Resources, Conservation and Recycling 54 (2010) 242–249

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Factors influencing the rate of recycling: An analysis of Minnesota counties☆

Shaufique F. Sidique[a,*], Satish V. Joshi[b], Frank Lupi[b]

[a] Faculty of Economics and Management, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[b] Department of Agricultural, Food and Resource Economics, Michigan State University, Agriculture Hall, East Lansing, MI 48824, USA

ARTICLE INFO

Article history:
Received 30 March 2009
Received in revised form 30 July 2009
Accepted 14 August 2009

Keywords:
Recycling
Recycling expenditure
Recycling education
Municipal solid waste
Waste management

ABSTRACT

This study analyzes the effects of various recycling and waste management policy variables on recycling rate by utilizing county-level panel data from Minnesota covering the period 1996–2004. The policy variables examined include variable pricing for waste disposal, expenditure on recycling education, provision of curbside recycling services and drop-off centers, and enactment of recycling ordinances. Unlike previous studies, this study accounts for the cumulative effects of the expenditure variable on recycling rate and also investigates whether different recycling programs such as curbside and drop-off recycling act as complements or substitutes in increasing recycling rates. This study also examines the effect of income and demographic characteristics on recycling rate. After accounting for random effects and endogenous variables, the results indicate that variable pricing of waste disposal increases the rate of recycling. Other policy variables such as the enactment of recycling ordinances and cumulative expenditures on recycling education are also found to be effective measures to increase recycling rate.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

Annual municipal solid waste (MSW) generation in the United States has increased from 88 million tons in 1960 to approximately 254 million tons in 2007 (USEPA, 2007). The escalating waste generation combined with concerns over landfill costs and availability of space have prompted regulators and policymakers to reform MSW policies at all levels, from the community to the state level. Waste management practices such as source reduction, recycling, and composting have been instituted in order to reduce materials from entering the waste stream.

A range of programs and policy instruments are available to policy makers for managing waste and recycling. Given the variety, analyses of the effectiveness of these practices are needed for improved policy decisions. Several studies have been conducted to understand the effects of various waste management policies on reducing waste and increasing the amount of recycling, and these studies have analyzed the impacts of policies on per capita waste generation and recycling demand (Podolsky and Spiegel, 1998; Kinnaman and Fullerton, 2000; Johnstone and Labonne, 2004; Callan and Thomas, 2006). However, most policymakers evaluate the effectiveness of recycling and waste management programs by looking at improvements in the rate of recycling because the rate of recycling is able to capture movements in the amount of recycling and waste generation at the same time, as opposed to separate measurement of per capita quantities. In fact some states like New Jersey have regulations mandating minimum recycling or diversion rates. One of the key features of this study is that we analyze the impacts of different policies on recycling rates.

Another feature of this study is the use of panel data on recycling rates. Most of the earlier studies on the effectiveness of recycling and waste management policies are based on cross-sectional data analyses, and hence they are unable to incorporate dynamics of certain policy variables (Podolsky and Spiegel, 1998; Kinnaman and Fullerton, 2000; Johnstone and Labonne, 2004; Callan and Thomas, 2006). Compared to these, the analysis in this paper uses county-level data from Minnesota covering the period 1996–2004, and the panel nature of the data enables analysis of cumulative effects over time.

The broad objective of this research is to examine the factors that affect recycling rates in Minnesota counties by utilizing a set of panel observations of recycling and waste management policies, along with income and demographic variables. Specifically, this research analyzes the effectiveness of various recycling and waste management policy variables on county rates of recycling. The policy variables that we examine include: variable pricing for waste disposal, expenditures on recycling education, provision of curbside recycling services and drop-off centers, and enactment of recycling ordinances. Unique to this study, we account for the cumulative effects of the expenditure variable on recycling rate. We

☆ The authors would like to thank Ann Bernstein and Mark Rust from the Minnesota Pollution Control Agency for providing the waste and recycling data, and the Office of the Vice President for Finance and Operations, Michigan State University for financial support.

* Corresponding author. Fax: +60 3 8948 6188.
E-mail address: shaufique@econ.upm.edu.my (S.F. Sidique).

0921-3449/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.resconrec.2009.08.006

also investigate whether different recycling programs such as curbside and drop-off recycling act as complements or substitutes in increasing recycling rates by considering the interactions between the variables. Lastly, this research examines the effect of income and demographic characteristics such as age, education and population density on the recycling rate.

2. Literature review

Household recycling and waste management literature can be divided into two broad classes: articles that use more comprehensive models incorporating the behavior of governments, firms, and consumers and articles focusing on consumer reactions to various pricing schemes (Linderhof et al., 2001). Articles of the first type are mostly theoretical while those of the second type are mostly empirical. Earlier theoretical studies in this area began analyzing waste generation without including recycling. Wertz (1976), for example, develops an economic model to explain household's decisions regarding waste production. Households are assumed to maximize utility, which is a function of goods consumed and waste generated, subject to a budget constraint incorporating the cost of waste disposal that increases with waste generated. The model analyzes, among other variables, the impact of unit pricing of waste disposal and income on the quantity of waste generated. The analysis suggests that the quantity of waste generated decreases when the waste disposal fee increases, and waste generation increases with income.

The study by Wertz (1976) was extended by Jenkins (1993) by modeling both the residential and commercial sectors' demand for solid waste services and most importantly by including recycling as a waste reduction option. The household utility maximization model suggests that the level of household income, the prices of goods consumed, payments from recycling deposit items and waste disposal user fees will affect the demand for solid waste services. A profit maximization model is developed to derive firms' demand for commercial solid waste services. The model assumes that the cost of production increases with recycling activities but is mitigated by the increase in revenue from selling recyclables. The final analysis suggests that the demand for commercial solid waste services is a function that is decreasing in costs of production, increasing in the revenue from sales of recyclables, and decreasing in the user fee for commercial solid waste services.

Saltzman et al. (1993) developed a theoretical framework for analyzing household waste generation and recycling. They adopted the model by Wertz (1976) and introduced recycling explicitly in the utility function. Unlike the study by Jenkins (1993), the recycling function of their study is more elaborate because it includes factors such as household's degree of ecological consciousness and the amount of time required to sort the recyclables from waste. Their study also conducts comparative statistics to examine the mixed impact of income on the household recycling effort. Hong (1999) adopted the household production function framework by Becker (1965) and Pollack and Wachter (1975) to develop a household solid waste generation and recycling function. He incorporated the time spent recycling in the utility function and derived the reaction functions for solid waste generation and recycling. He then developed a system of structural equations to investigate the interactions between household waste generation and recycling and found that household recycling efforts are expected to increase as waste collection fee increases.

Kinnaman and Fullerton (2000) developed a theoretical model to derive the recycling and waste disposal demand function for a community, and they then empirically estimated the impact of waste disposal fees and curbside programs on recycling and waste generation. Their paper established that the demands for waste disposal and recycling are functions of curbside recycling, price of waste disposal, mandatory recycling policies, deposit refund systems for recyclables, bans on yard waste disposal, income and demographic characteristics.

The empirical studies on recycling and waste management can be classified into two categories: the studies that utilize household level data (Fullerton and Kinnaman, 1996; Van Houtven and Morris, 1999; Hong, 1999; Hong and Adams, 1999; Linderhof et al., 2001) and the studies that utilize macro-level data such as a community or county-level data (Podolsky and Spiegel, 1998; Kinnaman and Fullerton, 2000; Johnstone and Labonne, 2004; Callan and Thomas, 2006). Most of the empirical work using household level data studies the impact of garbage pricing on waste generation. Fullerton and Kinnaman (1996) utilize individual household data in Virginia to estimate the effect of a garbage unit-pricing program on the weight of the garbage, the number of containers, the weight per can and the amount of recycling. They found that in response to unit-pricing, households reduced the number of garbage bags but not necessarily the weight of the garbage. They also found that there was an increase in the weight of recycling, but there was also evidence of illegal dumping. They concluded the incremental benefit of the unit-pricing program was small and outweighed by the administrative cost.

Van Houtven and Morris (1999) examined the implication of unit-based pricing on household waste generation in a waste demonstration project in Marietta, Georgia. Instead of paying a fixed collection fee, half of the participating households paid a fee for a reusable trash can and the other half paid for each trash bag collected. The data collected indicate that both the programs significantly reduced waste generation even after taking into account the increase in recycling. The bag program was also found to result in a larger reduction in waste generation compared to the can program. Hong (1999) studied the impact of unit-pricing and aggressive recycling programs on solid waste generation and recycling by employing data from a large household survey from Korea. The results indicated that an increase in waste collection fee paired with aggressive recycling programs was more effective in reducing the waste disposal than an increase in collection fee without any recycling program. They also found that a weight-based unit-pricing system was more effective in reducing waste compared to volume-based unit pricing as households tend to compact wastes to reduce charges in the latter form of pricing.

Hong and Adams (1999) studied the effect of disposal fee and household characteristics on recycling and waste generation by analyzing household level data from Portland, Oregon. They reported that an increase in the price of solid waste collection increased the demand for recycling, and they also found that an increase in the price of collection had a negative effect on the demand for waste disposal. Linderhof et al. (2001) utilized a large household panel data from a Dutch municipality to analyze the effects of weight-based pricing on household waste collection. They concluded that weight-based pricing had a strong negative effect on the amount of waste collected. Podolsky and Spiegel (1998) developed a theoretical model to derive the demand for municipal solid waste disposal and examine the effect of unit-pricing and household recycling on municipal solid waste disposed by using community-level data for 149 New Jersey municipalities. Unique to their study, the model assumed that households derive utility from the consumption of goods and incur disutility from recycling waste. The model suggests that the optimal level of waste generated will be at the level where the marginal disutility of recycling equals the unit price of disposal. Their empirical evidence indicates that unit price significantly reduces the amount of solid waste disposed. They also hypothesized that recycling affects waste disposal through two components. The first is the non-price component which is the direct effect of recycling reducing the amount of solid waste as the two activities are substitutes. The second component captures the indirect effect of unit pricing on waste disposal through changes in recycling. However, they found that only the non-price component of recycling significantly reduces waste disposal.

Another stream of research takes a social psychology approach which suggests that the presence of norms, both moral and social, may be important drivers of recycling behavior. See Hornik et al. (1995), Schultz et al. (1995) and Thogersen (1996) for reviews of this research, and more recent studies by Barr et al. (2003), Tonglet et al. (2004), and Sidique et al. (2009). Extensions to neoclassical utility theory to include norms have been proposed by Bruvoll and Nyborg (2004), Nyborg et al. (2006), Nyborg and Rege (2003) and Rege (2004). Drawing on this stream of research, Hage et al. (2009) investigate the determinants of recycling efforts of packaging waste in Swedish households, using data from a random sample of 827 households in four different Swedish municipalities. Ordered probit regressions were conducted to examine the relationship between the extent of recycling of four different types of packaging materials, i.e. paper, plastic, glass and metal with psychological variables such as moral obligation, social norms and also socio-economic variables. The results indicate that both economic concerns and moral obligations influence recycling outcomes at the household level. The study also found that convenience plays an important role in influencing recycling outcomes.

Most of the macro-level studies that we reviewed utilize cross-sectional data on recycling and waste management. As mentioned above, Podolsky and Spiegel (1998) in a study using community-level data for 149 New Jersey municipalities found that unit pricing significantly reduces the amount of solid waste disposal. Kinnaman and Fullerton (2000) derive a similar conclusion by analyzing cross-sectional data of more than 900 U.S. communities. They also found that curbside recycling programs encourage recycling. The main contribution of the Kinnaman and Fullerton paper, besides having employed a relatively large dataset was to recognize the endogeneity of local government policy decisions. Unlike most of the previous studies that assume that policy variables such as waste disposal pricing and provision of recycling facilities are exogenous; they argued that these variables tend to vary with community attributes and household characteristics. Since public policies are usually responsive to the conditions in the local community, Kinnaman and Fullerton treat disposal pricing and implementation of curbside recycling as endogenous variables and correct the endogeneity by using a two-stage least square (2SLS) estimation method.

Johnstone and Labonne (2004) is one of the few waste management studies that has used a panel dataset in its analysis. This study analyzes the determinants of solid waste generation using the municipal solid waste, demographic and economic data of 30 Organisation for Economic Co-operation and Development (OECD) countries from 1980 to 2000. Adopting the framework proposed by Kinnaman and Fullerton (1997), their study models the demand for municipal solid waste services as a function of waste pricing and demographic characteristics such as average data on household size, number of children in a household, the number of working adults in a household and proportion of urban population. Due to a lack of availability of the price data, they used population density and country dummies as proxies for waste disposal prices. It was argued that waste disposal pricing was reflected in the cost of disposal which was closely related to population density and the country itself. Their study found that household waste generation was relatively inelastic with respect to income and that urbanization increases waste generation. A limitation of the study is the use of country as the unit of analysis, which may not be appropriate because waste management policies and practices are mostly locally governed and can vary significantly within a country.

In a more recent study, Callan and Thomas (2006) examine the demand for disposal and recycling services by utilizing cross-sectional data of 351 municipalities in Massachusetts. Similar to Kinnaman and Fullerton (2000), their study allowed for the endogeneity of garbage unit pricing and the provision of curbside services, but their study differed by also allowing the demand for waste disposal and recycling to be simultaneously determined. In addition to variables for demographics, garbage pricing and curbside recycling, their study also incorporates an expenditure variable which measures state funded grants for recycling equipment and education. The results demonstrate that unit pricing indirectly affects garbage disposal through increased recycling and that availability of curbside services reduces disposal demand. The results also indicate that communities with grant allocation for recycling education or equipment recycle significantly more than communities without any allocation. It was also found that household size and age are significant determinants of the demand for disposal service, and education is a significant determinant of recycling. Hage and Söderholm (2008) analyze the factors determining the collection rates of household plastic packaging in Sweden, following the passage of the producer responsibility ordinance which mandates producers to collect and recycle packaging materials. Regression analysis was conducted based on a cross-sectional sample of 252 Swedish municipalities, and the results indicate that policy variable such as weight-based garbage pricing, socio-economic and demographic factors, and environmental preference (measured by percentage of votes for the Green party in the previous national election and presence of Green party members in local government) have significant influence on collection rates.

The analysis in this study builds on the above studies by using a more comprehensive panel dataset instead of cross-sectional data, using actual county-level data on waste generation and recycling rates instead of the common self-reported information on household recycling behavior, and analyzing cumulative effects and interactions of policy variables. Other strengths of the study are: the use of county as the unit of analysis which is appropriate since waste management policies and practices are usually locally governed; use of a large state level dataset that has uniform definitions, measures and reporting practices; and the use of appropriate econometric techniques as discussed later in Section 5.

3. Theoretical framework

We adopt the utility maximization model proposed by Kinnaman and Fullerton (2000) but with some slight modifications to explain waste generation and recycling in order to derive the function for the rate of recycling. Similar to their approach, we begin by explaining household choices and then apply this framework to the county's policy choices.

Assume an economy in a county comprised of N identical households with utility functions represented by

$$U_i = U(x_i, E_i) \tag{1}$$

where x_i represents composite goods and services consumed by household i and E_i is the environmental quality that the household i perceives to enjoy. The environmental quality function is specified as follows:

$$E_i = h(g_i, r_i; d_i) \tag{2}$$

where g_i is the amount of waste disposed and r_i is the amount of materials recycled by household i. The choice of the g_i and r_i in E_i is also dependent on a set of demographic characteristics, d_i. Substituting Eq. (2) into (1), we rewrite the utility function as

$$U_i = U(x_i, h(g_i, r_i; d_i)) \tag{3}$$

Each household maximizes utility subject to the following budget constraint:

$$x_i + p_g g_i + p_r r_i = m_i \quad (4)$$

where the price of composite goods x_i is normalized to unity, p_g is the price of waste disposal, p_r is the price of recycling and m_i is the total household income. Solving the utility maximization problem yields the following demand functions for waste and recycling:

$$g_i = g(p_g, p_r, m_i, d_i) \quad (5)$$

$$r_i = r(p_g, p_r, m_i, d_i) \quad (6)$$

The following equations outline the functions for the price of waste disposal and the price for recycling:

$$p_g = p_g(P, L, m_i, d_i) \quad (7)$$

$$p_r = p_r(F, S, m_i, d_i) \quad (8)$$

The price of waste disposal for a household will factor in the disposal fee (P) imposed by the waste service provider as well as other costs associated with the time and effort required by the household to handle the waste. The time and effort costs are assumed to be functions of household income and demographic characteristics. The price of waste disposal is also affected by regulations that enforce recycling (L). Presence of regulations such as the ban of certain recyclables in the waste stream will directly increase disposal costs because of possible penalty.

The price of recycling for a household is mainly the time and effort costs of separating, storing, transporting and depositing the recyclables. Similar to waste, time and effort costs can be functions of income and demographic characteristics. Time and effort costs can also be affected by policy variables such as the types of recycling programs (F) and recycling education related expenditures (S). Recycling programs such as curbside recycling services and drop-off recycling centers will reduce the time and effort costs faced by households to recycle. Recycling education expenditures will help increase recycling awareness and will educate households on the importance and benefits of recycling. Recycling education will also expose households to efficient methods of recycling and the availability of recycling facilities, and this will indirectly help reduce the time and effort costs associated with recycling.

Substituting Eqs. (7) and (8) into (5) and (6), we rewrite the waste and recycling demand functions as

$$g_i = g(P, L, F, S, m_i, d_i) \quad (9)$$

$$r_i = r(P, L, F, S, m_i, d_i) \quad (10)$$

We are able to derive the rate of recycling by using the information on waste and recycling, and the theory implies that the recycling rate function will have the same explanatory variables as in the waste and recycling demand functions. Recycling rate is defined as a percentage ratio of the weight of recycled waste to the total solid waste collected for disposal and incineration (Lund, 2001).

Since we assume that households within each county have the same utility function, results aggregated at the county level will represent aggregate household level decisions. Thus, the recycling rate function of a county is written as follows:

$$R_i = f(P_i, L_i, F_i, S_i, m_i, d_i) \quad (11)$$

We expect variable rate pricing to have a positive effect on recycling rate because in a variable pricing system, households will have to pay higher disposal charges when they produce more waste. This pricing system is expected to provide an incentive for households to increase recycling in order to reduce the amount of waste disposal. We also expect the presence of regulations that enforce recycling to increase the recycling rate. Mandatory recycling regulation forces people to recycle to avoid penalties, and this will increase recycling and reduce the amount of recyclables in the waste stream. County recycling programs are expected to increase the recycling rate. Recycling programs such as curbside recycling pickup and drop-off centers facilitate recycling activities by making recycling more convenient for households. We expect programs such as curbside recycling and drop-off centers to have a higher impact on recycling rate when implemented together than when they are implemented separately, i.e. we hypothesize a complementary relationship. We expect recycling education expenditures to be positively associated with the recycling rate because they increase awareness and reduce costs. In addition to directly affecting awareness, recycling education efforts are likely to promote evolution of social and moral norms towards desirability of recycling. As discussed in Section 2, extant social psychology research finds that social and moral norms are important drivers of recycling behavior. Since norms evolve over time, we expect cumulative expenditures on recycling education to have a significant effect on recycling rates.

We expect income to have a negative association with recycling rate. People with higher income generally consume more and tend to generate higher amounts of waste which leads to a lower rate of recycling. Also, when income increases the opportunity cost of recycling goes up, and this can lead to a reduction in recycling. The county demographic variables are represented by age, education and population density. We expect age to be positively related to recycling as people who are older, especially retirees, tend to have more time to spend on activities such as recycling. This view is supported by the findings of previous studies that middle aged and older people are more likely to recycle (Vining and Ebreo, 1990; Meneses and Palacio, 2005; Saphores et al., 2006). Further, prior research also suggests that older people are more likely to have a preference for being norm compliant (Hage et al., 2009; Bruvoll and Nyborg, 2004). We expect education to be positively associated with the rate of recycling. People with higher education are expected to be more aware of environmental issues which would encourage them to recycle. As for population density, one possibility is that it will be negatively associated with recycling rate. Residences in high population density areas are usually smaller than those in low population density areas. Since lack of space is one of the major inconveniences that discourage people to recycle, it is probable that high population density will lead to reduced recycling activities and increased waste generation, which results in an overall decrease in the rate of recycling.

4. Data and variable descriptions

The data used for this research are drawn from two different sources. The recycling and waste management data for this study are obtained from the Minnesota SCORE database, and county socio-economic and demographic data are from the US Census Bureau. Minnesota is among the pioneers of waste management reforms in this country. It began a statewide recycling effort as early as 1989 after the adoption of legislation based on the recommendation by the Governor's Select Committee on Recycling and the Environment (SCORE). The legislation provides state funding for waste reduction, recycling program management and household hazardous waste management. The waste management and recycling program in Minnesota is deemed to be one of the most successful state-level programs in the United States considering the local government investments and public participation. According to a report in BioCycle magazine's survey 2006, Minnesota has a recycling rate of 43% and is ranked second in the nation after Oregon with a recycling rate of 45%.

The SCORE database compiles data from annual surveys of waste management and recycling in all Minnesota counties. The SCORE survey is administered by the Minnesota Pollution Control

Table 1
Definitions of variables.

Variable	Definition
Rate	Residential recycling rate per annum (percentage)
VarP	1 if county implements variable rate pricing structure (0 otherwise)
Ordin	1 if county has an ordinance that requires residences to recycle (0 otherwise)
Curb	Percentage of population with access to curbside recycling
Drop	Number of drop-off recycling centers per 1000 persons in the population
EduExp	Cumulative (3 years) recycling education expenditure per capita ($)
Inc	Income per capita ($)
Age	Median age
Educ	Percentage of population with 4 or more years of college education
Den	Population density per square mile

Agency and is completed by county solid waste officers. The survey collects information on MSW generated, materials collected for recycling, solid waste collection system, recycling programs and management, waste and recycling revenue and expenditure, source reduction programs and other MSW policy initiatives. We augment the recycling and waste management data with income and demographic data for Minnesota counties from the US Census Bureau database covering the period from 1996 to 2004. The two data sources combine to create a balanced panel of complete variables for 774 observations representing 86 counties in Minnesota. The variables selected for our analysis are listed and defined in Table 1.

Recycling rate is computed by dividing the amount of residential recycling by the amount of total waste generated in the county.[1] *VarP* is our waste disposal pricing variable which is a dummy variable representing whether the county had a variable pricing scheme or not. The survey did not collect information on the actual unit prices charged. In contrast to the studies that use community-level data, we use county data with aggregate information for several different townships or communities and this makes it difficult to deduce the county waste price as the prices usually vary across communities. Furthermore, in most cases variable pricing meant two or three tier pricing for different container sizes, and this type of pricing is not a true unit pricing such as "by the bag" pricing of waste disposal[2] because the marginal costs of an additional unit of waste in a tiered pricing scheme are zero within a tier. Given these considerations, it is reasonable to operationalize variable pricing as a dummy variable. We expect the presence of *VarP* to be endogenously determined in a county.

Our recycling regulation variable is represented by *Ordin* which indicates whether a county enacts recycling ordinances to make recycling compulsory for the residents. We use *Curb* and *Drop* to represent recycling programs in a county. *Curb* measures the percentage of county's population with access to curbside recycling, and *Drop* measures the number of drop-off recycling facilities available per 1000 persons in the county. We also expect both *Curb* and *Drop* to be endogenous. The county's recycling education expenditure variable is represented by *EduExp* which is the 3-year cumulative recycling education expenditure for each county. Unlike previous studies, we use cumulative expenditures instead of current expenditure because we believe that expenditure on education has cumulative effects on recycling rate. The recycling awareness created from previous year's education will still have an impact on the current year's recycling activities. We may also

[1] Total waste generated is the summation of amount of recycling and MSW landfilled.

[2] This information on the types of variable pricing was obtained through telephone interviews with Minnesota Pollution Control Agency officers and waste management officers from several counties.

Table 2
Summary statistics of variables.

Variable	Mean	Std. deviation	Min	Max
Rate	16.00	6.71	1.55	40.18
Inc	24,704	4518	16,379	45,565
Age	38.10	3.69	29.00	48.10
Educ	11.73	0.05	4.44	39.61
Den	121.77	417.63	3.21	3348.21
VarP	0.82	0.39	0.00	1.00
EducExp	0.37	0.52	0.00	4.77
Curb	53.42	27.27	0.00	100.00
Drop	0.67	0.68	0.00	4.19
Ordin	0.23	0.42	0.00	1.00

$n = 774$.

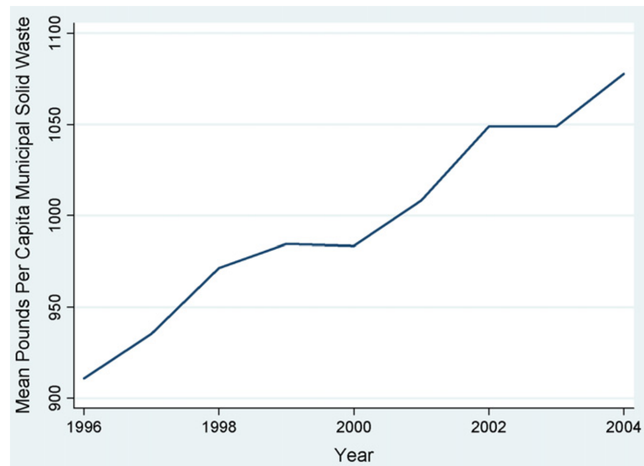

Fig. 1. Mean per capita municipal solid waste in Minnesota (1996–2004).

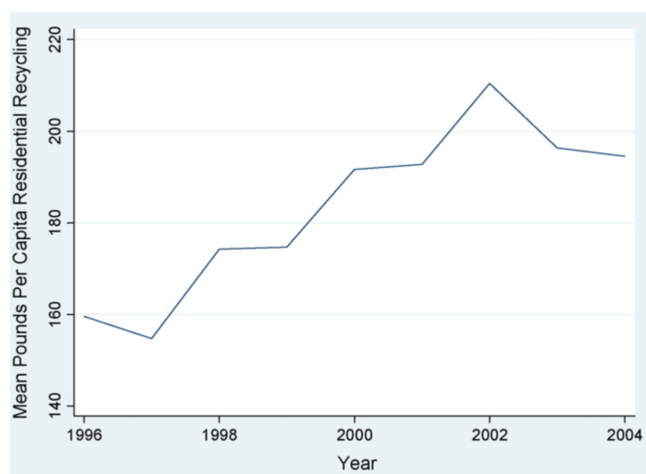

Fig. 2. Mean per capita residential recycling in Minnesota (1996–2004).

be able to avoid the potential endogeneity problem of an expenditure variable by using cumulative expenditure in our model. The income and demographic variables are represented by *Inc*, *Age*, *Educ* and *Den*. Table 2 provides the descriptive statistics of the variables in our model.

The SCORE survey data indicate that the mean recycling rate for Minnesota is 16% and the rate varies from 1.55% to 40.18%.[3]

[3] The calculated mean is lower than the mean published in the BioCycle magazine because we excluded recyclables such as used tires that were based on estimates.

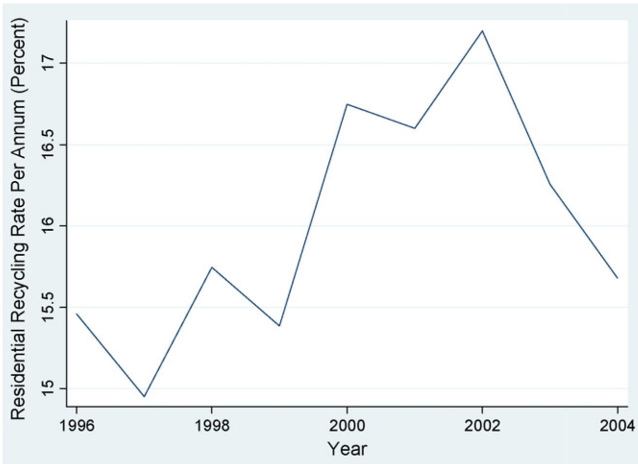

Fig. 3. Mean residential recycling rate in Minnesota (1996–2004).

Figs. 1 and 2 illustrate the trend in waste generation and the amount of residential recycling for Minnesota from 1996 to 2004.

Fig. 3 illustrates the residential recycling rates from 1996 to 2004. It is evident from Fig. 3 that generally there is an increasing trend in mean recycling rate with slight fluctuations from 1996 to 2002. The rate of recycling then decreases from 17% in 2002 to approximately 15% in 2004.

Eighty-nine percent of the counties in our data adopt variable pricing structure for waste disposal and 23% have enacted ordinances making recycling compulsory for residents. The mean expenditure for recycling education spent on a person is 37 cents, and it varies from 0 to $4.77. The mean percentage of population with access to curbside recycling services is 53.42% and the mean number of drop-off recycling centers per 1000 persons in the population is 0.67.

The US Census Bureau data indicate that the income and demographic characteristics of the counties in Minnesota vary considerably. The mean per capita income for Minnesota counties is $24,704, and the county average per capita income ranges from $16,379 to $45,565. The median age per county varies from 29 years old to approximately 48 years old. The mean percentage of population with a bachelor's degree or higher is approximately 11.74%, and it varies from 4.44% to 39.61%. The mean population density is 121.77 persons per square mile, and the density varies from as low as 3.41 persons per square mile to 3348.21 persons per square mile.

5. Econometric methods and results

We model the county recycling rate as a function of waste management policy, income and demographic variables. The linear econometric specification of the county recycling rate function is specified as follows:

$$\begin{aligned} Rate_{it} = {} & \beta_0 + VarP_{it}\beta_1 + Ordin_{it}\beta_2 + Curb_{it}\beta_3 + Drop_{it}\beta_4 \\ & + CurbDrop_{it}\beta_5 + EducExp_{it}\beta_6 + Inc_{it}\beta_7 + Age_{it}\beta_8 \\ & + Educ_{it}\beta_9 + Den_{it}\beta_{10} + Time_t\beta_{11} + a_i + u_{it} \end{aligned} \tag{12}$$

$Time_t$ is the dummy variable for each year except for the first year, and a_i and u_{it} are the components for the unobserved disturbance for county i at time t. Since we have a panel data, we are able to exploit the repeatability of the data by decomposing the unobserved disturbance to allow for a county-level effect. Thus, a_i represents the unobserved county-level effect and u_{it} is the idiosyncratic error that changes over time for each county. The dummy variables for years will allow for exogenous statewide changes in recycling rate over time.

We estimate the model using the random effects method as we assume that the unobserved effect is uncorrelated with each of our explanatory variables. We use Hausman's specification test to confirm that random effects is the appropriate specification for the county specific unobserved effects in our model as opposed to fixed effects. The test result indicates that unobserved effects are adequately modeled by random effects, and the model produces efficient and consistent estimators. Table 3 outlines the results of our regression models: pooled OLS, random effects model and random effects model with instrumental variables (IV). The pooled OLS model is estimated for comparison basis as the random effects model assumes strict exogeneity between the explanatory variables and the disturbance term. If this assumption fails, pooled OLS will produce more consistent estimators.

The pooled OLS results suggest that age and higher education have significant positive contributions to the rate of recycling. The results also suggest that an increase in income marginally reduces the rate of recycling where a 1000 dollar increase in annual income per capita will reduce the rate of recycling by 0.2 percentage point. Our pooled OLS model did not address the endogeneity problem of any of the policy variables. The policy variables that are significant in this model are *Curb*, *Drop* and *Ordin*. For this model, an increase in access to curbside recycling improves the rate of recycling—a 1 percentage point increase in access increases recycling rate by 0.04 percentage point. Adding one recycling drop-off center per 1000 populations was also found to increase recycling rates by 1.28 percentage points. The results also indicate that having a county recycling ordinance will increase the rate of recycling by 4.16 percentage point.

The random effects model without the endogenous policy variables has a lower explanatory power than the pooled OLS model, and we find that income, age and education are not significant in this model. However, in this model *VarP* significantly affects the rate of recycling. The implementation of a variable pricing (*VarP*) structure on waste disposal charges is suggested to increase recycling rate by 1.62 percentage points. *Ordin* remains significant in this model but *Curb* and *Drop* are no longer significant. Nevertheless, the interaction variable *CurbDrop* is significant in this model. This indicates that curbside and drop-off recycling are able to increase the rate of recycling when implemented together. Similar to the pooled OLS, our random effects model did not account for potential endogeneity of the policy variables.

The third model corrects for endogenous policy variables. We identify endogenous variables in our model by conducting endogeneity tests. The test is conducted by first estimating a reduced form OLS regression for the potentially endogenous variables. We regress these variables against all exogenous variables in our main equation (Eq. (12)), together with other exogenous variables that do not appear in the main equation but we believe are correlated with the endogenous variable. We then obtain the residuals from our reduced form regression and use it as an explanatory variable in OLS regression of our main equation. We conclude that a variable is endogenous if the reduced form residual is found to have a significant coefficient in the main regression (Wooldridge, 2006). The test found that *VarP*, *Curb* and *Drop* are endogenous. We correct for endogeneity of *VarP* by using the predicted value from its reduced form regression. We instrument for *Curb* and *Drop* with its 1-year lagged variables. The choice of 1-year lagged variables for *Curb* and *Drop* as the instruments is appropriate because we believe that the previous years' curbside recycling services and drop-off centers are exogenous to the current year's decision on the amount of recycling and waste generated in a county.

Correcting for endogeneity slightly improves the explanatory power of our random effects model, evident from the increase

Table 3
Determinants of the annual recycling rate in Minnesota counties.

Dependent variable = residential recycling rate per annum	Pooled OLS Coefficient	Std. error	Random effects Coefficient	Std. error	IV-random effects Coefficient	Std. error
VarP	0.315	0.576	1.623	0.923*	4.193	2.210**
Ordin	4.151	0.569***	2.969	1.078***	2.108	1.090**
Curb	0.037	0.014***	−0.011	0.02	0.008	0.012
Drop	1.274	0.620**	0.934	0.765	−0.684	0.484
CurbDrop	0.001	0.013	0.026	0.015*	0.022	0.010**
EducExp	−0.534	0.435	0.747	0.477	0.816	0.505*
Inc	−0.0002	0.0001**	−0.0001	0.0001	−0.0002	0.0001*
Age	0.38	0.076***	0.229	0.148	0.445	0.141***
Educ	0.151	0.064**	0.136	0.11	0.129	0.114
Den	−0.001	0.001	−0.001	0.001	−0.001	0.001
Year dummies	Yes		Yes		Yes	
Constant	0.262	3.379	4.956	5.341	−3.127	5.850
N	774		774		774	
R^2	0.206		0.167		0.173	

* $\alpha < 0.10$.
** $\alpha < 0.05$.
*** $\alpha < 0.01$.

in R^2 from 0.167 to 0.173. *VarP*, *Ordin* and *EducExp* are significant in this model. We found variable price (*VarP*) to have a bigger impact on increasing the rate of recycling after correcting for endogeneity. Implementation of a variable pricing structure on waste disposal was found to increase the recycling rate by 4.19 percentage points in the IV-random effects model as opposed to only 1.62 percentage points in the random effects model without endogeneity corrections. The coefficient for *EducExp* suggests a dollar increase in per capita cumulative education expenditure will increase recycling rate by 0.82 percentage points. Income and age are found to be significant in this model with the expected signs. Our estimates do not find a significant negative association between recycling rate and population density. One possible reason is that higher population density also makes investments in recycling infrastructure and education more economic. Hence densely populated counties are likely to have better recycling facilities and awareness. Another possible reason is that the large cities of Minneapolis and St. Paul are located in Hennepin and Ramsey counties, making these the two highest density counties in Minnesota. It may also be that the density variable captures differences in recycling attitudes and behavior within these urban counties.

6. Conclusions

The rate of recycling is an important indicator that is widely used by policy makers to assess the level of recycling activities in a community, county or state. This study examines the effect of policy, income and demographic variables on the rate of recycling in Minnesota counties. After accounting for random effects and endogenous policy variables, our results demonstrate that variable pricing of waste disposal significantly increases the rate of recycling. This confirms the previous findings from cross-sectional studies that variable pricing is an effective policy tool for increasing the amount of recycling and reducing waste generation. Our findings also indicate that regulations can be an effective means of increasing recycling. We found that the enactment of recycling ordinances making residential recycling mandatory increases the rate of recycling.

It is also interesting to note that curbside recycling services and drop-off centers are effective in increasing the rate of recycling when implemented together as a recycling program. Curbside and drop-off recycling were found to be insignificant in improving the rate of recycling if they are implemented separately. Educating the public on recycling was also found to increase recycling rate. The findings showed that the cumulative expenditure on recycling education increased recycling rate, at the 10% level of significance. Spending one dollar per person per year will increase the rate of recycling by approximately 2%.

References

Barr S, Ford NJ, Gilg A. Attitudes towards recycling household waste in Exeter, Devon: quantitative and qualitative approaches. Local Environ 2003;8(4):407–21.
Becker G. A theory of the allocation of time. Econ J 1965;75:493–517.
BioCycle. Why Minnesota ranks second in the nation in recycling. BioCycle 2006;47(July(7)):14 pp.
Bruvoll A, Nyborg K. The cold shiver of not giving enough: on the social cost of recycling campaigns. Land Econ 2004;80(4):539–49.
Callan SJ, Thomas JM. Analyzing demand for disposal and recycling services: a systems approach. East Econ J 2006;32:221–40.
Fullerton D, Kinnaman TC. Household responses to pricing garbage by the bag. Am Econ Rev 1996;86:971–84.
Hage O, Söderholm P. An econometric analysis of regional differences in household waste collection: the case of plastic packaging waste in Sweden. Waste Manage 2008;28(10):1720–31.
Hage O, Söderholm P, Berglund C. Norms and economic motivation in household recycling: empirical evidence from Sweden. Resour Conserv Recy 2009;53(3):155–65.
Hong S. The effects of unit pricing system upon household solid waste management: the Korean experience. J Environ Manage 1999;57:1–10.
Hong S, Adams RM. Household responses to price incentives for recycling: some further evidence. Land Econ 1999;75:505–14.
Hornik J, Cherian J, Madansky M, Narayana C. Determinants of recycling behavior: a synthesis of research results. J Socio-econ 1995;24(1):105–27.
Jenkins R. The economics of solid waste reduction: the impact of user fees. London: Edward Elgar Publishing; 1993.
Johnstone N, Labonne J. Generation of household solid waste in OECD countries: an empirical analysis using macroeconomic data. Land Econ 2004;80:529–38.
Kinnaman TC, Fullerton D. Garbage and recycling in communities with curbside recycling and unit-based pricing. NBER Working Papers 6021, National Bureau of Economic Research, Inc.; 1997.
Kinnaman TC, Fullerton D. Garbage and recycling with endogenous local policy. J Urban Econ 2000;48:419–42.
Linderhof V, Kooreman P, Allers M, Wiersma D. Weight-based pricing in the collection of household waste: the Oostzaan case. Resour Energy Econ 2001;23:359–71.
Lund HF. The McGraw-Hill recycling handbook. New York: McGraw-Hill Book Co; 2001.
Meneses GD, Palacio AB. Recycling behavior: a multidimensional approach. Environ Behav 2005;37:837–60.
Nyborg K, Howarth RB, Brekke KA. Green consumers and public policy: on socially contingent moral motivation. Resour Energy Econ 2006;28(4):351–66.
Nyborg K, Rege M. Does public policy crowd out private contributions to public goods. Public Choice 2003;115(3):397–418.

Podolsky MJ, Spiegel M. Municipal waste disposal: unit pricing and recycling opportunities. Public Works Manage Policy 1998;3:27–39.
Pollack RA, Wachter ML. The relevance of the household production function and its implications for the allocation of time. J Polit Econ 1975;83:255–77.
Rege M. Social norms and private provision of public goods. J Public Econ Theory 2004;6(1):65–77.
Saltzman C, Duggal VG, Williams ML. Income and the recycling effort: a maximization problem. Energy Econ 1993;15:33–8.
Saphores JM, Nixon H, Ogunseitan OA, Shapiro AA. Household willingness to recycle electronic waste: an application to California. Environ Behav 2006;38: 183–208.
Schultz PW, Oskamp S, Mainieri T. Who recycles and when? A review of personal and situational factors. J Environ Psychol 1995;15(2):105–21.
Sidique SF, Lupi F, Joshi SV. The effects of behavior and attitudes on drop-off recycling activities. Resour Conserv Recy 2009; doi:10.1016/j.resconrec.2009.07.012.
Thogersen J. Recycling and morality: a critical review of the literature. Environ Behav 1996;28(4):536–59.
Tonglet M, Phillips PS, Read AD. Using the theory of planned behaviour to investigate the determinants of recycling behaviour: a case study from Brixworth, UK. Resour Conserv Recy 2004;41(3):191–213.
USEPA. Municipal solid waste in the United States, 2007 facts and figures. USEPA; 2007.
Van Houtven GL, Morris GE. Household behavior under alternative pay-as-you-throw systems for solid waste disposal. Land Econ 1999;75:515–37.
Vining J, Ebreo A. What makes a recycler? A comparison of recyclers and non-recyclers. Environ Behav 1990;22:55–73.
Wertz KL. Economic factors influencing households' production of refuse. J Environ Econ Manage 1976;2:263–72.
Wooldridge JM. Introductory econometrics: a modern approach. Third edition Thomson South-Western; 2006.