THE DETERMINANTS OF MUNICIPAL RECYCLING: A TIME SERIES APPROACH

Neil Terry, West Texas A&M University

ABSTRACT

Since the late 1980s, recycling has been promoted as a viable means of addressing the problems associated with municipal waste disposal. This study shows that the composition of the municipal solid waste stream has a direct impact on the recycling rate. Empirical evidence shows that packaging and container items are recycled at a statistically significant rate. Other factors influencing municipal solid waste recycling include the demographic characteristics of society and landfill disposal.

INTRODUCTION

In an age of high technology and scientific innovation, it is ironic that one of man's oldest problems is becoming increasingly acute. The collection and disposal of modern municipal waste products is a monumental task. Recycling can be considered a solid waste management strategy. It is as useful as landfill dumping or incineration. Recycling occurs for three basic reasons: altruistic reasons, economic imperatives, and legal considerations. In the first instance, protecting the environment and conserving resources have become self-evident as being in everyone's general interest. Second, the avoided costs of environmentally acceptable landfill dumping and incineration have risen to a level where it now makes economic sense to recycle many waste materials. Finally, in responding to both public demand and a growing lack of alternative waste disposal methods, government is requiring recycling and providing a wide variety of economic and civil penalties and incentives to encourage recycling.

As the amount of municipal solid waste (MSW) to be disposed of increases and the number of available landfills decreases, communities all over the country are grappling with problems related to the management and disposal of garbage. Many communities have undertaken a variety of activities to dispose of municipal solid waste in economically responsible and environmentally viable manners. One approach to the management and disposal of municipal solid waste has been recycling. The purpose of this study is to use multivariate analysis to investigate the determinants of municipal solid waste recycling. Specific areas of interest include the impact of MSW composition, demographic characteristics, and landfill disposal on municipal recycling rates. This study is organized as follows. First, background information on federal and state recycling legislation is provided. The next section offers a brief discussion of the theoretical foundations for MSW recycling. The third section describes the sample data and sources. The fourth section provides a discussion of the empirical model and variables employed in the study. The next section presents an empirical evaluation of recycling determinants. The final section offers conclusions.

RECYCLING LEGISLATION

Recycling legislation has been national law since the 1970's National Environmental Policy Act (NEPA), which focuses on government's responsibility to maintain harmony between people and the environment. Section 4331(a) declares that it is the policy of the Federal Government to use all practical means and measures to create and maintain conditions under which man and nature can exist in productive harmony. Section 4331 (b) adds that it is the responsibility of the federal government to enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

Reacting to both public concern and the realities of the solid waste disposal problem, a plethora of waste reduction and recycling legislation has been sponsored in the last thirty years. Proposed legislation follows directly from responsibilities dictated in the 1970 NEPA act. In 1976, Congress passed the Resource Conservation and Recovery Act (RCRA). RCRA further emphasized the preservation of the environment through the following priorities: waste reduction, recycling, resource recovery, and landfilling. Although RCRA was passed as comprehensive solid waste management legislation, its main focus has been on the management of hazardous waste. Waste reduction and recycling amendments to the RCRA have been proposed within the last ten years. If adopted, states would be required to follow comprehensive solid waste management and waste reduction strategies for the next two decades. Other bills that are currently under review include actions such as a mandated national recycling goal of 25-50 percent, usage taxes on virgin materials, and recycling content legislation for items like newsprint, plastics, and tires.

A current goal of the EPA is to manage 25 percent of the United States' municipal solid waste through source reduction and recycling. While the 25 percent goal is not federal law, the EPA provides recommendations through which the goal can be reached. In a proposed revision of the federal Clean Air Act, the EPA proposed waste-to-energy incinerators to reduce the amount of garbage they burn by 25 percent through recycling and composting. The EPA has also imposed new requirements to control landfill gases and landfill leachate collection with covers and liners. The EPA landfill legislation has contributed to rising landfill disposal prices, which has indirectly encouraged recycling.

Many states have been studying the solid waste problem and developing solutions that include recycling, composting, and waste reduction strategies. The impetus for the legislation in many cases was the lack of available landfill capacity, the not-in-my-backyard (NIMBY) syndrome, the escalating expense of waste disposal, and the environmental consequences of disposal. According to Kreith [9], about 81 percent of all municipal solid waste was landfilled in 1980. Ten years later, that figure was down to 67 percent. Both recycling and incineration are continuously becoming more important in MSW management. State legislation has been directly responsible for the shift. By the end of 1992, 36 states had waste reduction goals. Additionally, 27 states required municipalities to develop recycling programs and 40 had banned some waste materials from landfills and/or incinerators.

Municipal solid waste legislation varies significantly from state to state. For some states, such as Minnesota and Illinois, passage of MSW-related legislation is an annual affair. For instance, in 1991, 94 solid waste related bills were introduced in the Illinois legislature, at least fifteen of those bills, including two that dealt with procurement of recycled products, became law. In other cases, states work on solid waste legislation periodically, revisiting the issue every five to ten years. For example, Pennsylvania passed omnibus solid waste legislation in 1968. In 1980 that legislation was updated, with particular emphasis on hazardous waste management. In 1988, the state legislature passed Act 101, the municipal Waste Planning and Waste Reduction Act, which, among other things, mandated some municipalities to establish recycling programs. The passage of legislation seems to have had an impact on statewide solid waste management strategies. At the present time, 20 states landfill less than 75 percent of the municipal solid waste. Five of those, Connecticut, Maine, Massachusetts, Minnesota, and New Jersey landfill less than 50 percent. That is a considerable change since 1988 when only six states landfilled less than 75 percent of their municipal solid waste.

Another measure of the effect of legislation is the number of programs that have been developed over the last several years. One way to chart the trend in recycling is to keep track of the most visible collection program, curbside recycling. In 1981, there were fewer than 300 known curbside recycling projects in all the United States [1]. The number of curbside programs increased to an estimated 1,042 by 1988 and 8,000 by 1999 [3, 14].

THEORETICAL BACKGROUND

An increasing amount legislation aimed at increasing MSW recycling has been put forth on the state and federal level over the past forty years. Most of the action has been on the state level in response to concerns about the environment and a perceived shortage of landfill space. States like Minnesota, Illinois, and Pennsylvania have had very active MSW recycling legislation. One of the factors in the push toward waste reduction legislation was the perception that landfill space is dwindling. While such an assertion is debatable, it is clear that the number of landfills in this country continues to decline. At the end of 1988, there were at least 7,924 landfills operating in this country. Today, fewer than 5,000 landfills are operating. Although the absolute number of landfills is decreasing steadily, it does not necessarily follow that there is a comparable decline in disposal capacity. New technologies that incorporate variations of baling and layering have dramatically increased disposal capacity per area. The increasing quantity of municipal solid waste regulations and legislation for landfill disposal has increased the MSW recycling rate over time. Capacity shortages and environmental regulation have contributed to increasing landfill disposal fees [12]. The average national price for landfill disposal has increased dramatically from $10 per ton in 1983 to over $50 per ton in 1999. Averages fail to describe the whole story. In the Northeast, landfill fees can be over $125. Starr [13] estimates that new federal and state solid waste landfill controls will increase landfill costs between $12 and $17 per ton on average. The increasing cost of landfill disposal should decrease the amount of MSW going into landfills and increase the amount of MSW recycled.

The composition of the waste stream has a direct impact on the level of recycling. Materials most suited for recycling are those intended for short-term consumer usage, which are discarded quickly, and which are present in large quantities in the solid waste stream. Packaging and containers make up a major portion of the MSW stream. Glass, steel, aluminum, plastic, and paper food and beverage containers are the primary items classified by the EPA as packaging and containers. The short-term usage combined with the large quantity in the waste stream implies that MSW recycling should increase as the relative composition of packaging and containers increase. Durable goods are generally defined as products having a lifetime of three years or more. Durable goods include major appliances, furniture and furnishings, rubber tires, small electronics, and consumer electronics. The long-term usage of durable goods implies that there should be a negative relationship between durable good generation in the waste stream and MSW recycling. The Department of Commerce defines nondurable goods as those having a lifetime of less than three years. Products made of paper and paperboard comprise the largest portion of nondurable goods. Nondurable products include paper and plastic plates, cups, and other disposable food service products; disposable diapers; clothing and footwear; and other miscellaneous products. Nondurable goods like paper products are highly recyclable while other items like disposable diapers are not currently recyclable. For details on recycling and composting specific items ranging from aluminum cans to yard waste see Lund [10].

Jenkins [8] claims that the presence of young adults have an impact on municipal solid waste generation. Young adults are defined in this study as the percentage of the population from 25 through 44 years of age. Jenkins shows that young adults generate a larger amount of municipal solid waste. Raising young children and trying to establish job tenure are claimed to limit the effort that young adults make toward minimizing MSW generation. The high MSW generation combined with a busy work and family schedule could imply a relatively low recycling rate for the young adult cohort. On the other hand, people in the young cohort might be more concerned about the future of the environment and better educated with respect to environmental issues and consequence. The Jenkins study also shows a negative relationship between household size and MSW generation. This relationship can be explained by the fact that packaging per person is a decreasing function. The relationship between household size and recycling has not been investigated. It is possible that household size could have a positive impact on recycling because of tipping fee cost avoidance considerations related to the volume of municipal solid waste generation. On the other hand, it is also possible that household size could have a negative impact on recycling because of the complications associated with managing a large household.

SAMPLE DATA{tc "SAMPLE DATA"}

The primary source of data for this study is the *Characterization of Municipal Solid Waste* by Franklin Associates [4]. Franklin Associates publishes a series of reports in association with the U.S. Environmental Protection Agency to characterize municipal solid waste in the United States. Annual data from 1960 through 2000 is used in the study. Franklin Associates employs two research methods in their analysis. The first is a site-specific approach in which the individual components of the municipal waste stream are sampled, sorted, and weighed. The second method is called the material flows methodology. The EPA's Office of Solid Waste and its predecessors in the Public Health Service sponsored work in the 1960s to develop the material flow methodology. This methodology is based on production data (by weight) for the materials and products in the waste stream, with adjustments for imports, exports, and product lifetimes. Information on the MSW recycling rate, MSW generation, packaging waste generation, durable goods waste generation, nondurable goods waste generation, and MSW discarded in landfills can all be found in the *Characterization of Municipal Solid Waste*. The Bureau of Labor and Statistics is the source of data on income, population, household size, and population age composition. The Bureau of Labor and Statistics is the principal fact-finding agency for the Federal Government in the broad field of labor economics and statistics. It has a dual role as the statistical arm of the Department of Labor and as an independent national statistical agency that collects, processes, analyzes, and disseminates statistical data.

MODEL FORMULATION AND VARIABLE DESCRIPTION{tc "MODEL FORMULATION AND VARIABLE DESCRIPTION"}

This study examines the influence of the explanatory variables on the recycling rate of municipal solid waste. The specific MSW recycling equation is presented as follows (where individual observations are represented by subscript i):

$$RR_i = \alpha_1 + \alpha_2\,INCOME_i + \alpha_3\,HHS_i + \alpha_4\,YOUNG_i + \alpha_5\,LANDFILL_i \\ \alpha_6\,NONDURABLE_i + \alpha_7\,DURABLE_i + \alpha_8\,PACKCON_i + u_i \qquad (1)$$

The following is a brief description of the explanatory variables and their expected sign:

RR = millions of tons of MSW recovered divided by millions of tons of MSW generated;
TIME = the observation number from one to thirty-five corresponding to 1960-1994 [+];
INCOME = average income per capita [+];
HHS = population divided by number of households [+];
YOUNG = percent of the population from 25 through 44 years of age [-];
LANDFILL = millions of tons of municipal solid waste discarded in landfills [-];
NONDURABLE = millions of tons of nondurable goods generated in the waste stream divided by millions of tons of municipal solid waste generated [-];
DURABLE = millions of tons of durable goods generated in the waste stream divided by millions of tons of municipal solid waste generated [-];
PACKCON = millions of tons of packaging and containers generated in the waste stream divided by millions of tons of municipal solid waste generated [+];
u = a stochastic error term.

It should be noted that recovery of municipal solid waste does not automatically equal recycling as defined by Franklin Associates. This makes the RR variable somewhat misleading. Recovery is defined as the removal of materials and products in the municipal solid waste stream for recycling or composting. For the purpose of this study, composting is considered to be a form of recycling as composted items are reused. If composting is considered to be a general form of recycling then recycled materials and recovered materials are one and the same.

The expected sign on the variables HHS, YOUNG, and NONDURABLE is unclear. While it is known that smaller households have resulted in higher per capita consumption rates of several products that end up in the waste stream, the relationship between household size and recycling is unknown [7]. The cohort of people classified by the YOUNG variable are known to generate relatively more MSW than any other age group but the recycling habits of this cohort are unknown. Many nondurable goods like paper products are highly recyclable while other items like disposable diapers are not currently recyclable. The composition of the MSW stream should have a direct impact on the recycling rate.

The variables TIME, INCOME, and PACKCON are expected to have a positive impact on the recycling rate. The variable TIME is used as a proxy for state and federal legislation. Over the course of time there has been an increasing amount of municipal solid waste and recycling legislation enacted into laws. This legislation should have a positive impact on MSW recycling. INCOME is also expected to have a positive coefficient in the model because it is anticipated that public concern for the environment is a positive function of income. The variable PACKCON should have a positive coefficient as an increasing composition of packaging materials and containers in the municipal solid waste stream should stimulate MSW recycling because the materials have the positive attributes of short-term consumer usage and reliable availability [2]. The EPA classifies packaging and container items separately from nondurables in their official data.

The variables LANDFILL and DURABLE are expected to have negative impacts on the dependent variable. Landfills are a substitute for recycling so it is anticipated that there is a negative relationship between municipal solid waste being discarded in landfills and the recycling rate [5]. Durable goods are designed for long term usage and are not designed for recycling. If the municipal waste stream is composed of a large amount of durable goods it is anticipated that the recycling rate will be relatively low.

STATISTICAL METHODOLOGY{tc "STATISTICAL METHODOLOGY"}

When time series data are used in regression analysis, often the error term is not independent through time. If the error term is autocorrelated, the efficiency of ordinary least-squares (OLS) parameter estimates are adversely affected and standard error estimates are biased. When autocorrelation is detected, several alternate methods that produce better estimates can be employed. In many cases the alternative methods yield estimates that are similar to OLS estimates. The estimation method employed in this study is known as the Yule-Walker (YW) estimation method. Harvey [6] calls this method the two-step full transform method. The procedure estimates parameters of a linear model whose error term is assumed to be an autoregressive process of a given order *p*, denoted AR(*p*). The general model for time *t* is $y_t = x_t B + v_t$; where $v_t = e_t - a_t v_{t-1} - a_p v_{t-p}$, x is a vector of regressor values, and *B* is a vector of structural parameters. Generalized least squares (GLS) can be employed to estimate unbiased and efficient regression parameters. The theoretical autocorrelation function can be to the parameter values through a system of equations known as Yule-Walker equations. If these equations are inverted, they can be used to solve for the parameter values in terms of the autocorrelation function. The Yule-Walker method is generalized least squares using the OLS residuals to estimate the covariances across observations [11].

The results in this study from the YW estimation method are almost identical to the results from unconditional least squares (ULS) and maximum-likelihood (ML) methods. The ULS and ML methods employ a Gauss-Marquardt algorithm. The ULS method minimizes the sum of squares while the ML method maximizes the log likelihood. In this study the sign, size, and significance of each estimated coefficient are approximately the same for the YW, ULS, and ML method. Only the YW results are presented because they yield slightly more efficient estimates. The idea behind smoothers and filters is to remove particular aspects of a time series. Smoothers attempt to remove the excess randomness of the time series and leave only the underlying smooth curve. A centered moving average smoother of length five was used to smooth the data in this study.

RESULTS{tc "RESULTS"}

The results from the Yule-Walker estimation method are summarized in Table 1. Using the YW method, the AR process is found to be significant at the five percent level up to order two. The AR (2) model includes the first-order lag, which is also significant at the five percent level. The most significant explanatory variable in Table 1 is LANDFILL. As expected, there is a negative relationship between landfill disposal and recycling. Hence, a fall in the amount of municipal solid waste dumped in landfills corresponds to an increase in the recycling rate. Environmental regulations and potential capacity shortages have increased landfill fees and discouraged landfill disposal over time. As cost effective means of landfill disposal decreases over time the recycling rate of MSW should continue to increase.

The composition of the waste stream is shown to have a direct impact on recycling. The explanatory variables PACKCON, NONDURABLE, DURABLE are all significant at the ten percent level, with two of the three significant at the five percent level. The positive coefficient on the PACKCON variable implies that a waste stream composed of a relatively large amount of packaging and containers augments MSW recycling. The result is not surprising since glass, aluminum, and plastic containers are a few of the most common items to recycle. The negative coefficients on the DURABLE and NONDURABLE variables imply that a waste stream composed of a relatively large amount of durable and nondurable goods decreases MSW recycling. Durable goods like major appliances and furniture are designed for long term usage. The characteristic of long-term usage makes durable goods unattractive to recycle. Nondurable goods like paper products are highly recyclable while other items like disposable diapers are not currently recyclable.

Table 1
Results from the Yule-Walker Estimation Method (MSW Recycling)

	Model 1	Model 2 (smoothed data)
Variables	Parameter Estimates (t-values)	Parameter Estimates (t-values)
INTERCEPT	-0.4316 (-1.84)	-0.7224 (-2.69)*
TIME	0.0096 (6.21)*	0.0079 (4.34)*
INCOME	0.0036 (1.18)	0.0027 (0.92)
HHS	-0.0153 (-0.54)	-0.0583 (-1.72)
YOUNG	1.8209 (5.82)*	2.2433 (5.46)*

LANDFILL	-0.0038	-0.0039
	(-9.86)*	(-9.74)*
NONDURABLE	-0.5833	-0.2607
	(-1.88)	(-0.73)
DURABLE	-2.4385	-2.5251
	(-4.60)*	(-5.32)*
PACKCON	2.0638	2.9438
	(8.12)*	(9.46)*
AIC	-276.0	-310.0
Total RSQ	0.9911	0.9955
Durbin-Watson	2.0402	2.0361

Note: * indicates p<.05

Time and income per capita are shown to have a positive impact on MSW recycling. The positive and significant coefficient on the TIME variable implies that regulation, legislation, public concern, and other factors have increased the municipal solid waste recycling rate over time. The TIME variable captures the positive MSW recycling trend. INCOME has the anticipated positive sign but the coefficient is not significant at the five percent level.

The relationship between household size and recycling is tested here and revealed to be insignificant at the five percent level. Hence, there does not appear to be a strong relationship between household size and recycling. The coefficient on YOUNG is found to be positive and significant. The result implies that there is a positive relationship between people in the 25-44 age cohort and recycling. This result implies that future concern for the environment and environmental education is relatively great in the 25-44 cohort.

The results from the Yule-Walker estimation method with a moving average smoother are also presented in Table 1. The smoothed data yield approximately the same sign, size, and significance in six of the eight variables. The autoregressive model was found to be an AR (2). The variables TIME, YOUNG, LANDFILL, DURABLE, and PACKCON are significant at the five percent level with the anticipated sign, as before. Once again, the variable INCOME has a positive coefficient but is not significant at the five percent level.

The two variables that yield different results with the smoothed autoregressive estimates are HHS and NONDURABLE. The HHS variable is negative and significant at the ten percent level in the smoothed data. The implication is that a decrease in household size decreases MSW recycling. It is possible that recycling is easier in a small household or that the relatively high MSW generation per person in a small household encourages recycling. It is also possible that over time a steady decrease in household size and a steady increase in MSW recycling create a confounding relationship. The TIME variable may not have incorporated all of the random walk over time. The NONDURABLE variable was significant at the five percent level in the Yule-Walker estimation method but is not significant when the data are smoothed. There may have been high correlation in the original estimate causing the significant coefficient. There is no reason to believe that there should be a consistent positive or negative relationship between nondurables and MSW recycling because of the deviation in the ability to recycle various nondurable items.

The results from the Yule-Walker estimation method with the moving average smoother are slightly more efficient than the results from the standard Yule-Walker estimation method. The smoothed YW model has a Root MSE of .0024 and an Akaike's information criterion (AIC) of -310. The standard YW model has a Root MSE of .0042 and an AIC measure of -276. A small Root MSE and AIC implies a better fit. The total r-square (Total RSQ) and the Durbin-Watson test for serial correlation is approximately the same in the two models.

CONCLUSIONS

This study uses a time-series approach to investigate the determinants of municipal solid waste recycling during the last forty years. The results verify the fact that the composition of the municipal solid waste stream impacts recycling. Packaging and container items constituting a large percentage of the municipal solid waste stream have a positive impact on recycling. This can be explained by the fact that the materials most suited for recycling are those intended for short-term consumer usage. Many packaging and container items fit this description. Durable goods, on the other hand, are products that are designed to last a minimum of three years. The long term usage nature of durable goods makes them undesirable items to have in the municipal solid waste stream if the objective is to recycle. The amount of municipal solid waste being discarded in landfills is shown to have a negative impact on the recycling rate. The inverse relationship implies that recycling offers an alternative to landfill disposal. One of the reasons for the increase in the MSW **{tc "CONCLUSIONS"}**
recycling rate has been the increase in landfill disposal fees brought about by legislation, regulation, and capacity shortages in certain locations. Income per capita also has a positive impact on MSW recycling but the impact is not statistically significant. While public concern for the environment is shown to be a positive function of income through the recycling variable, the relationship appears to be fairly weak. It is important to note that the results of this study are derived from aggregated data over a forty year time period. Further research with more detailed data is needed in order to determine the role of recycling in solving the municipal solid waste disposal problem.

REFERENCES{tc "REFERENCES"}

Alexander, J. (1993). *In Defense of Garbage*. Westport, CT: Praeger.

Carroll, W. (1995). "The Organization and Efficiency of Residential Recycling Services." *Eastern Economic Journal,* 21 (2), 215-225.

Duston, T. (1993). *Recycling Solid Waste*. Westport, CT: Quorum Books.

Franklin Associates (2000). *Characterization of Municipal Solid Waste in the U.S., 1960 to 2000*. Prairie Village, KS: Franklin Associates, Ltd.

Fullerton, D. and T. Kinnaman (1996). "Household Responses to Pricing Garbage by the Bag." *The American Economic Review*, 86 (4), 971-984.

Harvey, A. (1981). *The Econometric Analysis of Time Series*. New York: John Wiley & Sons, Inc.

Holthausen, D. and G. Morris (1994). "The Economics of Household Solid Waste Generation and Disposal." *Journal of Environmental Economics and Management*, 26 (3), 215-234.

Jenkins, R (1993). *The Economics of Solid Waste Reduction*. Hampshire, MA: Edgar Elgar.

Kreith, Frank (1994). *Handbook of Solid Waste Management*. New York: McGraw-Hill.

Lund, H. (1993). *The McGraw-Hill Recycling Handbook*. New York: McGraw-Hill.

Park, R. and B. Mitchell (1980). "Estimating the Autocorrelated Error Model with Trended Data." *Journal of Econometrics*, 13 (2), 185-201.

Repa, E. and A. Blakey (1996). "Municipal Solid Waste Disposal Trends." *Waste Age*, 27 (5), 170-180.

Starr, R. (1995). "Recycling: Myths and Realities." *The Public Interest*, 119 (2) 28-41.

Steuteville, R. (2000). "The State of Garbage in America." *Biocycle*, 41 (4), 54-62.