	Household level
Van Houtven and Morris (1999) [32]	Aggregate (quantity is weight, not volume)	No, but dummy for presence of each of two types of unit pricing program	No	Regional—Marietta, Georgia	Yes
Hong (1999) [7]	Aggregate	Yes	No	National—Korea	Yes
Hong and Adams (1999) [9]	Aggregate	Yes	No	Regional—Portland, Oregon	Yes
Sterner and Bartelings (1999) [26]	By material (community proportion, not quantity recycled)	No	Yes	Regional—Southwest Sweden	No
Kinnaman and Fullerton (2000) [14]	Aggregate	Yes	Yes	National	No
Nestor and Podolsky (1998) [21]	Aggregate	Yes	No	Regional—Marietta, Georgia	Yes
Callan and Thomas (1997) [1]	Aggregate (percent of total waste stream recycled)	No, but dummy for presence of unit pricing program	Yes	Regional—Massachusetts	No
Fullerton and Kinnaman (1996) [4]	Aggregate	Yes	No	Regional—Charlottesville	Yes
Rechovsky and Stone (1994) [23]	By material (proportion, not quantity, recycled)	No, but dummy for presence of unit pricing program	Yes	Regional—upstate NY	Yes

Table 1 (*continued*)

Author(s) (year)	Dependent variable	Independent policy variables		Data	
	Aggregate or material specific recycling quantities	Unit price	Recycling program attributes[a]	National or regional	Household level
Hong et al. (1993) [8]	Aggregate (recycling participation—yes/no)	Yes	No	Regional—Portland	Yes
Saltzman et al. (1993) [24]	By material	No	Yes	Regional—PA and NJ	No

[a] Two frequently studied recycling program attributes are whether it is curbside or drop-off and whether it is voluntary or mandatory.

3. Data description

The primary data source is a recycling survey mailed by Equifax, Inc. in 1992—a year of increasing popularity for unit pricing and soaring popularity for curbside recycling.[5] The survey was mailed to 4600 households residing in 20 US metropolitan areas (please see Table 2 for a list of the 20).[6] The survey was targeted toward middle and upper income households in these regions. Sixty-five percent of questionnaires, 2984, were returned. Households responded to questions about recycling participation, recycling program characteristics, household characteristics, and attitudes. Equifax supplemented the survey with its own data on age, income, education and other characteristics for each household.

From the Equifax data set, we selected only households that reported their communities had an ongoing recycling program ($N = 1939$). Those households who report no recycling program were not asked to report recycling percentages and thus were not eligible for inclusion in our data set. We then appended unit pricing data from three sources. The first is a 1997 report [19] that identifies which US communities had a unit pricing program for solid waste collection in 1992. The second is an EPA survey [30], which collected information regarding the actual unit prices charged in 1992 by many of the unit pricing communities that were then in existence. For those communities not included in the EPA survey, we conducted our own telephone survey of community solid waste officials to solicit information on unit prices and other characteristics of the unit pricing program.

[5] During 1992, the number of curbside recycling programs in the US increased by 10 percent, from just under 4000 to 5404 [27].

[6] These 4600 households were selected using a stratified sampling method from Equifax's 250,000 member Home Testing Institute Panel. For this panel of homes, Equifax has extensive data on socio-economic household characteristics such as income and education. The 4600 households were selected to provide a mix of ages and household income levels representative of the middle and upper middle class populations in these regions.

Table 2
Metropolitan statistical areas sampled

Boston/Hartford Corridor
Detroit
New York Metro (New Jersey side)
Philadelphia
Minneapolis/St. Paul
Atlanta
San Francisco
Phoenix
Houston
Tampa
New York City Metro (New York and Connecticut)
Portland
Camden, New Jersey
Chicago
Seattle
St. Louis
Los Angeles
Dallas-Fort Worth
Miami
Denver

Following our telephone survey, we eliminated 123 additional households living in communities with unit pricing from our data set for various reasons. The most common is that we were unable to contact a government representative who could provide information about the unit pricing program. In other cases, the community had multiple trash haulers and solid waste user fees, and we were unable to connect a particular household to a particular fee level. In addition, we deleted several observations due to missing values.

Finally, to reduce the bias associated with avid recyclers being more likely than others to know about drop-off programs, we retained only those households that reported the availability of curbside collection of at least one of the five materials. Stated differently, we excluded from our sample all households living in communities with only drop-off recycling. The reason is that drop-off programs are notorious for being poorly publicized.

Conversely, curbside programs are well promoted and widely recognized, at least in part because of the visibility of curbside containers on collection day. Where drop-off and curbside programs co-exist, drop-off programs are often jointly promoted with curbside recycling. For example, certain occasions such as the introduction or revision of a curbside program, warrant distribution of instructions for curbside recycling. (Instructions are also distributed to new residents of a neighborhood.) These instructions outline which materials can be placed at the curb and which cannot, and often give instructions for recycling the latter materials at existing drop-off centers.

The extent to which drop-off recycling is promoted alongside curbside recycling varies across communities. Widespread awareness of a curbside program certainly does not guarantee widespread awareness of drop-off centers. To identify communities where residents do have good information about all recycling options, including the less visible drop-off programs, would

Table 3
Unit pricing programs

MSA	Number of communities with unique unit price	Number of observations	Program type
Los Angeles	1	1	Subscription
San Francisco	8	20	Subscription
Chicago	7	10	Bag/tag/sticker
Detroit	1	1	Bag/tag/sticker
Minneapolis/St. Paul	2	2	Subscription
Portland	5	46[a]	Subscription
Philadelphia	1	2	Bag/tag/sticker
Seattle	7	34[b]	Subscription

[a] Of the 46 households living in the Portland MSA, 37 are located in the city of Portland.
[b] Of the 34 households living in the Seattle MSA, 18 are located in the city of Seattle.

require data that was unavailable to us, such as community level information on recycling promotion expenditures. In the absence of such data, however, we can reasonably expect that the bias associated with endogeneity of reporting the existence of a drop-off program will be reduced when we eliminate from our sample those communities with only drop-off recycling.[7] Our final data set consists of 1049 observations.

To examine the reliability of the policy information reported by respondents, we investigated whether respondents living in the same zip code area, the smallest geographical unit for which we had information, reported the same recycling program characteristics. There were many differences. Phone calls to municipalities as well as anecdotal information suggest that recycling programs differ across neighborhoods even within the same zip code. For instance, curbside recycling is often introduced to a region one neighborhood at a time. Gradual introductions might especially affect data for 1992 when many curbside programs had only recently been initiated. Another possibility is that urban parts of a zip code have curbside recycling while rural parts do not.

Of the final 1049 observations, 116 are households facing a positive unit price for solid waste collection.[8] Table 3 identifies the MSAs with unit pricing programs, the number of communities within each MSA with its own unique unit price, and the number of respondents residing in each MSA. The highest concentration of these respondents is in the Portland MSA, within which 37 respondents reside in the city of Portland, and nine respondents reside in four other Portland MSA communities each of which charges a unique unit price. Another concentration is in the Seattle MSA within which 18 respondents reside in the city of Seattle and 16 reside in six other Seattle area communities, each with its own unit price.

The majority of respondents facing a unit price live in western states. Of the 116 households, 104 live in communities with subscription programs where households subscribe to collection of a

[7] We discuss the implications of this concern about bias from avid recyclers for our results in Section 5.
[8] This is consistent with the Miranda and Bynum [17] finding that roughly 10 percent of all US citizens live in communities with unit pricing.

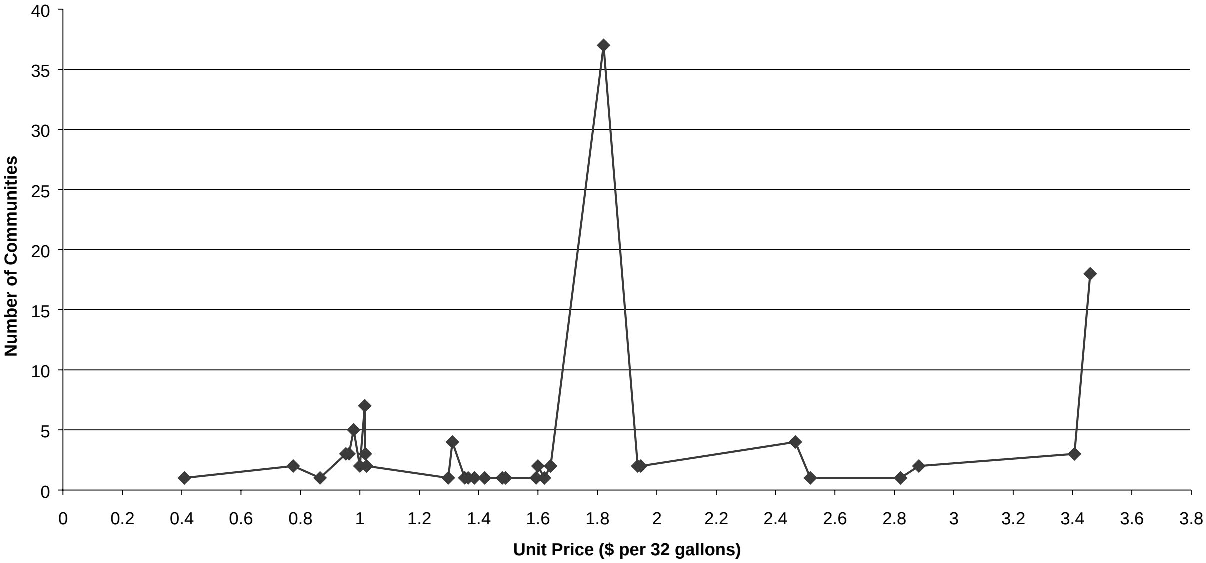

Fig. 1. Distribution of unit prices.

pre-specified number of containers. Households can change that number but the waste collection service must be notified (usually by telephone or mail) of the household's desire to change. This feature combined with weekly variations in trash generation probably leads to partially filled containers during some weeks and to storing excess waste until the next collection day during other weeks. The remaining 12 households live in communities with bag/tag/sticker programs where households place their garbage in specially marked plastic bags, or place specially marked tags or stickers on regular garbage containers, and pay a price for the specially marked items that includes the cost of collection. In these communities, households can more readily alter the number of containers discarded.

We define the marginal price of solid waste collection as the price of the second container of waste. The reason is that households virtually always generate some solid waste, so paying for collection of the first container is difficult to avoid. Not paying for the second container is more likely and can be achieved by increased recycling.[9] Fig. 1 shows the distribution of values for the price of the second container across the 116 households with unit pricing. The values range from \$0.41 to \$3.46. Households in communities with no unit pricing face a zero marginal price for solid waste collection.

Table 4 gives the mean values and standard deviations of the independent variables used in our ordered logit analysis. The first row gives the mean marginal price of solid waste collection, \$1.91 per 32-gallons, faced by the 116 households in communities with unit pricing programs. Two communities have a different price structure for yard waste and the second row of Table 4 gives

[9] Perhaps less easily, households also can avoid paying for the second container by generating less garbage in the first place.

Table 4
Summary statistics for independent variables

Variable	Mean value ($N = 1049$ unless otherwise noted)	Standard deviation ($N = 1049$ unless otherwise noted)
Policy variables		
1. Marginal price of solid waste collection ($ per 32-gallons)[a]	$1.91[b]	$0.86[b]
2. Marginal price of yard waste collection ($ per 32-gallons)[a]	$1.90[b]	$0.86[b]
3. Indicator variable for curbside collection of newspaper	0.916[c]	0.278[c]
4. Indicator variable for curbside collection of glass bottles	0.886[c]	0.318[c]
5. Indicator variable for curbside collection of aluminum	0.853[c]	0.355[c]
6. Indicator variable for curbside collection of plastic bottles	0.775[c]	0.417[c]
7. Indicator variable for curbside collection of yard waste	0.528[c]	0.500[c]
8. Number of materials collected curbside	3.9	1.2
9. Indicator variable for drop-off collection of newspaper	0.056[c]	0.229[c]
10. Indicator variable for drop-off collection of glass bottles	0.071[c]	0.256[c]
11. Indicator variable for drop-off collection of aluminum	0.104[c]	0.305[c]
12. Indicator variable for drop-off collection of plastic bottles	0.127[c]	0.333[c]
13. Indicator variable for drop-off collection of yard waste	0.057[c]	0.232[c]
14. Indicator variable for a mandatory recycling program	0.349	0.477
15. Indicator variable for a recycling program that was between 1 and 2 years old	0.407	0.492
16. Indicator variable for a recycling program that was older than 2 years	0.327	0.469
Socio-economic variables		
17. Population density (thousands of persons per square mile)	5.820	5.923
18. Indicator variable for household income between $10,000 and $14,999	0.068	0.251
19. Indicator variable for household income between $15,000 and $24,999	0.133	0.339
20. Indicator variable for household income between $25,000 and $34,999	0.135	0.342
21. Indicator variable for household income between $35,000 and $49,999	0.208	0.406
22. Indicator variable for household income between $50,000 and $74,999	0.258	0.438
23. Indicator variable for household income of $75,000 or higher	0.140	0.347
24. Household size	2.7	1.4
25. Age of household head	47.9	15.9
26. Indicator variable for a detached house	0.726	0.446
27. Indicator variable for home ownership	0.793	0.405
28. Indicator variable for highest level of education is high school graduate	0.511	0.500
29. Indicator variable for highest level of education is college graduate	0.247	0.431
30. Indicator variable for highest level of education is beyond college	0.195	0.397

[a] In the logit equations, this variable is in dollars per gallon.
[b] Mean is for the 116 households living in communities with unit pricing programs.
[c] Mean is for the observations included in each different material's logit analysis: $N = 1042$ for the newspaper equation; $N = 1033$ for the glass bottles equation; $N = 1012$ for the aluminum equation; $N = 1014$ for the plastic bottles equation; $N = 963$ for the yard waste equation.

the mean marginal price of yard waste collection. Subsequent rows report information on the characteristics of the recycling programs and the socio-economic characteristics of the respondents.

Table 5
Proportions of materials recycled

Material	Percentage and number of respondents recycling 0–10 percent	Percentage and number of respondents recycling 11–95 percent	Percentage and number of respondents recycling over 95 percent	Total	Number missing
Newspaper	8.8%	16.6%	74.6%	100%	
	92	173	777	1042	7
Glass bottles	11.3%	22.2%	66.5%	100%	
	117	229	687	1033	16
Aluminum	15.0%	21.8%	63.2%	100%	
	152	221	639	1012	37
Plastic bottles	17.8%	28.0%	54.2%	100%	
	180	284	550	1014	35
Yard waste	43.3%	22.8%	33.9%	100%	
	417	220	326	963	86

In addition to the data reported here, we created a series of dummy variables that indicate the MSA where each household is located. These variables are used in the regressions to control for unobserved regional effects such as weather and cultural differences.

Comparing a subset of the socio-economic data in Table 4 with 1990 US Census information about the characteristics of the general population in the 20 MSAs from which the sample is drawn, illustrates the effect of targeting middle and upper income households. While the sample has approximately the same household size distribution as the larger population, the sample is more highly educated; 44 percent of respondents graduated from college while only 22 percent of the larger population did. In addition, the sample under-represents the lower income segments of the population and over-represents households with incomes between \$50,000 and \$75,000. However, the median income of the sample is roughly \$40,000 which is only \$5000 above the median income in 1990 for the group of 20 MSAs. The sample also has a higher proportion of detached home dwellers than the population at large. These comparisons make explicit the fact that our results should be generalized only to middle and upper income segments of the population.

We constructed the dependent variable in our analysis using survey responses about recycling participation. Respondents were asked what proportion of the following materials they recycled through all available recycling programs: steel sided cans, glass bottles, plastic bottles, newspaper, magazines, aluminum, other plastics, yard waste and other. As noted already, we chose to study five of these materials and constructed a dependent variable for each of the five. The survey asked whether recycling percentages fell into one of seven possible categories: 0–10, 11–25, 26–50, 51–74, 75–84, 85–95 or over 95 percent. We aggregate the data into three categories of “proportion of the material recycled”—0–10, 11–95, and over 95 percent. Table 5 gives the percent of respondents falling into the three categories for each of the five materials. Except for yard waste, the majority of respondents recycled over 95 percent of each material. Table 5 also gives the number of respondents falling into each category and the number of missing observations for each of the five ordered logit equations.

4. Model specification

The model that we estimate seeks to identify which policy and socio-economic factors influence the level of recycling effort households expend on each recyclable material. We use a latent regression model for ordered data as the framework for estimation. As noted above, for each material type, we define three ordered categories: category 0 for 0–10 percent recycled, category 1 for 11–95 percent recycled and category 2 for over 95 percent recycled. For each material type, j, we consider the relationship

$$y^*_{ji} = \beta'_j x_i + \varepsilon_{ji},$$

where y^* is unobserved level of recycling effort (percentage of material j recycled) and i is an index of households. The vector x_i contains the marginal price, recycling program attributes, and socio-economic features for each household. β is a vector of coefficients to be estimated by maximum likelihood estimation (MLE) in an ordered logit model.[10] Assuming ε_{ji} is distributed standard logistic, the probability that we observe household i in category k, where $k = 0, 1$ or 2, for material j is given by

$$\Pr(y_{ji} = 0) = \frac{1}{1 + e^{\beta'_j x_{ji}}},$$

$$\Pr(y_{ji} = 1) = \frac{1}{1 + e^{-\mu + \beta'_j x_{ji}}} - \frac{1}{1 + e^{\beta'_j x_{ji}}},$$

$$\Pr(y_{ji} = 2) = 1 - \frac{1}{1 + e^{-\mu + \beta'_j x_{ji}}}.$$

5. Results

The intensity of household recycling activities by material is modeled as a function of the socio-economic variables and policy variables that are described in Section 3. We used the same set of independent variables for each material, except that the values for the curbside and drop-off indicator variables varied across materials depending on the type of collection available for the specific material. In addition, the marginal disposal price was different for yard waste.

The results of the econometric estimation of the ordered logit regression for each material are presented in Table 6. These results indicate the significance and direction of each variable's effect

[10] We select the ordered logit specification instead of the ordered probit because the binomial logit is more amenable to incorporating fixed effects than the binomial probit. (see [10]). In the case of a binomial logit or probit, traditional maximum likelihood estimators for the β's will be inconsistent when fixed effects are included in the model. However, the conditional logit model [15] can be used to find consistent parameter estimates for a logit when fixed effects are included. Unfortunately, the consistent estimator of β in a model with fixed effects that is well defined for an binomial logit is not well defined for an ordered logit. Therefore we simply estimate a regular ordered logit with regional metropolitan statistical area dummy variables included. We have also estimated the same model using an ordered probit specification and we find that the results (in terms of which variables are significant and the signs of the effects) are virtually the same.

Table 6
Econometrics results for ordered logit model

	News-paper	Glass bottles	Alu-minum	Plastic bottles	Yard waste
Variable name					
Constant	−3.4140***	−2.1129***	−1.7563***	−2.8715***	−2.6362***
	(0.7327)	(0.6027)	(0.6690)	(0.6885)	(0.6427)
Policy variables					
Drop-off	0.7886*	1.5184***	0.8617**	2.135***	1.1074***
	(0.4594)	(0.4137)	(0.3642)	(0.3984)	(0.1896)
Curbside	1.1423***	2.1026***	1.7808***	2.9083***	1.3111***
	(0.4164)	(0.4733)	(0.3577)	(0.4603)	(0.1896)
Mandatory and curbside	0.2467	−0.0379	0.2041	0.2226	0.1435
	(0.2030)	(0.1070)	(0.1797)	(0.1621)	(0.2037)
Total materials curbside	0.1434*	−0.0917	−0.1172	−0.0831	0.0677
	(0.0772)	(0.0612)	(0.0914)	(0.0790)	(0.0659)
Recycling program is between 1 and 2 years old	0.6111***	0.1668	0.1395	0.3272*	0.2684
	(0.1907)	(0.1312)	(0.1712)	(0.1670)	(0.1821)
Recycling program is over 2 years old	0.5614***	0.1737	0.2146	0.1300	0.4520**
	(0.2091)	(0.1518)	(0.1896)	(0.1745)	(0.2017)
Disposal price	−11.2608	0.1227	−4.7538	1.6401	−4.6836
	(7.8743)	(3.3013)	(6.1760)	(5.0294)	(5.1007)
Socio-economic variables					
Population density	0.0056	0.0000	−0.0083	−0.0044	−0.0511***
	(0.0179)	(0.0106)	(0.0151)	(0.0140)	(0.0188)
Household income between \$10,000 and \$14,999	0.9985**	0.4387	0.9363**	1.2334***	−0.3413
	(0.4170)	(0.2675)	(0.4147)	(0.3784)	(0.4128)
Household income between \$15,000 and \$24,999	0.4590	−0.0654	−0.1214	0.1881	−0.1285
	(0.3506)	(0.1999)	(0.3403)	(0.2809)	(0.3545)
Household income between \$25,000 and \$34,999	0.6408*	0.0380	−0.1043	0.6419**	−0.3247
	(0.3637)	(0.2007)	(0.3483)	(0.2941)	(0.3634)
Household income between \$35,000 and \$49,999	0.8246**	0.0075	0.0772	0.4555	−0.4338
	(0.3575)	(0.1972)	(0.3309)	(0.2807)	(0.3568)
Household income between \$50,000 and \$74,999	1.0418***	0.1268	0.0312	0.4673	−0.1164
	(0.3762)	(0.2112)	(0.3457)	(0.2977)	(0.3651)
Household income over \$75,000	1.2203***	0.0689	0.0915	0.5157	−0.2746
	(0.4277)	(0.2302)	(0.3838)	(0.3260)	(0.3986)
Household size	0.0437	0.0901**	0.0070	0.0717	0.1010*
	(0.0646)	(0.0406)	(0.0543)	(0.0491)	(0.0557)
Age of hh head	0.0175***	0.0049	0.0092*	0.0097**	0.0134**
	(0.0059)	(0.0034)	(0.0053)	(0.0048)	(0.0055)
Single family	−0.0065	0.0710	0.1708	0.4021**	0.7399***
	(0.2068)	(0.1114)	(0.1817)	(0.1694)	(0.1880)
Owner occupied	0.2651	0.3517**	0.3690*	0.2911	0.3779*
	(0.2118)	(0.1433)	(0.1964)	(0.1841)	(0.2165)
Highest education level is high school graduate	1.1600***	0.4879**	1.0557***	0.0862	−0.3421
	(0.3265)	(0.2095)	(0.3112)	(0.2662)	(0.3466)
Highest education level is college graduate	1.2460***	0.4711**	1.0612***	0.0533	−0.4060
	(0.3641)	(0.2251)	(0.3443)	(0.2879)	(0.3828)

Table 6 (*continued*)

	News-paper	Glass bottles	Alu-minum	Plastic bottles	Yard waste
Highest education level is beyond college	1.2520***	0.5269**	0.9415***	0.2480	−0.2598
	(0.3802)	(0.2388)	(0.3531)	(0.3037)	(0.3894)
Number of observations	1042	1033	1012	1014	963
Log likelihood	−693.146	−781.650	−849.992	−867.607	−848.263
Chi^2 statistic	137.609***	196.779***	136.450***	282.917***	357.350***
MSA controls	Yes	Yes	Yes	Yes	Yes
Heteroskedasticity corrected	No	Yes	No	Yes	No

Standard error reported in ( ).

*Significant at 90% level of confidence.

**Significant at 95% level of confidence.

***Significant at 99% level of confidence.

on the propensity to recycle different materials.[11] Because of the non-linear estimation procedure employed, the regression results in Table 6 do not provide a good indicator of the magnitude of the effect. To determine magnitudes, we use the estimated logit model coefficients to calculate the marginal effects of different independent variables on the probability that a typical household will fall into each of the three levels of recycling intensity: 0–10 percent of the material recycled, 11–95 percent recycled or over 95 percent recycled.[12] For the significant policy variables, these marginal effects are reported in Table 7. The table also converts the marginal effect into a percentage change from the actual probability a respondent will fall into a category and reports these percentage changes in parentheses.

The diverse nature of the communities and households represented in our data set led us to question the appropriateness of the standard assumption that all of the disturbance terms in the underlying model have a common variance. In particular, we suspected that the variance of the

[11] To examine the sensitivity of the results to our three-way partition of the dependent variable, we also estimated equations with the dependent variable separated into only two partitions—households who recycle between 0 and 10 percent of a material and those who recycle greater than 10 percent. For the aluminum, plastic bottle and yard waste equations, the significant policy variables remained so. However, for the newspaper equation, the indicator variable for drop-off collection and the variables representing the number of materials picked up curbside and the length of the recycling program became insignificant (although of the same sign) under the binomial specification. For the glass bottles equation, the indicator variables for both curbside collection and drop-off collection changed to insignificant (although of the same sign) under the binomial specification. Some of the socio-economic variables that were significant under the multiple category specification became insignificant under the binomial specification. Overall, the binomial specification gave similar, but somewhat weaker results for the bulk of the materials. (For this sensitivity analysis, we use a binomial logit model with MSA dummy variables instead of a conditional binomial logit model with fixed effects. We do this in order to provide the most straightforward comparison to our ordered logit model with three categories. For the results of a conditional binomial logit model, see footnote 21.)

[12] The equation that predicts the probability that an observation will fall into each of the three categories is non-linear in the independent variables. Therefore, the equation that defines the marginal effects of each independent variable on that probability is a function of all of the independent variables. We calculate marginal effects by using the average value for all of the independent variables except where noted in Table 7.

Table 7
Marginal effects of significant policy variables

	Newspaper	Glass bottles	Aluminum	Plastic bottles	Yard waste
Continuous policy variables					
Total materials curbside					
Recycle 0–10%	−0.0090				
	[−0.1020]				
Recycle 11–95%	−0.0162				
	[−0.0974]				
Recycle over 95%	0.0252				
	[0.0338]				
Indicator policy variables					
Drop-off					
Recycle 0–10%	−0.0932	−0.5467	−0.1900	−0.5291	−0.2696
	[−1.0559]	[−4.8268]	[−1.2647]	[−2.9804]	[−0.6226]
Recycle 11–95%	−0.0923	0.1284	−0.0027	0.1980	0.0743
	[−0.5562]	[0.5791]	[−0.0123]	[0.7069]	[0.3252]
Recycle over 95%	0.1856	0.4183	0.1926	0.3311	0.1953
	[0.2489]	[0.6290]	[0.3051]	[0.6104]	[0.5770]
Curbside (*not mandatory*)					
Recycle 0–10%	−0.1198	−0.6427	−0.3210	−0.6404	−0.3143
	[−1.3567]	[−5.6743]	[−2.1375]	[−3.6075]	[−0.7258]
Recycle 11–95%	−0.1347	−0.0028	−0.0941	0.0987	0.0718
	[−0.8112]	[−0.0126]	[−0.4308]	[0.3525]	[0.3141]
Recycle over 95%	0.2545	0.6455	0.4151	0.5417	0.2425
	[0.3413]	[0.9706]	[0.6574]	[0.9986]	[0.7164]
Drop-off to curbside					
Recycle 0–10%	−0.0266	−0.0960	−0.1311	−0.1113	−0.0446
	[−0.3008]	[−0.8474]	[−0.8728]	[−0.6270]	[−0.1031]
Recycle 11–95%	−0.0423	−0.1312	−0.0914	−0.0993	−0.0025
	[−0.2550]	[−0.5917]	[−0.4185]	[−0.3545]	[−0.0111]
Recycle over 95%	0.0689	0.2271	0.2225	0.2106	0.0472
	[0.0924]	[0.3415]	[0.3524]	[0.3882]	[0.1394]
Program length over 2 years					
Recycle 0–10%	0.0027				−0.0440
	[0.0310]				[−0.1016]
Recycle 11–95%	0.0053				0.0059
	[0.0318]				[0.0258]
Recycle over 95%	−0.0080				0.0381
	[−0.0107]				[0.1125]

Note: Numbers in brackets convert the marginal effect into a percentage change from the average intensity of recycling effort observed in the sample. For total materials curbside, the marginal effect is calculated assuming a one-unit increase in the total number of materials recycled curbside. For binary indicator variables, marginal effects are calculated by solving the model once with the significant indicator variable of interest set at one and all other variables set at their mean value, solving again with the indicator variable of interest set at zero and all other variables set at their means, and then taking the difference. The marginal effect for drop-off (curbside) is calculated with the curbside (drop-off) dummy variable set at zero. The "drop-off to curbside" marginal effect is defined as the difference between the marginal effect of curbside and the marginal effect of drop-off. For program length, the marginal effect gives the difference between having a program in place between 1 and 2 years and having a program for more than 2 years. The sum of marginal effects may not equal zero due to rounding.

disturbance terms surrounding the propensity to recycle could be a function of the presence of curbside recycling and the length of time that the recycling program had been in existence. We hypothesize that the variance of the regression disturbance terms are likely to be different across households that have curbside recycling for the relevant material and those that do not. By eliminating the need to transport recyclables to drop-off points at varying distances from the household, curbside recycling tends to even out the time required to recycle across households resulting in less variation in errors. Likewise, we expect households with greater potential experience with recycling to have disturbance terms with a lower variance than those with less experience with recycling. Greater experience with recycling allows households to develop a recycling habit, which will lead to less variation in the error terms.

Using these variables as determinants in a multiplicative model of heteroskedasticity of the form $\varepsilon_{ji} = \exp(\gamma z_i)$ where the z vector includes the three potential contributors to heteroskedasticity, we tested the ordered logit model for each material for the presence of heteroskedasticity.[13] We found that for two materials, glass and plastic bottles, we could reject the null hypothesis of homoskedasticity. Thus, we apply Harvey's multiplicative heteroskedasticity correction to the models for those two materials [6].

In the next three subsections, we discuss the results for three categories of independent variables: recycling program features, unit pricing policies and socio-economic characteristics. A final section describes potential problems presented by our data and their solutions.

5.1. Recycling program features

This analysis identifies several features of recycling programs that have a significant effect on intensity of household recycling effort. Two features that are always significant are availability of local drop-off recycling and existence of curbside recycling. Increasing the number of total materials included in the curbside recycling program has a positive effect on recycling effort for newspaper only. Length of program life is also an important determinant of the intensity of recycling effort for newspaper and yard waste. The effects of individual program features are discussed in greater detail in the following paragraphs.[14]

The two most commonly significant recycling program policy variables, the drop-off and curbside program indicators, serve as proxy measures of the convenience of recycling. Introducing a local drop-off program for recycling of a particular material decreases the time and storage costs

[13] There are three potential contributors because the amount of time a recycling program has been in place is represented by two categorical indicator variables (see Section 3).

[14] One popular program to encourage recycling of beverage containers is a deposit refund program. During the time period of our data, deposit refund programs existed in 10 states, five of which (New York, Massachusetts, Connecticut, California and Oregon) are sampled by our data set. However, the questionnaire directed respondents to report the percentage of materials recycled but to exclude containers returned for a deposit. Assuming that beverage containers are easy to recycle, a possibility is that excluding these containers from consideration might reduce the percentage of the waste stream that is easily recyclable. Thus, states with bottle bills might be less responsive to recycling incentives. Unfortunately, we are unable to test for this directly in our model without excluding the MSA dummy variables, which would create potential endogeneity problems. However, we did look at the coefficients on the indicator variables for those MSAs that have deposit–refund programs to see if they were systematically different in some way from those for the other regions. For glass bottles we saw no discernable difference. For aluminum cans, most of the coefficients for the MSAs with bottle bills were insignificant.

associated with other modes of recycling such as accumulating materials to haul to more distant recycling centers or participating in infrequent recycling drives for charity. Instituting a curbside recycling program makes recycling even more convenient, thus its effect on recycling effort should be bigger than the effect of a drop-off program. Curbside collection lowers the time and out-of-pocket costs of recycling by completely eliminating the need to transport recyclables to collection points or to store them for long periods of time. The results reported in Tables 6 and 7 conform to these expectations.

The econometric results reported in Table 6 show that for all materials, instituting a local drop-off program has a positive and significant impact on intensity of recycling effort. The marginal effects reported in Table 7 show that the magnitude of the effect of the drop-off program variable varies dramatically across materials. Introducing a local drop-off program increases the probability that over 95 percent of all glass bottles used in the household are recycled by 42 percentage points; for plastic bottles the marginal effect is 33 percentage points and for aluminum and newspapers it is 19. These results suggest that introducing a local recycling option has a smaller impact on materials for which there were recycling options even before the local drop-off program.[15] Charity drives, for example, have traditionally focused on collecting newspapers and/or aluminum. Newspaper carried to (or even purchased at) work may be recycled at work and beverage cans used outside the home may be recycled at the place of use. Adding a local drop-off program is likely to have little impact on this type of recycling behavior.

The different magnitudes also suggest that introducing a local drop-off program has a greater impact on materials for which transportation and storage would be most difficult for households. Without a local program, for materials not collected by special drives or recycled away from home, the household must travel to a distant recycling center. Relative to glass and plastic bottles, newspapers and aluminum (after it has been crushed) are compact and clean and thus more likely to be accumulated and transported long distances. In contrast, storing and transporting glass and plastic bottles is more burdensome to households. Adding a drop-off recycling program reduces households' transportation costs by improving the proximity of recycling centers. Improved proximity might also increase the frequency of drop-offs that would reduce households' storage costs. Thus, it is not surprising that introducing a drop-off program has a bigger impact on glass and plastic bottles than on newspapers and aluminum.

Introducing a local drop-off option for yard waste increases the probability that over 95 percent of it will be recycled by 19 percentage points. While the magnitude of this effect is similar to newspaper and aluminum, it represents a percentage increase above baseline recycling levels similar to that experienced for glass and plastic bottles—approximately 60. (Table 7 presents these percentage increases or semi-elasticities in brackets.) This finding suggests that drop-off recycling has a larger effect on yard waste (a material with high transportation and storage costs) than appears at first glance.

As expected, the presence of curbside recycling has a positive and significant effect on intensity of recycling activity for all five materials. The magnitude of this varies substantially across materials, just as the magnitude of the effect of the drop-off option did. Table 7 shows that introducing a curbside recycling program increases the probability that the average household

[15] This effect might be exaggerated because of a possible over-representation of avid recyclers reporting drop-off programs. Avid recyclers might be more likely to seek out recycling alternatives in the absence of a local program.

recycles over 95 percent of glass and plastic bottles by more than 50 percentage points; aluminum by more than 40 percentage points; and yard waste and newspaper by around 25 percentage points. The interpretation of the differences across materials is similar to that offered for the drop-off program variable. Bulky and potentially messy materials such as glass and plastic bottles are difficult to transport and thus more responsive to the introduction of curbside than are other materials. Also, the small percentage point response of yard waste to curbside recycling actually represents a fairly substantial percentage increase over baseline recycling levels.

Table 7 also shows the marginal effects of replacing an existing drop-off recycling program with a curbside recycling program. The size of the difference is fairly similar for glass bottles, aluminum and plastic bottles. Replacing a drop-off program with a curbside program leads to roughly a 20 percent increase in the probability of recycling over 95 percent of these materials. For newspaper and yard waste, replacing a drop-off program with a curbside program increases the probability of recycling over 95 percent by about 5 percent. This is a small percentage change for newspaper (9 percent) and a slightly larger percentage change for yard waste (14 percent).

Experience with a recycling program has a positive effect on recycling effort for newspaper; for yard waste, experience is significant only once the recycling program has lasted at least 2 years. Table 7 reports the marginal effect of having a program in place for more than 2 years versus having it in place between 1 and 2 years. The magnitudes are quite small. For yard waste, greater experience with recycling programs increases the probability that over 95 percent of it is recycled by less than 5 percent. In the case of newspaper, while program length has a positive effect on recycling effort, the coefficient on the indicator variable for a program of over 2 years in length is smaller than the coefficient on the indicator variable for a program of between 1 and 2 years in length. This means that the marginal effect of going from a program of 1–2 years in length to a program of over 2 years in length is actually negative, but only slightly so. The finding that recycling effort increases with experience is consistent with Reschovsky and Stone [23] which finds that the probability of participating in recycling rises for newspaper, glass, plastic, cardboard, metal and composting when households feel knowledgeable about the recycling program.

Our findings on the effects of other features of curbside recycling programs are mixed. The total number of materials collected curbside has a small, significant, positive effect on the intensity of newspaper recycling. Increasing the number of materials collected curbside by 1 leads to a 2.5 percent increase in the probability that a typical household will recycle over 95 percent of its newspaper waste. Making a curbside recycling program mandatory has no statistically discernable effect on intensity of recycling effort for any of the materials.[16] This finding is congruent with Kinnaman and Fullerton's [14] result that communities in states with mandated recycling do not recycle significantly greater quantities.

[16] This finding could be attributable to a lack of enforcement of a mandatory recycling rule or law. If people perceive that the rule will not be enforced, then they have no incentive to comply. Unfortunately, we were unable to obtain systematic information on the enforcement of mandatory recycling requirements. The information we did locate was unclear about whether enforcement was for a mandatory recycling requirement or for curbside separation rules. Folz [3] reports that the use of enforcement tactics increased from 37 percent of the cities in his sample in 1989 to 55 percent in 1996. The enforcement tactics used are described as refusing to pick up trash, tagging bins with instructions about proper recycling practice or issuing written warnings about improper separation of recyclables from other solid wastes. We conclude that there is evidence that mandatory requirements are sometimes enforced, however, we do not have a clear sense of how often they are enforced.

5.2. Unit pricing policy variables[17]

The econometric results reported in Table 6 indicate that the price of disposal is not a significant determinant of intensity of household recycling effort for any of the materials. This finding suggests that increasing the price of disposal does not increase the intensity of recycling effort. There are several possible explanations why the data reveal no effect.

First, the average price of disposal for the unit-pricing communities in our sample simply may be too low to create a response from our relatively high-income households. The sample's median household income is approximately $40,000 per year, which equates to an hourly wage of roughly $20. At that wage level, if the amount of time associated with recycling 32 gallons of trash is more than 5.75 min then the household will have time costs of recycling that exceed the avoided $1.91 average disposal charge. Thus, as an incentive to recycle, unit pricing is ineffective.

Second, a disposal price provides only an indirect signal to increase recycling, whereas it provides a direct signal to reduce trash. When faced with the prospect of paying a unit price for trash disposal, households may respond by changing their purchasing habits or making other changes in behavior that have a more direct impact on waste disposal. We return to this point in the conclusion of the paper.

Finally, most of the unit pricing programs included in our sample are subscription can programs which provide a discontinuous signal to reduce disposal and therefore may provide only a weak incentive to households to recycle instead of disposing of solid waste [21]. Communities with bag/tag/sticker unit pricing programs may be more responsive to a given price level.

Our finding of no effect of disposal price on recycling efforts is consistent with the findings of earlier studies by Kinnaman and Fullerton [14], Fullerton and Kinnaman [4] and Reschovsky and Stone [23]. All of these earlier studies find that unit pricing does not significantly affect the level of recycling or the probability of participation in recycling programs. However, our findings differ from those of Hong [7], Callan and Thomas [1] and Hong et al. [8]. For a sample of Korean households, Hong [7] finds that a unit price has a significant positive effect on the recycling rate and that the elasticity of recycling with respect to price is approximately 0.5. Callan and Thomas [1] finds that the presence of unit pricing increases the recycling rate by approximately 6.5 percent. Hong et al. [8] indicates that unit pricing increases the probability that households will participate more often in recycling. Van Houtven and Morris [32] finds that the presence of unit pricing positively affects the probability that a household will participate in recycling but has no effect on the quantity of recyclables set out for collection.

5.3. Socio-economic factors

The econometric models also include a number of socio-economic variables describing various characteristics of the households. The statistical significance and size of the effects of these

[17] Initially we set out to identify the effects of the level of the disposal price as well as other unit pricing program characteristics such as program type (bag/tag/sticker, subscription can) on the propensity to recycle. However, due to the small number of observations for bag/tag/sticker communities, we were unable to identify the effects of the type of unit-pricing program on the intensity of household recycling efforts (see Table 3).

variables on intensity of recycling effort vary substantially across materials. Below we discuss those variables that have a statistically significant effect.

Household income has a significant and positive effect on intensity of recycling effort for newspaper only.[18] We can calculate the "marginal" effects of moving from one income category to the next highest income category. For example, we find that for a typical household, moving from the "income between $35,000 and $49,999" category to the "income between $50,000 and $74,999" category leads to a 3.6 percent increase in the probability of recycling over 95 percent of all newspaper waste generated.

The level of education attained by the most highly educated person in the household has a significant but small effect on intensity of recycling effort for all materials except plastic bottles and yard waste.[19] The marginal effects for a typical household of moving from the "high school graduate" category to the "college graduate" category is to increase the probability of recycling over 95 percent of aluminum and newspaper by 0.1 and 1.5 percent, respectively. Curiously, for glass bottles, the level of education has a small negative effect on intensity of recycling effort.

A number of other socio-economic variables also influence the intensity of yard waste recycling efforts. Increasing population density by 1000 persons per square mile leads to a 1.3 percent increase in the probability that a typical household recycles 10 percent or less of its yard waste. A likely reason is a growing scarcity of appropriate outdoor storage space as population becomes denser. Residents of single-family dwellings are substantially more likely to recycle larger quantities of their yard waste than residents of multi-family dwellings. Again, the reason might be a lack of outdoor or indoor storage space. Household size has a significant and positive effect on recycling efforts for glass bottles and yard waste. Increasing the number of occupants of the average household by 1 person leads to a 3 percent increase in the probability that the household will recycle over 95 percent of its glass bottle waste and a 2 percent increase in the probability of recycling over 95 percent of yard waste. This finding may be due to the fact that glass bottle and yard waste recycling are time intensive—bottles must be cleaned, yard waste must be bagged. As the number of occupants rises, the amount of time required from each occupant decreases thereby reducing the implicit cost on any one individual. Finally, age has a positive, but small, impact on intensity of recycling for all materials except glass bottles.

5.4. Data limitations

A perennial problem with survey research is the non-response problem: are there systematic biases introduced into the data by the exclusion of those who failed to respond to the survey? A concern regarding our own data is that bias exists because respondents who are avid recyclers may have been more inclined to mail back the questionnaire. These individuals may recycle

[18] This finding is in harmony with the theoretical results in Saltzman et al. [24]. They suggest that as long as newspaper is a normal good, because its recyclable content cannot be altered by the household, the impact of income on recycled newspaper should always be positive. The impact of income on other recyclable materials will be determined by whether the goods that are the source of the material are normal as well as to what extent the household can reduce the amount of a material associated with a good. For example, the glass content of beverage products can be reduced by switching to plastic or cardboard so that when income increases, glass recycling might decrease.

[19] Recall that the sample is more highly educated than one would expect of a randomly selected sample.

on their own initiative and thus, compared to the general population, be less responsive to recycling incentives. The methods for correcting such bias require information about the characteristics of the questionnaire recipients who did not respond, or, at a minimum, street addresses for those who did not respond.[20] Unfortunately our efforts to obtain that information were futile.

There is another reason why our data might mis-state the response to recycling incentives that would be expected from the general population. Avid recyclers may be better informed than others about the existence of recycling options. This problem is less of a concern for curbside recycling options that are quite visible to the least enthusiastic recyclers. The concern is larger for drop-off recycling options. If avid recyclers are more knowledgeable than other community members about all recycling options, their natural enthusiasm for recycling might make them appear less responsive to a drop-off program. In the absence of a drop-off option, avid recyclers are more likely than others to have already located recycling opportunities outside their own community. Thus, our estimate of the response to drop-off recycling incentives might be biased downward.

However, it might also be biased upward. The general population might be less responsive than avid recyclers to drop-off programs simply because they are less likely to be aware of a program's existence. The net result of these two opposite sources of bias is unclear. Future research could clarify this uncertainty by analyzing all households rather than only households who report awareness of program existence.

Our data set lacks information on community characteristics that might influence the intensity of household recycling effort for all members of a community. Community-level variables such as measures of recycling promotion activities or the general attitude toward environmental issues should be included in our equations because omitting these variables can cause a problem of endogeneity. Of particular concern is that the excluded community level variables might be correlated with the dependent variable, which would result in biased coefficient estimates for the included independent variables. To address these concerns, we test for the significance of regional indicator variables which are included to capture unobserved community-level heterogeneity.[21] The results of *F*-tests suggest that MSA level indicator variables as a group are significant determinants of recycling intensity for each material.

[20] Cameron et al. [2] discuss econometric methods for dealing with non-response bias in mail surveys. Their method uses zip-code-level information for non-respondents combined with data collected from the survey to estimate a pooled-data probit model for response probability.

[21] To examine the sensitivity of the results to the use of an ordered logit-model specification with fixed effects, we estimated a binomial logit model with fixed effects using a conditional maximum-likelihood estimator. For this model we partitioned the dependent variable into two groups—respondents recycling between 0 and 10 percent of a material and those recycling greater than 10 percent. The sign and significance of the policy variables were very similar for all the equations except the one for newspaper. For it, many of the significant policy variables became insignificant under the binomial specification except the curbside indicator variable which remained significant. There were more differences in the sign and significance of the socioeconomic independent variables. In many cases, a variable that was significant under the ordered logit specification was insignificant under the binomial logit specification. The sign changes were only for insignificant variables. Overall, we chose to focus on the ordered logit results because the advantages from the third partition seemed to outweigh the disadvantages of modeling fixed effects with MSA indicator variables.

6. Conclusion and policy implications

This study uses a unique household-level data set, representing primarily middle and upper income households in 20 MSAs across the country, to examine the effect of two popular solid waste programs, curbside recycling and unit pricing, on the percent recycled of five different materials found in the municipal solid waste stream: glass bottles, plastic bottles, aluminum, newspaper, and yard waste. The study also assesses the impact of other attributes of recycling programs (e.g. mandatory or voluntary) along with socio-economic characteristics of households on recycling activity. The results presented here provide new insights that could help policy makers to improve the cost-effectiveness of a community's recycling program and to design a program to achieve mandated recycling rate goals. Consistent with expectations, a curbside recycling program increases households' intensity of recycling and the results differ across recyclable materials. The effect of a unit pricing program, on the other hand, is less clear.

The analysis indicates that drop-off and curbside recycling programs increase households' intensity of recycling for the five materials. The magnitude of the effect of these programs varies dramatically across materials with the largest impacts on glass and plastic bottles. The size of the impact on yard waste recycling effort is also large relative to the average intensity of recycling effort observed in the sample. We conclude that introducing a local recycling option has a smaller impact on materials, such as newspaper and aluminum, for which there were recycling options such as charity drives or workplace or other away-from-home recycling stations even before the local drop-off program.

We further conclude that introducing a local drop-off program has a greater impact on materials such as glass and plastic bottles whose transportation and storage would be most difficult for households. Local governments should take this finding into consideration when selecting which materials to include in a recycling program.

Curbside recycling programs have a bigger effect on behavior than drop-off programs. For three of the materials, a curbside program increases the probability that the average household recycles over 95 percent by approximately 20 percent more than the increase generated by a drop-off program. Nonetheless, drop-off programs also are effective at increasing recycling. A budget-constrained community with no recycling program at all could see measurable waste diversion with the introduction of a less expensive drop-off alternative. Local governments considering implementing curbside recycling could compare the benefits of the expected increase in recycling activity to the incremental costs of implementing curbside as opposed to drop-off recycling.

The impact of unit pricing on the intensity of recycling effort for specific materials is less clear. Unit pricing gives a direct incentive to decrease waste quantities. In response to such a program, households might adjust their consumption towards goods that generate easy-to-recycle wastes, likely those wastes eligible for collection by a local recycling program.[22] These easy-to-recycle wastes increase in quantity; however, the *percentage* of that quantity that is recycled might not change. If unit pricing does increase recycling quantities by shifting consumption toward materials that are collected by a community's recycling program, its impact on recycling will not be detected by examining the percent of a material a household recycles.

[22] Such an adjustment is suggested by Hong [7] which finds that the price elasticity of total waste quantities is positive but the price elasticity of non-recyclable waste quantities is negative.

Our findings indicate that the added convenience created by a recycling program creates a stronger incentive to recycle than having to pay at the margin for trash disposal. Of course, the levels of unit prices charged are important to the impact of the program. The mean fee for our sample was $1.91 per 32-gallon container. At these price levels, collecting more materials at curbside will produce greater waste diversion than will implementing unit-pricing. However, if the costs of adding a particular material to a curbside program exceed the waste diversion and recycling revenue benefits of doing so, then adding materials may not be worthwhile.[23]

Recycling programs appear to become more effective over time. Greater experience with a recycling program leads to increased recycling effort directed at newspapers and yard waste. However, the magnitudes of these effects are quite small. Of interest to policy-makers perhaps is that this effect is not negative; that is, households do not appear to become less enthusiastic over time about participating in recycling.

Of course, which materials to include in a recycling program also depends on the market prices of recyclable materials and on collection and processing costs. For example, our findings suggest that introducing curbside recycling has a big effect on the recycling of plastic bottles, one of the highest valued materials of those we studied.[24] However, collection and transportation costs are also high for plastic bottles due to their low density. Policy makers can combine the insights from this study with information on the material composition of their local waste stream, local collection and transportation costs and current market prices for recyclable plastic to decide if curbside recycling is a cost-effective means of managing plastic waste.

The study suggests several issues for future research. First, due to a lack of variation in our data, we were unable to analyze the differences in responses to the two main approaches to implementing unit pricing for solid waste disposal services: bag/tag/sticker versus subscription can. Van Houtven and Morris [32] and Nestor and Podolsky [21] analyze data from Marietta, Georgia and find that there are differences and that a bag program causes larger reductions in waste quantities than a subscription can program. Future research could explore if the different program types affect recycling of different materials in different ways.

Second, the nature of our data set has limited us to focusing on recycling intensity (percentage of each material type generated by the household that is recycled). However, policy makers and solid waste planners ultimately need more information about how recycling program characteristics and unit prices affect material-specific quantities of both recycling and waste disposal by households. Providing such information requires national household-level data on quantities of materials recycled and discarded.

Third, research into the costs of implementing curbside recycling programs with different scopes compared to the costs of implementing a drop-off program as well as a unit pricing program would be useful to policy makers seeking to design effective and efficient waste management strategies.

[23] One consideration that might change this calculation is if consumers are willing to pay a positive price for curbside recycling programs because of associated reductions in environmental impacts upstream or other perceived environmental benefits. Kinnaman [12] finds that the households included in his survey do exhibit a positive willingness to pay for recycling programs.

[24] The following are average prices recyclers were paying for materials in late January or early February, 2000 in eight urban centers across the country: Aluminum cans—$750 per ton; Natural HDPE (a type of plastic container)—$300 per ton; Newspaper number 8—$70 per ton; Amber glass—$27 per ton [28].

Finally, our data sample is focused on middle and upper income households in urban and suburban areas of the U.S. Therefore, our conclusions are applicable to these types of households. Future research is needed to identify the implications of solid waste and recycling policies for the recycling behavior of lower income households, of households in more rural areas in the US, and of households in other countries.[25]

Acknowledgments

The authors wish to express gratitude to Professor James Abert of Georgetown University for sharing his unique recycling data set with us. They also thank Margaret Walls, Anna Alberini, Jeff Krautkramer and two anonymous referees for helpful comments and suggestions.

References

[1] S.J. Callan, J.M. Thomas, The impact of state and local policies on the recycling effort, Eastern Econom. J. 23 (1997) 411–423.
[2] T.A. Cameron, W.D. Shaw, S.R. Ragland, Nonresponse bias in mail survey data: salience vs. endogenous survey complexity, in: J. Herriges, C.L. Kling (Eds.), Valuing Recreation and the Environment: Revealed Preference Methods in Theory and Practice, Edward Elgar, Cheltenham, UK, 1999.
[3] D.H. Folz, Recycling policy and performance: trends in participation, diversion, and costs, http://web.utk.edu/~dfolz/recycle1.html, accessed January, 2001.
[4] D. Fullerton, T.C. Kinnaman, Household responses to pricing garbage by the bag, Amer. Econom. Rev. 86 (1996) 971–984.
[5] N. Goldstein, C. Madtes, 12th annual biocycle nationwide survey: the state of garbage in America, Biocycle 40 (2000) 40–48,79.
[6] A.C. Harvey, Estimating regression models with multiplicative heteroskedasticity, Econometrica 44 (1976) 461–466.
[7] S. Hong, The effects of unit pricing system upon household solid waste management: the Korean experience, J. Environ. Manage. 57 (1999) 1–10.
[8] S. Hong, R.M. Adams, H.A. Love, An economic analysis of household recycling of solid wastes: the case of Portland, Oregon, J. Environ. Econom. Manage. 25 (1993) 136–146.
[9] S. Hong, R.M. Adams, Household responses to price incentives for recycling: some further evidence, Land Econom. 75 (1999) 505–514.
[10] C. Hsaio, Analysis of Panel Data, Cambridge University Press, Cambridge, UK, 1986.
[11] R.R. Jenkins, The Economics of Solid Waste Reduction, Edward Elgar Publishing Limited, Hants, England, 1993.
[12] T.C. Kinnaman, Explaining the growth in municipal recycling programs: the role of market and non-market factors, J. Public Works Manage. and Policy 5 (2000) 37–51.
[13] T.C. Kinnaman, D. Fullerton, How a fee per-unit garbage affects aggregate recycling in a model with heterogeneous households, in: A.L. Bovenberg, S. Cnossen (Eds.), Public Economics and the Environment in an Imperfect World, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1995.
[14] T.C. Kinnaman, D. Fullerton, Garbage and recycling with endogenous local policy, J. Urban Econom. 48 (2000) 419–442.
[15] D. McFadden, Conditional logit analysis of qualitative choice behavior, in: P. Zarembka (Ed.), Frontiers in Econometrics, Academic Press, New York, 1974.

[25] Hong [7] has analyzed data for Korea, Sterner and Bartelings [26] for Sweden.

[16] M.L. Miranda, J.E. Aldy, Unit pricing of residential municipal solid waste: lessons from nine case study communities, J. Environ. Manage. 52 (1998) 79–93.
[17] M.L. Miranda, D.Z. Bynum, Unit based pricing in the United States: a tally of communities, Report, The United States Environmental Protection Agency, September 1999, submitted.
[18] M.L. Miranda, J.W. Everett, D. Blume, B.A. Roy Jr., Market-based incentives and residential municipal solid waste, J. Policy Anal. Manage. 13 (1994) 681–698.
[19] M.L. Miranda, S. LaPalme, Unit based pricing in the United States: a tally of communities, Available from Nicholas School of the Environment, Duke University, or http://www.epa.gov/economics, 1997.
[20] G. Morris, D. Holthausen, The economics of household solid waste generation and disposal, J. Environ. Econom. Manage. 26 (1994) 215–234.
[21] D.V. Nestor, M.J. Podolsky, Assessing incentive-based environmental policies for reducing household waste disposal, Contemporary Econom. Policy 16 (1998) 401–411.
[22] M.J. Podolsky, M. Spiegel, Municipal waste disposal: unit pricing and recycling opportunities, Public Works Manage. Policy 3 (1998) 27–39.
[23] J.D. Reschovsky, S.E. Stone, Market incentives to encourage household waste recycling: pay for what you throw away, J. Policy Anal. Manage. 13 (1994) 120–139.
[24] C. Saltzman, V.G. Duggal, M.L. Williams, Income and the recycling effort: a maximization problem, Energy Econom. 15 (1993) 33–38.
[25] L.A. Skumatz, Pay as you throw: variable rate incentives in solid waste management, in: Proceedings of Air and Waste Management Association International Symposium, Rochester, New York 1994, pp. 277–288.
[26] T. Sterner, H. Bartelings, Household waste management in a Swedish municipality: determinants of waste disposal, recycling and composting, Environ. Resource Econom. 13 (1999) 473–491.
[27] R. Steuteville, N. Goldstein, The state of garbage in America, BioCycle 34 (1993) 42–50.
[28] J. Truini, Waste news commodity pricing report, Waste News 5 (2000) 30.
[29] US Environmental Protection Agency, Office of Solid Waste, Charging households for waste collection and disposal: the effects of weight or volume-based pricing on solid waste management, EPA/530-SW-90-047, September 1990.
[30] US Environmental Protection Agency, Office of Solid Waste Guide to EPA's unit pricing database: pay-as-you-throw municipal solid waste programs in the US, EPA/230-B-93-002, April 1993.
[31] US Environmental Protection Agency, Office of Solid Waste, Municipal solid waste factbook, Version 4.0, Washington, DC, 1997.
[32] G.L. Van Houtven, G.E. Morris, Household behavior under alternative pay-as-you-throw systems for solid waste disposal, Land Econom. 75 (1999) 515–537.