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Curbside Recycling in the Presence of Alternatives*

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December 2006

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ABSTRACT

We measure the extent to which curbside access affects quantity recycled. We use novel data to distinguish between new recycling and material diverted from other recycling modes. We find that the marginal impact of expanding curbside programs on total recycled quantities is small, in part because curbside programs significantly cannibalize returns from drop-off recycling centers. Failure to account for cannibalization from other modes may substantially over-estimate the benefits of curbside programs. We conclude with simple cost-effectiveness comparisons. Results suggest that incremental expansion of curbside access may not be cost-effective.

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I. Introduction

Americans produce about 375 million tons of municipal solid waste annually, or 1.3 tons per capita. Twenty-five to thirty percent of this material is recycled (Kaufman et al. 2004). These historically high recycling rates have often been attributed to growth in residential curbside access. Indeed, curbside programs have grown from 2,000 in 1990 to over 9,700 in 2000, and over 50 percent of the U.S. population now has curbside access.

Systematic empirical evidence on the impact of curbside programs, however, is rare. In this paper, we measure the extent to which curbside access affects recycled quantities. Importantly, we use novel data to distinguish between new material and material diverted from other recycling modes such as recycling centers. Failure to account for cannibalization from other modes may substantially over-estimate the benefits of curbside programs.

The impact of curbside recycling access on quantities recycled has important policy implications, as curbside programs are both costly and controversial. Curbside collection, transportation, sorting, and processing costs average approximately $2-$7 per household per month. Costs can be considerably higher in suburban and rural areas. These costs have generated debate in many municipalities, and the best available evidence suggests the number of curbside programs fell by nearly nine percent between 2000 and 2002 (Kaufman et al. 2004).[1]

[1] This is the most recent data available. There is no way to conclusively determine whether these numbers represent fewer programs or different data collection techniques. However, five states had very significant reductions. At the very least, it is clear that the growth of curbside programs has slowed dramatically in the recent past.

We investigate the impact of curbside programs in the presence of alternative recycling modes using a panel of aluminum, glass, and plastic beverage container returns data from California's Department of Conservation. These data offer several advantages over the cross-sectional survey data found in most earlier studies. First, our data form the basis for payment disbursement to recyclers and are extremely reliable. Second, we use material specific *quantity* data. While many studies have examined indirect recycling measures such as the average stated propensity to recycle, our data directly measure the quantities of aluminum, glass and plastic recycled. Third, our data covers a wide geographic region over a relatively long time period. The resulting panel structure of the data provides a number of features desirable for econometric identification. For example, curbside programs were adopted locally and progressively introduced over time, so all areas were not affected equally. We are also able to control for unobservable heterogeneity while accounting for potential program endogeneity.

We measure the impact of marginal changes in the level of curbside on the quantity recycled using a fixed-effects panel data approach. For each material, we first examine the effect of curbside program expansion on the quantity of beverage containers returned at the curb. Next, we investigate the effects of curbside programs on the material-specific total amount of beverage containers recycled. After noting clear discrepancies between these first two effects, we consider the extent to which curbside expansion cannibalizes from recycling centers. Finally, we explore this diversion in more detail. In particular, we study the effect of structural and demographic characteristics on the diversion response.

We find four main results. First, *the impact of expanding curbside programs on total beverage containers recycled is small*. Second, much of this result obtains because *curbside programs significantly cannibalize returns from recycling centers*. Third, *the degree of cannibalization varies by material type.* We find that diversion is strongest for heavier and bulkier materials like glass. Fourth, *the degree of cannibalization is sensitive to structural and demographic characteristics.* For example, we find that diversion of glass is particularly pronounced when income is high and unemployment is low.

Of the relatively small number of empirical papers that study recycling, our research is perhaps most closely related to Jenkins et al. (2003)'s important analysis. Their paper used household survey data to demonstrate that the presence of a curbside program for a given material increased the probability that over 95 percent of an average household's material would be recycled by between 25 to 50 percent. Jenkins et al. (2003) further investigated the marginal effect of replacing a recycling center with a curbside program on households' propensity to recycle. Our paper differs in that it investigates the marginal effect of increasing curbside access on observed recycled quantities, controls for program endogeneity, and explores the effect of changes in curbside access on returns to existing recycling centers. This latter distinction is important since curbside programs typically supplement, rather than replace, recycling centers.

Our paper also shares features with Ashenmiller (2006). Ashenmiller (2006) uses a unique individual level dataset from Santa Barbara, CA to assess the impacts of income and education on recycling behavior. The study finds that cash recycling is an important source of income for some poor households. Despite fundamentally different economic questions, our paper and Ashenmiller (2006) both focus on recycling activities in the presence of a bottle bill. Additionally, both studies consider returns by material.

Our research also builds upon a broader empirical literature that examined the change in waste and recycling behavior as a function of policy variables and socio-economic characteristics.[2] Using cross-sectional survey data, Hong *et al.* (1993) and Hong and Adams (1999) found that an increase in waste disposal fees increased curbside recycling participation and quantities recycled, but did not generate large reductions in trash. Rechovsky and Stone (1994) used similar data and found that curbside programs increased total recycling rates if implemented in conjuction with mandatory recycling and unit-based waste pricing. Fullerton and Kinnaman (1996) directly measured household waste generation, and their results suggested that garbage unit pricing increased curbside recycling, volumetric compacting, and illegal dumping significantly. Callan and Thomas (1997) and Kinnaman and Fullerton (2000) used geographically diverse cross-sectional community level data and further examined the effects of unit pricing and recycling. An important contribution of Kinnaman and Fullerton (2000) was illustrating the potential endogeneity of curbside program implementation. Finally, Ando and Gosselin (2005) made clear the importance of storage and distance to recycling facilities in a household's recycling decision.

This paper proceeds as follows. Section II reviews the institutional context and describes our data from the California Department of Conservation. Section III presents our conceptual framework and our empirical methodology. Section IV presents our key results and their sensitivity. We first establish that incremental expansion of curbside

[2] See Walls and Palmer (1997) and Palmer, Sigman, and Walls (1997) for excellent examples of the related analytical literature. Choe and Fraser (1998) provides a nice overview.

access has a very small effect on material-specific total beverage containers recycled. Next, we demonstrate that this result largely obtains due to diversion from existing recycling streams. We then explore how various structural characteristics impact this diversion. Section V interprets our results for economics and policy. We conclude with simple cost effectiveness comparisons that incorporate the paper's empirical results. Results suggest that saved household time costs would need to be large for incremental expansion of curbside access to be cost-effective.

II. Institutional Context & Data

The Data Generating Process

The Resource Conservation and Recovery Act (RCRA) of 1976 and its amendments govern the federal management of waste. With few exceptions, RCRA delegated household waste management regulations to state and local governments. California, the setting for the empirical case study that follows, primarily regulates municipal solid waste and recycling with its Integrated Waste Management Act (AB939, SB1322). The Act's most critical provisions were its diversion mandates. These directives required cities and counties to redirect 25 percent of landfill material by 1995 and 50 percent by 2000 (relative to 1990 levels).

Like many other states and Canadian provinces, California achieves part of its overall waste management goals with beverage container legislation.[3] Beverage containers represent a significant portion of municipal solid waste (MSW) streams and recycling returns. For the US as a whole, beer and soft drink cans represent 78 percent of aluminum MSW and 95 percent of aluminum recovery. Beer and soft drink bottles

[3] CA, CT, DE, HI, IA, ME, MA, MI, NY, OR, and VT currently have beverage container legislation. Collectively, these states represent approximately 30 percent of the United States' population. Further, AR, IL, TN, and WV have bottle bill campaigns.

represent 52 percent of glass MSW and 53 percent of glass recovery. Soft drink bottles represent approximately 44 percent of PET (polyethylene terephthalate) plastics, but the overall recovery of all plastics is small (~5 percent) (USEPA 2002).

In California, the Beverage Container Recycling and Litter Reduction Act (AB2020) endeavored to achieve an 80 percent recycling rate for all aluminum, glass, and plastic beverage containers covered by the Act. Initially, eligible containers included beer, wine coolers, and soda bottles and cans. In 2000, containers holding non-carbonated beverages like water, fruit juice, coffee, and sports drinks were added to the program.[4] To encourage recycling and to discourage litter, AB2020 established a deposit/refund system to be managed by the state's Department of Conservation. Under this system, distributors send redemption payments to the state, pass these costs on to retailers and consumers, and consumers may then redeem their California Redemption Value (CRV)[5] at a certified recycling center.[6]

The administration of AB2020's deposit/refund system generated key portions of our unique dataset. Most notably, we have aluminum, glass, and plastic beverage container return quantities for each of the state's recycling centers. Since these data were used to reimburse the centers for CRV redemption values paid to consumers, they are very accurate. California's Department of Conservation, Division of Recycling also tracks the locations and characteristics of the recycling centers. AB2020 required that a redemption center exist within ½ mile of any supermarket with over $2 million in gross

[4] This expansion, SB332, was passed in 1999 but implemented in 2000.
[5] CRV is based upon weight, but payments are calibrated to be equivalent to payments based upon container counts. During our entire sample period, the CRV amounted to 2.5 cents for smaller containers and 5 cents for larger containers. The CRV has since been increased to 4/8 cents.
[6] For a more complete description of AB2020 and an analysis of its impacts on recycling and the California economy, see Berck et al. (2003). That study also examined the effect of CRV rates on recycling returns.

annual sales, and there are over 2,000 operational drop-off recycling centers.[7] In our context, drop-off recycling centers include both supermarket and non-supermarket locations. Since these centers are independent businesses, they vary in hours of operation and other characteristics.

California's Department of Conservation (DOC) also tracks curbside beverage container program characteristics and quantities returned at the curb. Precise beverage container curbside quantities are estimates based upon extensive sampling by the DOC.[8] Curbside programs can vary considerably. Some curbside programs only accept limited material types, some require material sorting, and a small number are coupled with mandatory recycling. Even for beverage containers, materials recycled at the curb do not generate refund payments for households.

Our Sample

Our sample of California Department of Conservation recycling data consists of quarterly observations for the six year period 1995-2000. Time series variation in our data allows us to exploit panel techniques to control for unobserved heterogeneity while accounting for potential program endogeneity. This particular period is promising for exploration because curbside programs were expanding, there were no major changes to the bottle bill or its associated redemption values, and data were readily available. For confidentiality purposes, all data is aggregated to the county level.

We exclude the 14 California counties with incomplete data or no curbside recycling during our sample period. The omitted counties are considerably more rural than included counties. As a consequence, the results of our analysis should be

[7] Exemptions from this mandate are possible, but relatively rare.
[8] In the econometrics that follow, the inclusion of county-level fixed effects prevents bias if the quality of this estimation systematically varies by county.

extrapolated to predominantly rural areas with a degree of caution.[9] The resulting dataset consists of 1052 observations; we observe 44 counties over the 24 quarters between 1995(1) and 2000(4) with 4 missing data points.

Table 1 presents descriptive statistics. For each variable of interest, we report the mean and standard deviation for the first sample year, the last sample year, and the entire sample.

Table 1. Summary Statistics

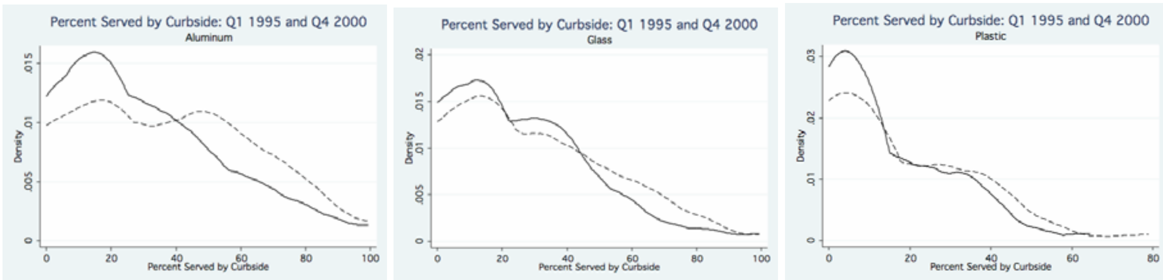
	1995		2000		Entire Sample	
	Mean	Std. Dev	Mean	Srd. Dev.	Mean	Std. Dev.
Per Capital Lbs. of Beverage Containers Sold						
Statewide Aluminum Containers Sold	2.5935	0.3305	2.3913	0.3130	2.4640	0.3312
Statewide Glass Containers Sold	9.7454	0.9174	13.6305	1.6412	11.0834	1.8079
Statewide Plastic Containers Sold	0.8610	0.1859	3.3211	0.5316	1.3788	0.9041
Aluminum (AL) Beverage Container Returns						
Per Capita Lbs. of AL Returned – Curbside	0.0695	0.0754	0.1052	0.1017	0.0789	0.0839
Per Capita Lbs. of AL Returned – Total	2.3009	0.6343	2.0300	0.6150	2.1238	0.6151
Per Capita Lbs. of AL Returned – Drop-Off	2.2314	0.6771	1.9248	0.6674	2.0449	0.6567
Glass Beverage Container Returns						
Per Capita Lbs. of Glass Returned – Curbside	1.1985	1.3642	1.9189	2.0977	1.3261	1.5291
Per Capita Lbs. of Glass Returned – Total	5.8295	2.5269	6.7788	3.0400	5.8393	2.6526
Per Capita Lbs. of Glass Returned – Drop-Off	4.6309	1.9670	4.8599	2.1111	4.5132	1.9866
Plastic Beverage Container Returns						
Per Capita Lbs. of Plastic Returned – Curbside	0.0723	0.0706	0.2174	0.1971	0.1099	0.1213
Per Capita Lbs. of Plastic Returned – Total	0.3437	0.1403	0.6494	0.2705	0.4626	0.2025
Per Capita Lbs. of Plastic Returned – Drop-Off	0.2714	0.1324	0.4320	0.2471	0.3527	0.1830
Curbside Access						
Percent of Pop. with Curbside Access – AL	27.7986	26.5420	34.7741	28.3421	31.5966	27.6271
Percent of Pop. with Curbside Access – Glass	22.9945	23.3447	26.8972	25.3531	25.5091	24.5298
Percent of Pop. with Curbside Access – Plastic	13.0128	15.8300	16.1966	18.6621	14.9827	17.4929
Recycling Center Characteristics						
Recycling Centers per unit Area	0.0303	0.0523	0.0279	0.0464	0.0292	0.0496
Recycling Centers: Average # of Hours Open	39.2975	6.5706	38.4767	5.5229	39.3006	5.9530
Recycling Centers: Std. Dev. of Hours Open	11.9717	8.5248	11.7373	7.5636	11.6598	7.9592

[9] See Jakus et al. (1996, 1997) for a discussion of recycling determinants in rural communities.

The summary statistics in Table 1 indicate that total sales of glass and plastic beverage containers increased over the sample. Sales of aluminum beverage containers fell. Curbside beverage container quantity returns increased substantially for aluminum, glass, and plastic, but overall material-specific beverage containers recycled increased only moderately for glass and plastic and fell for aluminum. Returns to recycling centers increased for both glass and plastic, but fell for aluminum. Aggregate changes in recycled quantities are unlikely attributable to changes in recycling center characteristics, as these remained relatively constant over the period.

Summary statistics in Table 1 also indicate that the availability of curbside recycling increased over the sample period. In 1995, on average, 28, 22, and 13 percent of the population of each county had access to curbside recycling for aluminum, glass, and plastic beverage containers, respectively. By 2000, the average percent of the population served by curbside had increased to 35, 27, and 16 percent, respectively. Since the penetration of curbside programs is central to the ensuing analysis, we explore curbside access in more detail in Figure 1. The kernel density estimates in the figure, intuitively speaking, are non-parametrically smoothed histograms of curbside penetration for the first and last quarters of our sample. The key thing to note is the rightward shift in each density, indicating that curbside availability was notably higher in 2000(4) than 1995(1). Figure 1 also shows that curbside programs were heterogeneously implemented across time, county, and materials.

Figure 1. Kernel Density Estimates:
Percent of the Population Served by Curbside Programs



Solid lines represent the density estimates for quarter 1 of 1995. Dashed lines represent the density estimates for quarter 4 of 2000. The figures indicate that there is heterogeneity in curbside program implementation across counties, time, and materials. Across all materials, curbside implementation was higher at the end of our sample.

Observed variation in the materials collected by curbside programs is consistent with evidence for the United States as a whole (USEPA 1994). In particular, plastic recycling is rare relative to aluminum and glass, as plastic has a high volume-to-weight ratio (McCarthy 1993). In our sample, an average of 50.5 percent of the population of each county with access to curbside recycling was able to return aluminum, glass, and plastic beverage containers at the curb. 27.7 percent was able to curbside recycle only aluminum and glass, 18.6 percent was able to curbside recycle only aluminum, and 3.2 percent was able to curbside recycle only aluminum and plastic.

III. Analysis
Conceptual framework

In this sub-section, we construct a conceptual framework for empirically analyzing disposal decisions in the presence of multiple recycling modes. The purpose of this simple framework is to motivate empirical specification and variable choice. The framework shares features of the models in Kinnaman and Fullerton (2000) and Jenkins et al. (2003), but differs by emphasizing choices between recycling modes.

Consider a representative consumer. In a first stage allocation decision, the agent maximizes a weakly separable utility function over the consumption of beverages, other goods, and waste disposal services. Optimization is subject to a time/money budget constraint. The solution to this first stage problem yields waste disposal service expenditures W and material-specific beverage container expenditures E_i. Assuming fixed prices, E_i implies beverage container quantities B_i.

Assume that B_i and W are exogenous to a second stage within-group optimization over the choice of *disposal method.* For each material type *i,* total beverage quantities B_i can be recycled at the curb (CS_i), recycled at drop-off recycling centers (RC_i), or not recycled (NR_i). The latter option incorporates trash, illegal dumping, etc. Preferences among disposal methods may depend upon household characteristics α. In this framework, subutility is maximized over disposal methods subject to a subgroup expenditure constraint and a quantity adding up constraint:

$$\text{(1)} \qquad \max u_i(CS_i, RC_i, NR_i; \alpha) \quad s.t. \quad \begin{array}{l} p_{CS_i} \bullet CS + p_{RC_i} \bullet RC + p_{NR_i} \bullet NR \leq W \\ CS_i + RC_i + NR_i = B_i \end{array}$$

Solving the representative consumer's choice problem (1) yields a system of estimable conditional demands for each material *i*:[10]

$$\text{(2)} \qquad \begin{aligned} CS_i &= f(p_{CS_i}, p_{RC_i}, p_{NR_i}, B_i, W, \alpha) \\ RC_i &= f(p_{CS_i}, p_{RC_i}, p_{NR_i}, B_i, W, \alpha) \\ NR_i &= f(p_{CS_i}, p_{RC_i}, p_{NR_i}, B_i, W, \alpha) \end{aligned}$$

[10] It is also possible that recycling of one material may depend on the price of curbside for other materials. In this conceptual framework, each material-specific equation would be augmented with $p_{CS,j\neq i}$. We explore this spillover effect in the sensitivity analysis.

A reduced-form version of the system of equations in (2) serves as the basis for our empirical estimation. Since we do not have data on non-recycled beverage containers, we follow Kinnaman and Fullerton (2000) and estimate each material-specific system as a series of demand equations. Since the independent variables in each equation are the same, there is no bias from estimating the system as separate equations.

As noted in Section II, our data are collected at the county-level. As with all economic analyses not performed at an individual level, aggregation consistent with economic theory implies strong restrictions on the structure of preferences. In particular, individual utility must follow the Gorman form and the marginal propensity to recycle must be independent of income within a given county.[11]

Variables

To examine the impact of curbside recycling on quantities returned at the curb, total recycling quantities, and recycling center quantities, we construct variables consistent with the conceptual framework developed above. Our key dependent variables are material-specific per capita recycled quantities of beverage containers. For example, we consider per capita pounds of aluminum beverage containers recycled at the curb, recycled in total, and recycled at drop-off recycling centers.

Important explanatory variables include those that represent the time and money prices of recycling modes in (2). In this vein, the key explanatory variable is the percent of a county's population served by curbside programs. This serves as a proxy for the price of curbside recycling. We also include recycling centers per square mile and two measures of recycling center hours open as proxies for the price of drop-off recycling

[11] When income enters the econometrics that follow, it enters linearly. This is consistent with a constant marginal propensity to recycle. Here, aggregation also requires linearity in price.

centers. The California Redemption Value (CRV) refund, while naturally a large part of drop-off recycling center price, remains constant across space and time is therefore relegated to the regression constant.[12]

Other independent variables include total quarterly per capita consumption of each material at the state-level, since our conceptual framework indicates that quantities recycled are a function of total beverages consumed. County-level data is not available, so we augment statewide beverage sales with county-specific average temperature (a well known predictor of packaged beverage consumption).[13] We also include quarterly dummies and year dummies to account for seasonality and broad trends in the real price of beverages, beverage consumption, and the propensity to recycle.

Finally, we exploit the panel structure of the data by including fixed effects. This captures systematic differences across counties and serves as a proxy for α in our conceptual framework. Fixed-effects may represent county-specific factors such as size, location, density, and demographic characteristics like education and income.

Regression Model

We ask three questions. First, to what extent does increasing the share of the population with access to curbside recycling increase the quantity of beverage containers recycled at the curb? Second, to what extent does increasing the share of the population served by curbside programs increase the total quantity of beverage containers recycled? Third, to what extent does increasing the share of the population served by curbside programs cannibalize beverage container returns from other recycling modes?

[12] The price of non-recycling may be a function of unit pricing for trash and/or penalties for illegal disposal. Where credible data exists, we explore these issues in the sensitivity analysis section.
[13] Climate data are from the National Oceanic and Atmospheric Administration's Climatic Data Center.

Operationally, we regress material-specific beverage container returns on the share of the population served by curbside programs. A natural concern is that our policy variables may be statistically endogenous. For example, counties with curbside recycling programs that on average succeed in bringing back large quantities of material may seek to expand their use. Alternatively, perhaps counties with low total recycling on average may be particularly motivated to expand curbside access. However, the included county-level fixed effects prevent bias from this type of statistical endogeneity.[14] An important implication is that identification comes from within-county time variation rather than variation between counties.

In short, the basic regression model for each material can be written $y_{it} = \mathbf{X}_{it}\boldsymbol{\beta} + \alpha_i + \varepsilon_{it}$, where *i* indexes the unit of observation (county) and *t* indexes time (quarters). α_i captures time invariant county-level fixed effects and ε_{it} represents the usual idiosyncratic error term. The columns of the matrix **X** include all of the preceding sub-section's explanatory variables. As previously noted, the most important of these is the share of a county's population served by curbside in that period.

The regression model has three noteworthy features. First, the dependent variables are material-specific. This is important because materials vary considerably by weight and bulk, which affect the ease of recycling. Further, policy decisions are frequently material-specific, as many curbside programs are limited to a subset of container types. Second, the dependent variables measure beverage container recycling quantities. The advantage of quantity data is that they match conceptual conditional demand models more directly than often-cited measures such as propensity to recycle. Third, the

[14] It is also possible that there is statistical endogeneity in a time variant fashion. However, this seems less plausible since it is unlikely that counties observe returns and very rapidly adjust curbside access.

endogeneity controls afforded by the fixed effects α_i are novel relative to the previously cited literature.

IV. Empirical Results
What is the Effect of Curbside Access on Curbside Returns?

We begin by considering the most immediate impact of curbside access: to what extent does increasing curbside coverage increase the quantity of material recycled at the curb? While the related theoretical results are unambiguous, the empirical evidence on this question remains surprisingly equivocal. For example, Reschovsky and Stone (1994) fail to reject the hypothesis that curbside recycling programs alone do not yield an increase in the propensity to recycle.

Results from fixed-effects linear regressions of curbside beverage container return quantities on the percent of the population served by curbside programs and other covariates are presented in Table 2. Computed standard errors are heteroskedastic-consistent. T-statistics appear in parentheses.

Table 2. Regression Results: Quantity Recycled at the Curb

Variable Description	Aluminum	Glass	Plastic
Percent of the Population Served by Curbside	0.0014***	0.0198***	0.0028***
	(3.72)	(4.14)	(4.09)
Number of Recycling Centers per area	-0.3975	-8.6955***	-1.9540***
	(-1.13)	(-3.13)	(-4.02)
County average number of Recycling Centers hours open	0.0014**	0.0187***	0.0003
	(2.42)	(3.21)	(0.32)
Standard Deviation of Recycling Centers hours open	-0.0007**	-0.0084**	-0.0012*
	(-2.01)	(-2.23)	(-1.87)
Average Temperature	0.0001	-0.0006	-0.0002***
	(0.37)	(1.33)	(-2.65)
Second Quarter Dummy	-0.0300*	0.0856	0.0184*
	(-1.87)	(0.66)	(1.91)
Third Quarter Dummy	-0.015	0.181	0.0522***
	(-0.88)	(1.06)	(3.11)
Fourth Quarter Dummy	-0.0029	-0.0054	0.0196**
	(-0.57)	(-0.06)	(2.48)
1996 Year Dummy	-0.0041	-0.0626	-0.0032
	(-1.29)	(-1.22)	(-0.57)
1997 Year Dummy	0.0018	-0.1142*	0.0044
	(0.41)	(-1.78)	(0.69)
1998 Year Dummy	0.0035	-0.1592**	0.0003
	(0.61)	(-2.43)	(0.05)
1999 Year Dummy	0.0168**	-0.0093	0.0212***
	(2.23)	(-0.11)	(3.25)
2000 Year Dummy	0.0342***	0.5580***	0.0643
	(4.71)	(2.81)	(1.26)
Per Capita Total Quantity Sold (Statewide)	0.0431**	0.0191	0.0269
	(2.14)	(0.39)	(1.34)
Constant	-0.0862	1.1723*	0.2721***
	(-1.22)	(1.94)	(4.2)
Fixed Effects		43 County-Specific Fixed Effects	
R-squared	0.73	0.93	0.72

[a] The dependent variables are the quantities returned to curbside programs for the listed materials.
[b] Superscripts ***,**, and * indicate statistical significance at the 1% , 5%, and 10% levels of significance.
[c] Each county-level analysis consists of 1,052 observations from 44 counties over the 24 sample quarters.

Results in Table 2 indicate that the estimated impact of increasing curbside access on curbside beverage container returns is positive and statistically significant for all materials. For example, a one percent increase in the percent of a county's population served by curbside results in a 0.0014, 0.0198, and 0.0028 pounds per capita increase in the quantity of aluminum, glass, and plastic beverage containers collected at the curb. For aluminum, this coefficient translates into 1.77 percent of mean curbside quantity. In other words, a one percent increase in the percent of the population served by aluminum curbside programs translates roughly into a 1.77 percent increase in returns of aluminum beverage containers to the curb. For glass, a one percent increase in the population served by glass curbside programs yields a 1.49 percent increase in mean curbside quantity. For plastic, the coefficient translates into a 2.55 percent increase. It is important to note that all results should be interpreted as changes on the margin, conditional on average county-level institutions and covariates.

Increasing the number of recycling centers per area has a negative and significant effect on curbside returns for both glass and plastic beverage containers. This intuitive result provides some preliminary evidence that curbside and recycling center programs may be substitutes. Similarly, an increase in the variability of hours open is significantly negatively associated with aluminum, glass, and plastic curbside returns. However, an increase in the average number of drop-off center hours open is positively associated with curbside returns for aluminum and glass. Perhaps center hours induce spillover effects from increased recycling awareness.

All other explanatory variables have the anticipated signs. Increases in total beverage container sales are associated with increased curbside quantities, and significantly so for aluminum. Curbside returns are seasonal and tend to increase over time for all materials, although non-linearly.

What is the Effect of Curbside Access on Total Recycling Returns?

We now consider the impact of curbside access on total recycling returns. Results of the preceding sub-section indicated that, on the margin, increased curbside access is associated with increased beverage container returns at the curb. However, for policymakers a more relevant question is whether curbside programs increase *total* beverage container recycling.

Results from fixed-effects linear regressions of total beverage container return quantities on the percent of the population served by curbside programs and other covariates are presented in Table 3. Again, computed standard errors are heteroskedastic-consistent and t-statistics appear in parentheses.

Table 3. Regression Results: Quantity Recycled in Total

Variable Description	Aluminum	Glass	Plastic
Percent of the Population Served by	0.0014	0.0044	0.0022***
Curbside	(1.18)	(0.89)	(2.81)
Number of Recycling Centers per	3.4053***	29.2705***	0.3243
area	(2.92)	(5.33)	(0.53)
County average number of Recycling	0.0003	0.0527***	0.0049**
Centers hours open	(0.06)	(3.97)	(2.25)
Standard Deviation of of Recycling	0.0039	-0.0168	-0.0017
Centers hours open	(0.84)	(-1.53)	(-0.94)
Average Temperature	0.0015***	-0.0005	-0.0001
	(6.65)	(-0.64)	(-0.85)
Second Quarter Dummy	-0.1048	0.222	0.0274*
	(-1.3)	(0.99)	(1.85)
Third Quarter Dummy	0.0716	0.7679***	0.0933***
	(0.9)	(2.86)	(3.85)
Fourth Quarter Dummy	0.0529*	0.0553	0.0609***
	(1.88)	(0.37)	(5.45)
1996 Year Dummy	-0.1249***	-0.2364**	0.0448***
	(-5.11)	(-2.4)	(4.59)
1997 Year Dummy	-0.1423***	-0.3863***	0.0727***
	(-5.27)	(-3.32)	(7.26)
1998 Year Dummy	-0.1913***	-0.5212***	0.0726***
	(-5.59)	(-4.43)	(6.76)
1999 Year Dummy	-0.1758***	-0.2138	0.1020***
	(-4.87)	(-1.4)	(9.32)
2000 Year Dummy	-0.2236***	0.6085*	-0.0264
	(-5.77)	(1.79)	(-0.39)
Per Capita Total Quantity Sold	0.2021**	0.111	0.1337***
(Statewide)	(1.99)	(1.43)	(5.18)
Constant	0.0498	4.3294***	0.0569
	(0.17)	(4.71)	(0.59)
Fixed Effects		43 County-Specific Fixed Effects	
R-squared	0.88	0.92	0.76

[a] The dependent variables are the total quantities recycled for the listed materials.
[b] Superscripts ***,**, and * indicate statistical significance at the 1% , 5%, and 10% levels of significance.
[c] Each county-level analysis consists of 1,052 observations from 44 counties over the 24 sample quarters.

Results in Table 3 indicate that the estimated impact of increasing curbside access on total beverage container returns is positive, but small. In fact, for aluminum and glass beverage containers, we cannot reject a null hypothesis of no relationship between increased curbside access and total returns. For plastic, the coefficient translates into 0.48

percent of mean total quantity. In other words, a one percent increase in the percent of the population served by plastic curbside programs translates roughly into a 0.48 percent increase in total returns of plastic beverage containers. While the aluminum and glass coefficients are not statistically different from zero, we note that the coefficients translate into 0.07 and 0.08 percent increases in total returns, respectively.

In contrast to the results for a marginal expansion of curbside, Table 3 indicates that the effects of recycling center characteristics on total recycling are substantial. For example, recycled quantities increase significantly with the average number of open hours for both glass and plastic beverage containers. Further, increasing the density of recycling centers has a large and significant impact on aluminum and glass returns.

What is the Effect of Curbside Access on Recycling Center Returns?

Taken together, the results presented in Tables 2 and 3 are initially puzzling. Table 2 indicates that increases in curbside availability are associated with increases in quantities recycled at the curb. However, Table 3 indicates that increases in curbside availability are not associated with increases in total recycling for aluminum and glass. Further, marginal increases in total recycling for plastic are modest relative to the marginal increases in curbside returns. If greater curbside access increases returns at the curb, but not in total, perhaps curbside programs are diverting recycling from other alternatives on the margin.

Results from fixed-effect linear regressions of *recycling center* beverage container return quantities on the percent of the population served by curbside programs and other covariates are presented in Table 4. Computed standard errors are heteroskedastic-consistent and t-statistics appear in parentheses.

Table 4. Regression Results: Quantity Recycled at Recycling Centers

Variable Description	Aluminum	Glass	Plastic
Percent of the Population Served by Curbside	0.0001	-0.0154***	-0.0006
	(0.01)	(-3.3)	(-1.01)
Number of Recycling Centers per area	3.8028***	37.9660***	2.2783***
	(3.37)	(7.77)	(4.06)
County average number of Recycling Centers hours open	-0.0011	0.0340***	0.0047**
	(-0.21)	(2.87)	(2.58)
Standard Deviation of of Recycling Centers hours open	0.0046	-0.0084	-0.0006
	(1.02)	(-0.8)	(-0.37)
Average Temperature	0.0015***	0.0001	0.0001
	(6.89)	(0.18)	(1.17)
Second Quarter Dummy	-0.0748	0.1364	0.009
	(-0.96)	(0.73)	(0.7)
Third Quarter Dummy	0.0865	0.5869***	0.0411**
	(1.13)	(2.63)	(2.08)
Fourth Quarter Dummy	0.0558**	0.0606	0.0413***
	(2.05)	(0.49)	(4.59)
1996 Year Dummy	-0.1208***	-0.1738**	0.0480***
	(-4.98)	(-2.17)	(5.56)
1997 Year Dummy	-0.1442***	-0.2720***	0.0683***
	(-5.42)	(-2.84)	(7.79)
1998 Year Dummy	-0.1947***	-0.3620***	0.0723***
	(-5.81)	(-3.73)	(7.71)
1999 Year Dummy	-0.1927***	-0.2045	0.0808***
	(-5.5)	(-1.65)	(8.49)
2000 Year Dummy	-0.2579***	0.0504	-0.0906*
	(-6.85)	(0.19)	(-1.78)
Per Capita Total Quantity Sold (Statewide)	0.1589	0.0919	0.1068***
	(1.61)	(1.46)	(5.36)
Constant	0.136	3.1571***	-0.2151***
	(0.49)	(3.97)	(-2.63)
Fixed Effects		43 County-Specific Fixed Effects	
R-squared	0.90	0.90	0.80

[a] The dependent variables are the quantities returned to recycling centers for the listed materials.
[b] Superscripts ***,**, and * indicate statistical significance at the 1% , 5%, and 10% levels of significance.
[c] Each county-level analysis consists of 1,052 observations from 44 counties over the 24 sample quarters.

Results in Table 4 indicate that the estimated impact of expanding curbside access on drop-off recycling center returns is negative for glass and plastic beverage containers. Results are economically and statistically significant for glass, and perhaps economically significant for plastic. For glass, the coefficient translates into 0.34 percent of total recycling center return quantity. In other words, a one percent increase in the percent of the population served by glass curbside programs translates roughly into a 0.34 percent decrease in returns of glass beverage containers to recycling centers. For plastic, a one percent increase in the percent of the population with plastic curbside access translates into a 0.17 percent decrease in plastic recycling center returns.

Note also that the collective outcomes of Tables 2-4 satisfy an important adding-up identity. For each material, the marginal total impact of expanded curbside access is equal to the marginal increase in curbside returns less any marginal diversion from drop-off recycling centers. For glass, the 0.0044 pounds per capita increase in total recycling equals the 0.0198 pounds per capita increase at the curb less the 0.0154 pounds per capita diversion from recycling centers. Similarly, the 0.0022 pounds per capita increase in total plastic recycling equals the 0.0028 pounds per capita increase at the curb less the 0.0006 pounds per capita diversion from recycling centers. Finally, the 0.0014 pounds per capita increase in total aluminum recycling equals the 0.0014 pounds per capita increase at the curb since diversion from recycling centers is approximately zero.

The adding-up conditions allow us to further interpret our diversion results. Most notably, approximately 78 percent of incremental glass curbside quantities are cannibalized from existing drop-off recycling centers. Despite the fact that increasing curbside access for glass recyclables does increase glass beverage container curbside returns, the majority of incremental quantities come from materials previously recycled at recycling centers. Net recycling gains are small. Further, approximately 21 percent of incremental curbside plastic beverage containers are cannibalized from existing recycling centers.

Table 4 also indicates that the effects of recycling center characteristics on recycling center returns are substantial. For example, drop-off returns of all materials increase significantly when the density of recycling centers increases. Drop-off quantities of glass and plastic also increase considerably when the average number of open hours increases on the margin.

Sensitivity Analysis

The preceding section established that increasing curbside recycling programs has a positive effect on the quantity of containers collected at the curb, but a small effect on total recycled containers. For bulkier and heavier materials like glass and plastic, these small incremental changes in total returns are at least partially attributable to significant cannibalization from existing recycling streams. Below, we provide evidence that these results are robust to the choice of variable definition and model specification.

First, we consider the possibility that aluminum returns are different from other materials because aluminum containers frequently earn additional scrap value payments beyond the California Redemption Value. However, results are robust to including the scrap value of aluminum as a regressor. Magnitudes of the program variables of interest remain approximately constant, and significance is unchanged.

Second, we investigate the sensitivity of the results to other program variables. For example, the larger literature on municipal solid waste has often emphasized the effects of garbage unit pricing ("pay-as-you-throw" programs) on household refuse and recycling choices. See, for example, Fullerton and Kinnaman (1996) and Callan and Thomas (1997). In our conceptual framework, the presence of unit pricing programs may well proxy for the price of non-recycling. In our analysis, the fixed effects likely pick up most pay-as-you-throw impacts, since there was little variation in such programs at the county-level for our sample period. However, as a sensitivity experiment, we included a time variant variable indicating the share of the county that had unit pricing programs in place. Including such a variable did not significantly change magnitudes or significance.

Third, we consider the possibility that characteristics of curbside programs importantly affect our estimates. For example, a few California communities have mandatory recycling, where households are penalized if trash bins contain recyclable materials. Consistent with Jenkins et al. (2003), we detect no significant impact of mandatory recycling on total returns. Inclusion of a variable that measures the share a county's population subject to mandatory recycling also does not substantially alter other variables' coefficients or significance. Further, some curbside programs require presorting of materials. The inclusion of a variable that measures the share of a county's population that must presort materials, however, does not significantly change our results. Point estimates and standard errors are similar to those presented in Tables 2-4.

Finally, we consider the possibility that recycling of one type of material may depend on the availability of curbside recycling for other materials. We therefore regress beverage container recycling quantities on the percent of the population served by commonly observed curbside collection programs.[15] Results from the augmented regressions are similar to those presented in Tables 2-4. Increasing curbside access generally increases beverage containers recycled at the curb. Diversion is strongly present for glass, not present for aluminum, and may be economically (but not statistically) significant for plastic. Interestingly, we also find some evidence in support of the

[15] In our sample, we never observe glass and/or plastic collection without aluminum collection. 44 percent of program expansions or introductions simultaneously collected aluminum, glass, and plastic beverage containers. 41 percent of program expansions or introductions collected only aluminum beverage containers. 12 percent of program expansions or introductions collected only aluminum and glass. Aluminum and plastic expansions or introductions were rare. Therefore, specific variables include the percent of population served by aluminum only curbside programs, aluminum and glass only curbside programs, aluminum and plastic curbside only programs, and aluminum, glass, and plastic curbside programs.

hypothesis that the impact of curbside expansion may be stronger when all materials are collected versus when only a subset is collected.

Further Exploration

The analyses of the preceding sub-sections presented evidence that cannibalization between recycling modes is occurring, with economically significant effects for glass and plastic. Here, we extend our analysis to study the impact of structural and demographic characteristics on the diversion response. This extension links to a previous literature that explored the relationship between socioeconomic characteristics and the general propensity to recycle. See, for example, Hong, Adams, and Love (1993) and Hong and Adams (1999).

To this end, we augment the diversion regressions (summarized in Table 4) with time variant county-level socioeconomic variables, such as the median family income, unemployment, and population density in a given county. For each material, we include these regressors directly and interacted with our curbside access variables. Results from fixed-effects linear regressions of recycling center beverage container return quantities on the percent of the population served by curbside programs, socioeconomic interactions, and other covariates are presented in Table 5. Note that identification still comes from county-specific variation over time, since we retain fixed-effects. Computed standard errors are heteroskedastic-consistent and t-statistics appear in parentheses.

Table 5. Socioeconomic Regressions Results: Drop-Off Center Quantities

Variable Description	Aluminum	Glass	Plastic
Percent of the Population Served by	-0.0148**	-0.0132	-0.0025**
Curbside	(-2.26)	(-1.56)	(-2.3)
Density * Percent Served by	-0.0012	0.0066	0.0021***
Curbside	(-1.00)	(1.61)	(3.56)
Unemployment * Percent Served by	0.0001	0.0012***	0.0001
Curbside	(0.5)	(2.81)	(1.16)
Mean Family Income * Percent	0.0005**	-0.0005**	0.0001
Served by Curbside	(2.4)	(-2.13)	(0.57)
Density	0.1167	-0.8563	0.3772***
	(0.38)	(-0.75)	(2.89)
Unemployment	-0.0101	-0.0664***	-0.0043*
	(-1.48)	(-3.62)	(-1.78)
Median Family Income	-0.0277	-0.0137	-0.0061*
	(-1.54)	(-0.5)	(-1.83)
Number of Recycling Centers per	5.1819***	30.2655***	4.5511***
area	(2.84)	(4.11)	(5.07)
County average number of Recycling	-0.0009	0.0326***	0.0042**
Centers hours open	(-0.17)	(2.69)	(2.31)
Standard Deviation of of Recycling	0.0048	-0.0088	-0.0009
Centers hours open	(1.06)	(-0.85)	(-0.56)
Average Temperature	0.0015***	0.0001	0.0001
	(6.76)	(0.02)	(1.17)
Second Quarter Dummy	-0.0757	0.1356	0.0058
	(-0.97)	(0.74)	(0.45)
Third Quarter Dummy	0.0885	0.5944***	0.0367*
	(1.14)	(2.69)	(1.88)
Fourth Quarter Dummy	0.0489*	0.0382	0.0360***
	(1.72)	(0.31)	(3.96)
1996 Year Dummy	-0.1268***	-0.1704**	0.0460***
	(-5.13)	(-2.15)	(5.45)
1997 Year Dummy	-0.1488***	-0.2619***	0.0652***
	(-5.33)	(-2.69)	(7.41)
1998 Year Dummy	-0.1973***	-0.3247***	0.0713***
	(-5.26)	(-3.13)	(6.95)
1999 Year Dummy	-0.1985***	-0.1608	0.0781***
	(-5.15)	(-1.24)	(7.63)
2000 Year Dummy	-0.2693***	0.0995	-0.1019**
	(-6.41)	(0.36)	(-2.04)
Per Capita Total Quantity Sold	0.1575	0.0895	0.1072***
(Statewide)	(1.58)	(1.44)	(5.51)
Constant	0.8189	6.1415**	-0.8704***
	(0.92)	(2.38)	(-2.98)
Fixed Effects		43 County-Specific Fixed Effects	
R-squared	0.90	0.90	0.80

[a] The dependent variables are the quantities returned to recycling centers for the listed materials.
[b] Superscripts ***,**, and * indicate statistical significance at the 1% , 5%, and 10% levels of significance.
[c] Each county-level analysis consists of 1,052 observations from 44 counties over the 24 sample quarters.

We begin our interpretation of the results in Table 5 by considering the coefficients on the uninteracted curbside access variables. Holding median family income, unemployment, and population at zero, the marginal effect of an increase in the percent of the population served by curbside on drop-off recycling center beverage container returns is negative for every material. The results are statistically significant for aluminum and plastic and similar in magnitude to the significant results in Table 4 for glass. While too much emphasis should not be placed on interpreting outcomes conditioned on zeroed socioeconomic variables, results are at least suggestive that economically significant cannibalization between recycling streams is robust across specifications.

Results in Table 5 also show that the interaction between population density and curbside access is significant for plastic. An intuitive interpretation of the positive coefficient is that the diversionary response becomes stronger (more negative) as density decreases. In other words, consumers are more likely to forego redemption payments in exchange for convenience, particularly for bulky items like plastic containers, when population density decreases.

Table 5 further indicates that the interaction between unemployment and curbside access is significant for glass. An intuitive interpretation of the positive coefficient here is that the diversionary response becomes stronger (more negative) as employment increases. In other words, consumers are more likely to forego redemption payments in exchange for convenience, particularly for heavy items like glass containers, when employment increases.

The results in Table 5 on the interaction between median family income and curbside access are mixed. For glass, an intuitive interpretation of the significant negative coefficient is that the diversionary response becomes stronger (more negative) as median family income increases. In other words, consumers are more likely to forego redemption payments in exchange for convenience when income increases. For aluminum, however, the interaction coefficient is significant and positive. While this result is perhaps initially puzzling, there are at least two plausible explanations. First, when income is relatively high, there may be spillover effects from increased awareness of recycling options. Thus, as curbside programs become more prominent, returns to all recycling streams increase. Second, when median family income is particularly high, increases in curbside access may lead to disproportionately higher levels of scavenging. In this context, scavenging refers a situation in which materials originally left at the curb are removed by third parties and returned to recycling centers for their cash redemption value. Since scavenging is most likely to occur for light, compactable materials such as aluminum, this explanation seems plausible. For a complete analysis of this phenomenon, see Ashenmiller (2006).[16]

V. Interpretation and Policy Discussion

This paper uses a novel dataset to investigate the extent to which curbside access affects recycled quantities. Results suggest marginal increases in curbside availability increase returns at the curb, but have very small impacts on total recycled quantities of beverage containers. Specifically, a one percent increase in the percent of a county's population served by curbside programs increases total beverage container recycling returns by only 0.48 percent for plastic, 0.08 percent for glass, and 0.07 percent for aluminum. Impacts for glass and aluminum are statistically indistinguishable from zero.

A large reason for the small net gains from incrementally expanding curbside programs is cannibalization from existing recycling streams, particularly for heavier and bulkier materials. We detect no diversion for aluminum, but nearly 21 percent of incremental plastic curbside quantities are diverted from existing recycling center returns.

[16] Note that scavenging does not impact the important *total* recycled beverage container results in Table 3 and can only lead to a conservative understatement of the key cannibalization results in Table 4.

For glass, a full 78 percent of incremental curbside quantities are diverted from recycling centers.

Clear policy implications arise from our results. First, examining only the impact of curbside programs on curbside quantities, as is often done in policy discussions, may seriously overstate the returns to marginal changes in curbside programs. Second, while curbside program expansion may generate significant increases in total recycling over some range, program expansion does not generate considerable recycling increases over the observed range of variation in our data. In other words, at least for beverage containers in California, expanding curbside programs beyond recent levels generates very small increases in total recycling.[17] Implications for strict benefit-cost analyses follow directly.

Quantity Comparisons

To further put our results in perspective, we conduct some simple quantity comparisons that incorporate our empirical results. We first consider the efficacy of expanding curbside access relative to expanding recycling center hours of operation. For glass, a one percent increase in the percent of the population served by curbside generates 12 times less total recycled quantity than expanding recycling center hours by one hour per week. In other words, the same increase in total glass beverage recycling is obtained by increasing the percent of the population with access to curbside by one percent or by expanding recycling center hours of operation by as little as 5 minutes per week (60 minutes/12). Extensive diversion from recycling centers simply implies that incremental

[17] Between 1995 and 2000, the average county in the average month of our sample served 32 percent of its population with aluminum beverage container curbside programs, 26 percent of its population with glass beverage container curbside programs, and 15 percent of its population with plastic beverage container curbside programs.

changes in curbside programs do not result in large incremental changes in total glass beverage container recycling.

For plastic, a one percent increase in curbside access generates 2.3 times less total recycled quantity than expanding recycling center hours by one hour per week. In other words, the same increase in total plastic beverage recycling is obtained by increasing the percent of the population with access to curbside by one percent or by expanding recycling center hours of operation by approximately 30 minutes per week (60 minutes/2). For aluminum, point estimates suggest that a one percent increase in the percent of the population served by curbside generates 4.7 times more total recycled quantity than opening recycling centers an additional one hour per week. Here, recycling centers would have to expand hours of operation by approximately 300 minutes per week in order to bring in as much additional aluminum as increasing the percent of the population with curbside access by one percent.

We next compare the efficacy of expanding curbside access relative to expanding the *number* of recycling centers. For glass, a one percent increase in curbside access generates 6 times less total recycled quantity than adding one recycling center per county. In other words, the same increase in total glass is obtained by expanding the number of recycling centers per county by one or by increasing the percent of the population with access to curbside by 6 percent. For aluminum, a one percent increase in the percent of the population served by curbside generates 2.2 times less total recycled quantity than expanding the number of recycling centers by one per county. For plastic, point estimates suggest a one percent increase in the percent of the population served by curbside generates 7.3 times more total recycled quantity than an additional center per county.

Cost Effectiveness Comparisons

To further put our results in perspective, we also conduct some simple cost effectiveness comparisons that incorporate our empirical results and the quantity comparisons above. These exercises take as given a policy objective of returning a fixed number of beverage containers of a given material type.[18] To conduct the comparisons, we first discuss the costs associated with incremental curbside expansion and incremental recycling center expansion.

Our average sample county contains 740,000 people, so a one percent increase in the population served by curbside supplies approximately 7,400 people. We divide by this number by the national mean of 2.57 individuals per household to obtain an incremental increase of 2,880 households. Conservative estimates suggest operating expenses for California curbside programs are approximately \$2.40 per household per month (Skumatz (1999)). Thus, on average, a one percent increase in the percent of the population served by curbside generates approximately \$6,912 in incremental operating expenses per county per month (\$82,944 per county per year).

Our average sample county contains 44 recycling centers. Increasing center hours by one hour per week then generates an additional 176 hours per county per month on average. We are unable to obtain precise numerical estimates for recycling center operating costs, but expenses typically include low-skilled labor costs, transportation costs to the sorting facility, modest administration and overhead expenses, taxes, and capital costs (USEPA (1994)). In general, these costs are quite low, since convenience

[18] This objective loosely corresponds to stated policy objectives. California's Department of Conservation states its primary goal for this program is "to achieve and maintain high recycling rates for each beverage container type" and its long-term program goal is "to achieve an 80 percent recycling rate for all aluminum, glass, plastic, and bimetal beverage containers in California" (CADOC 2006).

zone and other recycling centers often simply consist of several material-specific bins, an operator, some scales, and record-keeping materials.

Ideally, comparisons would identify *all* costs of a complete analysis. For example, a complete assessment would account for the relative differences in time costs between expanded curbside programs and drop-off recycling center expansion. Jakus *et al.* (1996), Jakus *et al.* (1997), and Ando and Gosselin (2005) find that factors that decrease time cost importantly impact households' propensity to recycle. Consequently, given available data, our cost-effectiveness analysis can be interpreted as providing a sense of how large the non-measured costs of center expansion would have to be to make incremental curbside cost-effective relative to incremental recycling centers.

Table 6 presents our simplified cost effectiveness comparisons. Recall that calculations assume a fixed policy objective of recycling a fixed number of beverage containers. We first summarize the quantity comparisons from the preceding discussion. From these figures and the observed costs discussed above, we then calculate break-even points for recycling center operating costs. For example, consider the third column of row 1 in Table 6. First, we divide the $6912 incremental increase per county per month in curbside expenditures by 176 hours per county per month to obtain the hourly break-even center operating expenses if the curbside increase and the recycling center increase generated the same change in total incremental beverage containers recycled. We then multiply this amount by the differential returns between the programs (12) to obtain the final break-even operating expenses per recycling center hour.[19]

[19] The last column of row 1 in Table 6 is similarly obtained. We simply multiply the annual incremental increase per county in curbside expenditures ($82,944) by the differential returns (6).

Table 6. Simple Cost Effectiveness Analyses[a]

Material	Total Recycling Returns: Expanding Curbside Access by 1 Percent vs. Expanding Recycling Center Hours by 1 Hour per Week	Break-Even Operating Expenses per Recycling Center Hour	Total Recycling Returns: Expanding Curbside Access by 1 Percent vs. Expanding Recycling Center Numbers by 1 Per County	Break-Even Annual Costs per Recycling Center
Glass	12 times smaller*	$471.27*	6 times smaller*	$497,664*
Aluminum	4.7 times greater	$8.36	2.2 times smaller*	$182,477*
Plastic	2.3 times smaller*	$90.32*	7.3 times greater	$11,362

[a] All calculations based upon total recycled quantity results in Table 3.
Superscript * indicates a calculation derived from a statistically significant coefficient.

All calculations in Table 6 based upon statistically significant coefficients yield results with high break-even expenses. Abstracting from unobserved costs, the break-even points can be interpreted as follows. For glass, the annual operating expenses of a single recycling center would have to exceed approximately $497,000 for a one percent increase in the percent of population served by curbside to be more cost effective than an additional recycling center per county. For aluminum, the annual operating costs of a recycling center would have to exceed roughly $182,000 for a one percent increase in the percent of population served by curbside to be cost-effective relative to an additional recycling center per county. Similarly, glass and plastic recycling center hourly operating expenses would have to surpass $471 and $90 for incremental curbside expansion to be more cost effective than an additional working hour per center. [20]

Of course, these comparisons do not identify all subtleties of a complete analysis. For example, both recycling centers and curbside programs can simultaneously accept multiple materials. In other words, the material-specific cost effectiveness comparisons

[20] During our sample period, the state paid per container "handling fees" to recycling centers in convenience zones. For example, in 1999 the state paid fees of 1.7 cents per eligible container over the CRV. However, if a recycling center redeemed more than 500,000 containers in a given month, they were no longer eligible to receive the handling fee. At the margin, this creates a clear disincentive for some recycling centers to expand their accessibility. Our results suggest that eliminating this disincentive may also be a cost effective means of increasing total recycled quantities.

may not be independent of one another. Further, these calculations take a policy objective as given that may not be socially optimal. For example, a full benefit-cost analysis may find that curbside programs have sufficient spillover effects to other materials (e.g. paper, etc.) to offset their costs. This represents a promising area of future research.

Conclusion

Curbside recycling rarely exists in isolation. This paper uses novel and reliable data to analyze the impact of curbside recycling when other recycling modes are present. We consider the impact of access to curbside recycling on quantities returned to the curb, total quantities returned, and quantities returned to drop-off recycling centers.

We find that the impact of incrementally expanding curbside programs on total quantities of beverage containers recycled is small. Much of this result obtains because curbside programs significantly cannibalize returns from recycling centers. Since we focus on beverage containers, we observe diversion even when the recycler must forgo a cash payment in order to return materials to the curb. It seems plausible that our direct diversion results for beverage containers understate the direct diversion incentives for materials outside of our sample. In other words, if we had data on paper and other materials, we would expect our key results to be stronger.

Finally, our calculations indicate incremental curbside access expansion may not be the least cost option for increasing beverage container recycling returns. Recall that these are marginal results, and curbside programs are already prominent in many areas. Specifically, our results indicate that household time cost differences would need to be large for the marginal costs of recycling center availability to outweigh the marginal costs of curbside expansion.

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