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Analysis of Optimal Solid Waste Recycling Policy: Evidence from U.S. Using Panel Data

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Abstract

We analyze how implementation of a market-based program of optimal recycling can be pursued and used to promote environmental quality. Presently in the U.S. economy, due to the relatively low private monetary costs of solid waste disposal, households and firms have little or no incentive to undertake recycling. As a result, most current recycling programs are apt to yield less than efficient outcomes. The paper offers a model for achieving an optimal level of recycling, and applies a combination of time-series and cross-sectional data to analyze and verify the potentials of an optimal recycling policy initiative toward an enhanced environmental management.

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Keywords: Recycling rate, Fixed and Random effects, Endogenous variables, Sample selection bias.

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1. Introduction

Due to the relatively low private monetary costs of solid waste disposal, households and firms have little or no incentive to undertake recycling. Because of this, any recycling program under this setting would yield a less that efficient outcome. The question then arises as to whether or not a more efficient recycling program can be devised. In North America, various regional "Solid Waste Action Teams" have evolved and implemented innovative means to promote the three R's (reduce, recover, and reuse) of environmental resource management of solid waste – generally referred to as the policy of recycling. Among its many programs are the drive to inform and educate the public about alternatives for waste reduction, the adoption of a maximized recycling system, and installations of collection depots for recyclable materials.

Many State governments across America had set the goals of decreasing solid waste by at least 50 percent by the year 2020. A primary approach for reaching this goal has been the recycling initiative which aims primarily to divert waste from land-fill sites in order to reduce land use as well as the environmental risks associated with land-fill sites. There is also the desire to reduce consumption of natural resources. Moreover, as well as environmental objectives, there are considerable economic benefits to be secured from recycling: reduction of garbage collection costs for municipalities, revenue from the sale of recycled materials, and the creation of jobs. In 1991 the U.S. Environmental Protection Agency estimated that more than half of the existing landfills in North America would reach capacity by 1995. At the time, the precision of this forecast was subject to some skepticism; yet it goes to highlight the environmental problem of solid waste disposal. In Japan, where landfill space is particularly scarce, measures to promote more environmentally benign solid waste management have been widely pursued in recent years. In 1989, about 40 percent of Japan's solid waste was being recycled, including about 50 percent of the paper, 55 percent of glass bottles, and 66 percent of food and beverage cans. The program involved a massive reuse campaign to persuade many Japanese to conserve and reuse commodities such as TV sets, refrigerators, cars, and clothing. To facilitate recycling, citizens were compelled to separate combustible waste (which made up about 72 percent of the total), and deposit it at specially designated depots from which it would be trucked to incinerators. With the weight and volume of waste thus reduced, the remainder, about 9 percent of the total initial waste, was then deposited in landfills.

The U.S. experience indicates that if consumers bear the cost of disposal, they have an incentive either to reuse waste materials or to return them to collection centers. By so doing they avoid disposal costs, while at the same time they reap financial rewards by supplying a needed product. The effect is lower prices of products made from recycled materials compared to higher prices of products made exclusively from virgin raw materials, as long as quality is not adversely affected. This sort of economic incentive can be utilized to implement a recycling program that make people adjust their lifestyle choices to promote "greener" outcomes. This paper applies a model based on the idea of such an incentive-based program to determine an optimal recycling approach to environmental quality.

The rest of the paper is organized as follows. Section 2 reviews some recycling studies in the literature. Section 3 develops an optimal recycling model that can be used to achieve efficient recycling policy initiatives. The empirical model to test the model outlined in Section 3 is presented in section 4, while section 5 presents the data source and the description of variables in the empirical model. The empirical results are discussed in section 6, and the last section presents a summary, conclusions and policy implications.

2. Solid Waste Recycling: Some Previous Literature

Liang, Chunwen, Luchen, and Huang. (2018) had observed that the mainstream research on the subject of resource conservation and recycling tended to have mainly focused on recycling, waste management, sustainability, and environmental impact. The authors also noted that life cycle assessment, material flow, and substance flow analysis, have been the most popular methods of focus in recent years. They predicted that the emerging hot topics of future great interest would include food waste, electric and electronic waste, packaging waste, carbon footprint, resource efficiency, and the circular economy.

In a general equilibrium contextual analysis, De Beir, Fodha, and Girmens (2007) considered how recycling could be subsidized if/where recycling costs are high, as an incentive to recycle all of the available waste. The researchers proposed that recycling should even be taxed in in such a case, in order to make the competitive equilibrium to be an optimal allocation. They also concluded that, if recycling is efficient enough, it allows to internalize environmental externalities, in which case it would simply amount to a tax instrument. Recent studies have analyzed decision making toward the optimal recycling method for overall service performance in recycling waste tire rubber, in which it was noted that there were limited studies focusing on the recycling method assessment and decision-making approach in the sector (Yu, Chen, et. al., 2020). The work proposed an optimal procedure designed to fill the gap, resulting in different crumb rubber recycling methods being prepared and tested to determine fitness. They determined how an experimental work revealed the significance of an optimal recycling method on the service performance within the market sector.

The issue of electric vehicle manufacturers' battery recycling strategy under government subsidy in China, was studied (Shao, Deng, et. al., 2018). To address the increasing environmental concerns about used electric vehicle batteries in China, the researchers applied a consumer utility function to capture consumer environmental awareness associated with battery recycling, and used a game-theoretical approach was to analyze the interaction between the government and the manufacturer. They found that, with an exogenous government subsidy, the manufacturer either recycles all the batteries, or does not recycle any batteries at all, if the impact of the recycling scale on costs is not remarkable; otherwise, the manufacturer would recycle some used batteries when the benefit from recycling is moderate. The authors concluded that, interestingly, an increased subsidy causes the manufacturer's battery recycling rate to decrease if the subsidy is sufficiently large. And if/when the government subsidy is endogenous, either full recycling, no recycling, or partial recycling could still occur. The optimal battery recycling rate, and social welfare, are lower in a non-cooperative game than in a cooperative game, if the benefit from recycling is relatively low.

In a most recent study about the increasing number of garment enterprises that are paying greater attention to the importance of recycling, Cao and Ji (2022) analyzed the strategy of recycling garment products and re-manufacture, which forms what the researchers labelled as "a closed-loop supply chain." They state that, because recycling involves a complex system, the recycling strategy of clothing brands will not only affect the reverse channel of closed-loop supply chain, but also affect the consumer demand of forward channel, and then affect the profit of supply chain. Thus, in order to solve this problem, they propose a "closed loop supply chain" composed of a manufacturer, a retailer, and a collector, to establish three different Stackelberg leadership models, and derive the optimal recycling strategy. Their model is used to show how consumers' sensitivity to the recycling price would affect the optimal decision of supply chain members. Further, they conclude that increase of recycling is not always necessarily beneficial to the profits of supply chain members; and that by comparing the profits under the three models, it is found that the retailer leadership model is the most effective scenario of the "closed-loop supply chain." The results provide a reference for garment enterprises to formulate recycling strategies.

Kinnaman, Shinkuma, and Yamamoto (2014) estimated the average social cost of municipal waste management as a function of the recycling rate. The authors defined social costs to include all municipal costs as well as external disposal costs. The study suggested that average social costs are minimized with recycling rates well below observed and mandated levels in Japan. Cost-minimizing municipalities were estimated to recycle less than the optimal rate; and with these results being robust to changes in the components of social costs, the researchers concluded that it indicated that Japan, and perhaps other high-income countries, might be setting inefficiently high recycling goals. And earlier in a preceding study, Kinnaman (2010) found that after experiencing nearly twenty years of increases in national recycling rates, the recycling rates in some high-income countries had leveled off at between 20 percent and 30 percent over ten years, which indicated some sort of a steady state level. The question then would be whether the observed steady state would be socially optimal. The author obtained data from both the United States and Japan, and used them to determine that the net social costs of recycling either remain constant (in Japan) or fell with increases in the recycling rate above 8 percent (in the United States). He also found that the net private costs of recycling (those costs internalized by municipal governments) also fell with increases in the recycling rate for all recycling rates over 25 percent. He then proposed that policies aimed to increase the recycling rate over existing levels would therefore be socially beneficial, which led him to wonder why municipal governments had not continued to increase their recycling rates and reduced their own costs in the process.

Earlier works on recycling had established clearly that because solid waste is one of the major residuals generated by economic activities, and as society began to be increasingly faced with rising disposal costs, communities were apt to implement serious programs of encouraging recycling activities (Hong, Adams and Love, 1993; Ezeala-Harrison, 1995; Ebreo, 1999). These studies examined the role of price incentives and other socio-economic factors in household recycling. Hong et al.'s study modeled participation in recycling as an ordered Probit choice using a large data sample of households from the Portland, Oregon, metropolitan area, and estimated the demand for solid waste collection, with results indicating that increases in disposal fees encourage recycling, even though demand for solid waste collection services is not reduced substantially. Ebreo's (1999) work was a survey of several communities conducted to investigate the public's response to solid waste issues. It examined the relation between respondents' beliefs about environmentally responsible consumerism and environmental attitudes, motives, and self-reported recycling behavior. The study addressed three attributes, namely, the public's perception of environment-related product attributes; a socio-demographic characterization of environmentally concerned consumers; and the depiction of the relations between attitudes, motives, recycling behavior, and environmental consumerism. The researcher found that respondents were most concerned about product toxicity and least concerned about product packaging; and that only age and gender were predictive of respondents' ratings. And several measures of general environmental concern, recycling attitudes, and recycling motives were found to be related to both categories of product attributes.

Kinnaman and Fullerton (2000) had estimated the impact of garbage fees and curbside recycling programs on garbage and recycling amounts, and found that without correction for endogenous policy, a price per bag of garbage has a negative effect on garbage accumulation, and a positive cross-price effect on recycling; while correction for endogenous local policy increased the effect of the user fee on garbage and the effect of curbside recycling collection on recycling. However, introducing a fee of $1 per bag was estimated to reduce garbage by 412 pounds per person per year (amounting to 44%), but to increase recycling by only 30 pounds per person per year.

Carrus, Passafaro and Bonnes (2008) conducted two field studies in which they applied their "model of goal-directed behavior", to predict intentions to recycle household waste, and examined the role of attitudes, subjective norms, perceived control, anticipated emotions, past behavior and desire, in the prediction of pro-environmental behavioral intention. Their results predicted that negative anticipated emotions and past behavior are significant predictors of desire to engage in pro-environmental action. And in an earlier study, Guerin, Crete, and Mercier (2001) had offered a better understanding of recycling as a function of both individual and contextual variables. The researchers provided a cross-national study that examined how differences in national settings and social and institutional factors, as well as interaction with a series of individual characteristics influenced engagement in recycling behavior in 15 countries within the European Union. They conclude that conservation behavior is greatly influenced by the ecological mobilization in which it occurs; and that the more activists participate nationally in environmental organizations, the more the population would be likely to participate in environmental programs such as the recycling of domestic waste.

A 2007 case study of household waste management in the U.K.'s Environment and Behavior, in which three aspects of waste management behaviors (waste reduction, reuse, and recycling) were examined, posited that environmental values, situational characteristics, and psychological factors all play a significant role in the prediction of waste management behavior, within the context of a core intention-behavior relationship. The framework was tested in a self-report questionnaire of 673 residents of Exeter, UK. It was found that the predictors of reduction, reuse, and recycling behavior differed significantly, with reduction and reuse being predicted by underlying environmental values, knowledge, and concern-based variables. Recycling behavior was characterized as highly normative behavior.

In a quantitative survey comprised of a postal questionnaire sent to a random sample of 360 households drawn from the electoral register, it was found that householders were very willing to participate in recycling, as shown by nearly 80 percent who claimed to recycle paper, but that local recycling services were too unreliable and inconvenient to allow them to do so comprehensively (Martin, Williams, and Clark, 2006). They also found that recycling participation tended to be higher among more affluent and older people, and lower among less affluent and younger households; which led the authors to the supposition that probably the Borough's preponderance of terraced housing militated against a high recycling rate. This meant that local authorities could include the provision of bespoke recycling services to suit the variety of residential conditions across the UK, as a way of enhancing recycling behavior, identify non-recyclers, and explore how householders' underlying psychological, cultural and social attitudes to recycling impinge upon recycling participation rates. Omran, Mahmoud, Aziz, and Robinson (2009) carried out an investigative study of householders attitudes to the recycling of solid wastes in northern Malaysia among selected areas of high, middle and low income households. The study indicated that participation in recycling of household waste depended on the level of awareness and understanding of recycling based on level of education and accessibility to recycling facilities and strategies such as providing recycling bins in every residential area.

Yet a study by Ramaya, Lee, and Lim (2012) examined the determinants of recycling behavior among 200 university students from the perspective of the Theory of Planned Behavior (TPB). The researchers analyzed data using Structural Equation Modeling technique, and found that environmental awareness was significantly related to attitude towards recycling, whilst attitude and social norms had significant impact on recycling behavior. They determined, however, that convenience and cost of recycling were not significant reasons for recycling, with implications that schools and governmental agencies could play significant roles in educating and encouraging positive recycling behavior in society. Park and Berry (2013) analyzed the effectiveness of municipal solid waste (MSW) recycling programs. They conducted an empirical analysis using cross-sectional multiple regression analysis. Their results suggested that the convenience-based hypothesis was supported by showing that curbside recycling had a positive effect on MSW recycling performance and that financial cost-saving incentive-based hypotheses were partially supported, to the effect that individual level incentives can influence recycling performance. Citizen environmental concern was found to positively affect the amount of county recycling, while education and political affiliation yielded no significant results.

The foregoing survey of the literature indicates that the recycling program has immense potential for improvement. An optimal recycling policy is envisaged, that would result in a longer-term cost- efficient program which would be beneficial in overall resource and environmental management. The following analysis is offered to emphasize the immense potentials of consistent programs of efficient and optimal recycling policy initiatives in the free market economy.

3. Modeling Optimal Recycling Rate

We presume that society wishes not only to minimize the potential environmental adversities arising from its continual use of natural resources, but also constantly pursues the maximization of its overall welfare (subject, of course, to well-defined constraints). The central assumption is that all aspects of production and consumption activities add to, or take away from, the environment. Since such activities are recurrent over time, society must devise means to manage the residue.

The economy comprises of k sectors, where:

N_i = total material resource consumption in each sector i per time period,

F_i = volume of fresh (virgin) material resource consumption in each sector i per time period,

R_i = volume of recycled materials used by each sector i per time period,

VSD = total volume of society's solid waste disposal per time period,

VPR = volume of private sector solid waste recycled per time period,

V = total volume of waste generated per time period.

By definition, the total volume of resource use per time period is made up of the sum of virgin resources and recycled materials. That is,

$$\Sigma_1^k(N_i = F_i+R_i), \quad i=1,2\ldots k, \qquad (1a)$$

from which it follows that

$$\Sigma_1^k F_i = \Sigma_1^k(N_i-R_i) = \Sigma_1^k[N_i(1-\rho_i)], \qquad (1b)$$

where

$\rho_i = R_i/N_i$ = rate of reuse of materials (or recycling rate) for each sector.

Further we can write:

$$V = VSD+VPR = VSD+\Sigma_1^k \rho_i N_i. \qquad (1c)$$

Sustainable development policy goals dictate that the society aims at reducing F_i, provided welfare is not compromised. There are essentially two ways to reduce F_i: option 1 is to reduce overall quantity of material resources for each sector (N_i); option 2 is to increase the reuse (recycling) rate in each sector (ρ_i). But option 1 is apt to be recessionary; therefore, option 2 must be adopted, as society is left with the only alternative option of raising ρ_i. But to what level? An optimal level of ρ_i is required for each sector.
The economy wishes to maximize its social welfare subject to the constraints imposed by equations (1a) and (1c). Society's welfare is a function of the utility that society derives from consumption of its material resources:

$$W = W(U), W'(U) > 0, W''(U) < 0 \qquad (2a)$$

$$U = U(\Sigma_1^k N_i), U'(.) > 0, U''(.) < 0 \qquad (2b)$$

where:
W = welfare level of society per time period,
U = utility level of society per time period.

Substituting (1a) into the welfare function, and rewriting slightly, we have

$$W = W[U\{\Sigma_1^k(F_i(1+R_i/F_i))\}],$$

or

$$W = W[U\{\Sigma_1^k(F_i(1+\rho_i N_i/F_i))\}]. \qquad (3)$$

This optimization problem is stated in the Lagrangean form:

$$Max_{F,\rho}\, W[U\{\Sigma_1^k(F_i(1+\rho_i N_i/F_i))\}] + m_1\{\Sigma_1^k(N_i-F_i-R_i)\} + m_2(V-VSD-\Sigma_1^k \rho_i N_i) \qquad (4)$$

where the *m's* are Lagrangean multipliers.

The first-order systems are given by:

$$W'U'[-(\rho_i N_i/F_i)+1+(\rho_i N_i/F_i)] - m_1 = 0 \quad (5a)$$

$$'U'F'_i N_i/F_i - m_2 = 0 \quad (5b)$$

$$\Sigma_1^k (N_i - F_i - R_i) = 0 \quad (5c)$$

$$V - VSD - \rho_i N_i = 0 \quad (5d)$$

Solving these: (5a) and (5b) yield

$$F_i/F'_i N_i = m_1/m_2.$$

We assume that $m_1 = m_2$, that is, changes in N (the economy's resource consumption level) and V (the economy's volume of solid waste disposal) have identical effects on social welfare. This is because any additional resource consumption (or reduction in resource consumption) presumably adds to welfare exactly as much as waste disposal (or increases in pollution) adds to it.
Thus,

$$F_i/F'_i N_i = 1,$$

or

$$F_i^* = F'_i N_i > 0. \quad (6)$$

This gives the optimal level of fresh natural resource use for each sector *i* of the economy per time period.

Also (5c) and (5d) yield:

$V\text{-}VSD\text{-}\rho_i\{\Sigma_1^k(F_i+R_i)\} = 0$, and substituting (6) we have:

$$V\text{-}VSD\text{-}\rho_i\{\Sigma_1^k(F'_i N_i+R_i)\} = 0,$$

from which we obtain the optimal recycling rate for each sector i of the economy as

$$\rho_i^* = (V\text{-}VSD)/\Sigma_1^k(F'_i N_i+R_i) > 0. \quad (7)$$

This result indicates that an optimal recycling target is achievable in the economy. Equation (7) implies that such a target is a function of the volume of solid waste generated in the economy over the time period (V), the level of waste disposal (VSD), the effect of resource management on the *current reserve* of the stock of resources

(F'_i), the size of total natural resource consumption in the economy ($\Sigma_1^k N_i$), and the total volume of recycled materials used in the economy ($\Sigma_1^k R_i$).

In a world in which the monetary costs of waste disposal for an optimizing household and/or firm are very small, these agents will undertake little or no effort to adopt more environmentally benign solid waste management. Such a situation will always yield an inefficient outcome in which marginal private costs/benefits of waste disposal never equal marginal social costs/benefits of waste disposal. In such a voluntary non-compulsive recycling system coupled with centralized waste-disposal at landfills financed through taxes, the cost of waste disposal for a typical household/firm is very small (limited to small transportation costs incurred in sending solid wastes and other scrap material to collection sites and spots). Although the monetary costs of solid waste disposal are high for government and small for the household/firm, the costs of recycling are relatively high for the household/firm; therefore individual households/firms would ordinarily be more inclined to dispose, and less inclined to recycle, their solid waste. To enhance recycling efforts, therefore, there is the need to determine and implement policies that would raise recycling choices among individuals and households/firms.

4. Empirical Analysis

We present an empirical analysis of the theory under certain estimation situations inherent in a panel data. First, we will discuss and estimate the three popular models used to analyze panel data. Second, we will present and estimate a model where sample selection and a single endogenous explanatory variable are present in the model.

The standard approach often used to estimate a linear panel data regression is (i) a Pooled model; (ii) a Fixed effects model; and (iii) a Random effects model. The three types of models can be written as:

$$Y_{it} = \alpha + \beta X'_{it} + \varepsilon_i \qquad (\textit{Pooled Model}) \tag{8}$$

$$Y_{it} = \alpha_i + \beta X'_{it} + \varepsilon_{it} \qquad (\textit{Fixed Effects Model}) \tag{9}$$

$$Y_{it} = \alpha + \beta X'_{it} + \varepsilon_{it} + \upsilon_{it} \qquad (\textit{Random Effects Model}) \tag{10}$$

where $X'_{it} = [X_{1it}, X_{2it}, \ldots. X_{kit}]$, and $\beta' = [\beta_1, \beta_2, \ldots.. \beta_k]$. The subscript i denotes cross-section/individual units that are observed, so that $(i = 1,2, \ldots, N)$. The subscript t denotes the time-series dimension, so that $(t = 1,2, \ldots. T)$, and the α_i is time-invariant characteristics or fixed effect.

In the pooled regression model, the fundamental assumptions are that: the regression coefficients are the same for cross-section units; the regressors are non-stochastic, that is, the errors are not correlated with the explanatory variables:

$Cov(\varepsilon_{it}, X_{it}) = 0$ and $\varepsilon_i \sim iid(0, \sigma_\varepsilon^2)$ or ε is white noise.
The fixed effects models assumes that:
$E(\varepsilon_{it}) = 0$; $Cov(\varepsilon_{it}, \varepsilon_{jt}) = 0$; $Var(\varepsilon_{it}) = E(\varepsilon_{it}^2) = \sigma_\varepsilon^2$; $E(\varepsilon_{it}, X_{1it}) = E(\varepsilon_{it}, X_{2it}) = \ldots\ldots = E(\varepsilon_{it}, X_{kit}) = 0$; and X_{kit} not constant. The individual effect, α_i , is constant over time t and specific to the individual cross-sectional units i. The term α_i captures the unobservable and non-measurable characteristics that differentiate individual units, while the slope parameters are assumed to be constant in both the individual and time dimension.
For random effects model, the fundamental assumptions are that:
$E(\varepsilon_{it}) = (\upsilon_i) = 0; Cov(\upsilon_i, \varepsilon_{it}) = E(\upsilon_i, \varepsilon_{it}) = \sigma_{\varepsilon,\upsilon}; Var(\upsilon_i) = E(\upsilon_t^2) = \sigma_\upsilon^2;$
$E(_i, X_{1it}) = E(\upsilon_i, x_{2it}) = \ldots. E(\upsilon_i, X_{kit}) = 0$ and $\upsilon_i \sim N(0, \sigma_\upsilon^2); \varepsilon_{it} \sim N(0, \sigma_\varepsilon^2)$.
The υ is a random variable and differences in individual values of the intercept for each individual are reflected in the error term, υ. It is important to note that the υ is the cross-section or individual-specific error component, and ε_{it} is the combined time series and cross-section error component.

4.1 Model with Sample Selection Bias and Endogenous Explanatory Variable

In situations where the sample for the study was not randomly selected from the population, a sample selection bias will occur and the classical OLS estimates will be biased. For fixed effects models, the sample selection is a problem when selection is related to the idiosyncratic errors ε_{it}. Also, if some of the explanatory variables are endogenous and are correlated with the error term in the primary equation, the OLS estimates will be biased and inconsistent. To address the two issues, we specify the model as:

$$Y_{it} = \alpha_i + \gamma F_{it} + \beta X'_{it} + \varepsilon_{it} \qquad (11)$$

$$F_{it} = \theta w + \psi \qquad (12)$$

$$Z_{it} = \delta m + \mu_{it} \qquad (13)$$

and

$$Z_{it} = 1,\ if\ \delta m + \mu \geq 0;\ Z_{it} = 0,\ if\ \delta m + \mu < 0. \qquad (14)$$

where w is the exogenous variables in equation 12, Z is an indicator function, m is the exogenous variable in equation 13, and ψ, μ are disturbance terms in equations 12 and 13, respectively. The first equation 11 is the structural equation of interest. The second equation is the endogenous explanatory variable F_{it} in equation 11. It is the reduced form equation for the endogenous variable F_{it}. The third equation is the selection equation. It is the probit equation that represents the probability of being in the sample. The explanatory variables (m) in equation 13 include most of the explanatory variables in equation 11 plus other explanatory variables that determine Z_i. We assume that (i) (m, Z) are always observed, (ii) (Y, F) are observed when $Z = 1$, (iii) (ε, μ) is independent of m with zero mean $[E(\varepsilon, \mu)] = 0)$, (iv) $\mu \sim N(0,1)$, (v) $E(m, \mu) = 0$. Assumption (v) indicates that we need an instrument that is correlated with F but is not correlated with or orthogonal to the disturbance term (ψ). Assuming a joint multinomial distribution, the conditional disturbance terms in equations 11-13 for the entire population is given by $(\varepsilon, \psi, \mu) \sim N(0, \Sigma)$ and the variance-covariance matrix of the disturbance term is:

$$\Sigma = Cov(\varepsilon, \psi, \mu) = \begin{pmatrix} \sigma_{\varepsilon}^2 & \rho_{\varepsilon\psi} & \rho_{\varepsilon\mu} \\ \rho_{\psi\varepsilon} & \sigma_{\psi}^2 & \rho_{\psi\mu} \\ \rho_{\mu\varepsilon} & \rho_{\mu\psi} & 1 \end{pmatrix}$$

From these assumptions the Heckman's inverse Mill's ratio (λ) can be written as:

$$\lambda(\delta m) = \frac{\phi(\delta m)}{\Phi(\delta m)} \tag{15}$$

where ϕ is the density function for standard normal distribution and Φ is the cumulative distribution for standard normal variable. After adjusting for sample selection bias and using instrument for the endogenous variable, the equation of interest (11) is specified as:

$$Y_{it} = \alpha_i + \gamma \hat{F}_{it} + \beta X_{it}^{'} + \rho\hat{\lambda} + \varepsilon_{it} \tag{16}$$

The ρ is the coefficient of λ and it measures the the covariance between the two residuals ε and μ. Under the null hypothesis that there is no selectivity bias, we have $\rho = 0$. This can be tested by means of a conventional t-test.

5. Data Source and Description of Variables

We utilize a panel data that consists of USA Municipal Solid Waste (MSW) (also known as trash) from selected U.S. States at different time periods. MSW consists of everyday items such as product packaging, yard trimmings, furniture, clothing, bottles and cans, food, newspapers, appliances, electronics and batteries. The waste includes residential and commercial and institutional locations. The data set is obtained from different sources and it includes: (i) USA Environmental Protection Agency (EPA); The EPA has collected and reported data on generation and disposal of waste national, states and local for over 30 years. (ii) USA Department of Commerce or Agriculture. The department provides yearly expenditures on resource exploitation. (iii) U.S State and Local Waste Characterization Studies. Reports are available for almost all States; these studies publish data on many variables for certain period of time. (iv) Waste Today Magazine; various publications provide industry news, resources and information on Municipal Solid Waste collection, Landfill sites, Waste-to-Energy facilities, and waste recycling plant owners. (v) Department of Energy and Environmental Protection for different States. (vi) Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures. (vii) U.S Census Bureau. (viii) States Annual Financial Reports. (ix) States' Annual Reports and budget web sites, and (x) States' yearly expenditures on resource Conservation and/or Maintenance. The selection of the States in our study was based on the States that have data for the variables in the study.

There are 20 individual States: Arizona, Arkansas, California, District of Columbia, Florida,, Kentucky, Maine, Maryland, Massachusetts, New Mexico, New York, North Carolina, Oklahoma, Pennsylvania, South Carolina, Texas, Virginia, Washington, Illinois, and Michigan; across 17 time periods from 2004 to 2020. The study looks at three types of variables that are likely to influence the MSW recycling rate: (1) the variables derived from the theory and presented in equation 7, $(V, N, F, R, VSD, VPR, \rho^*)$; (2) some socio-economic and demographic variables presented in many recycling rate studies, (3) recycling programs enacted by States' governments to encourage recycling and waste management, and mandatory recycling policies/requirements. It is important to note that waste management or disposal refers to the actual, transportation, and processing of waste, while recycling is the process of reclaiming raw materials (disposed waste) and reusing them to create new goods. Therefore, not all disposed waste (unwanted and 'unusable waste') are recycled.

The recycle rate (RR, which is the ρ variable in equation 7) is the yearly percentage of the total municipal Solid Waste generated that was recycled in each state. In cases where there was no data for a particular year, the recycle rate was calculated as:

$$RR = \frac{(Total\ MSW\ recycled)}{(Total\ MSW\ Generated)} \times 100.$$

Note the denominator of this ratio is (Total MSW recycled + Total MSW disposed of).

The variable (V) is the total volume of MSW generated by each state per period of time. We expect this variable to have a positive effect on the recycling rate. The plausible reason is that as more solid waste is accumulated, the higher would be the potential costs of waste disposal, as well as the maintenance of landfill sites. This would therefore motivate and compel people and authorities to seek for more ways

to do recycling.
The total volume of natural resource consumption by each state per period of time (N_i) was proxied by the yearly expenditure on resource exploitation (for example, mining, agriculture, fishing, crude oil, rigging and so on). We expect this variable to have positive effect on the recycling rate because the greater the volume of material resources used, the higher would be the accumulation of waste and cost to the government and therefore the need to recycle more.
The Volume of fresh (virgin) material resource consumption in each state per period of time (F_i) is the sustainable development initiatives variable. It is proxied by the yearly expenditure on resource conservation or maintenance by each state. The argument is that greater government spending on resource conservation (such as expenditures made to promote sustainable development and the three R's (reuse, Reduce, Recycle), will ostensibly lead to higher rate of recycling. This would mean a lesser need to harvest more virgin resources–lesser expenditure on resource since recycled resources would be a close substitute.
The total volume of society's Municipal solid waste disposed (VSD) is the waste that was discarded and not recycled. Society waste is comprised of total waste generated by individual households, business firms and industries, and public sector agencies, within the State's municipalities, per time period, which is calculated as:

$$VSD = \frac{(Total\ Municipal\ Solid\ Waste\ disposed)}{(Total\ volume\ of\ MSW\ generated) - (Total\ volume\ recycled)} \times 100.$$

We expect this variable to have a negative impact on the recycling rate. As more waste is disposed, less waste will be recycled and therefore the recycling rate will fall.
The total volume of private sector industrial State's Municipal Solid Waste recycled (VPR) is the total industrial Solid Waste that was recycled in each state per period of time. It is calculated as:

$$VPR = \frac{(Total\ Industrial\ Solid\ Waste\ recycled)}{(Total\ Solid\ Waste\ generated) - (Industrial\ Solid\ Waste\ disposed)} \times 100.$$

Industrial Waste is the waste produced by industrial activities. It included materials that are rendered useless during the manufacturing process such as that of factories, mills and mining operations. It is classified as (i) Solid waste, (ii) Toxic waste and (iii) Chemical waste. The expectation is that as we increase the recycling of industrial solid waste, the solid waste generated in the state would be reduced and therefore the recycling rate would increase.
The total yearly volume of recycled materials used by each State per period of time (R_i) is proxied by the annual expenditure on recycling. By definition, the recycling rate is the ratio of the volume of recycled materials to the volume of the total waste generated. As more recycled materials are used, more materials are likely to be

recycled and consequently the recycling rate will increase. We therefore expect this variable to be positively related to the recycling rate.

In addition to the variables derived from the optimal recycling theory (equation 7), there are other socio-economic and demographic factors or variables that influence the recycling rate. Such variables in the study include the median income of the states (MEDINC), the educational level of the population in each state (EdU), the median age of the population of each state (AGE), the tipping fees of MSW (TF), and the total population of the each state (POP).

The median income of the State's population can determine the state's ability to invest in quality recycling programs. Kinnaman (2010) found that 1000 dollars increase in the Municipal household income increases the recycling rate by 5 percent.[4] Studies that investigated the effect of education on the demand for recycling argue that higher levels of education are linked with higher environment values and greater appreciation for valuing future time periods.[5] However, some studies found that the recycling rate is inversely related to individuals with college or bachelor degree. (Kinnaman, 2010) and (Callan and Thomas, 2006) studies found a positive relationship between the recycling rate and education, but the rate reduced with those having college or bachelors degree. To capture the effect of different levels of education, we included those with no high school education (EDU1; those with high school education (EDU2), and those with college education (EDU3). Several studies indicate that older individuals have the tendency to recycle more than younger individuals. (Callan and Thomas, 2006), (Folz and Hazlett, 1991), and (Sidique, Lupi, and Joshi, 2010) found age to be positively and significantly related to the recycling rate. The argument is that older individuals have more time to recycle. The Tipping fee (TF) is the fee paid by anyone who disposes waste in a landfill that is based on the weight of waste per ton. This is a cost to the state for waste disposal. An increase in the fee reduces the incentive to dispose trash in the landfill and therefore increases recycling participation (Noehammer and Byer, 1997). All things being equal, an increase in the state's population will affect the recycling rate. (Kinnaman, 2010) found that the recycling rate is higher in small cities than in large cities. The implication is that an increase in the State's population has adverse effect on the recycling rate. The argument is that an increase in the State's population leads to an increase in the solid waste generated, and the State's government may find it more difficult to manage it (Callan and Thomas, 1997; 2006). Also, a negative relationship was found between housing density and the recycling rate (Martin, Williams, and Clark, 2006).

The last set of variables are the policy variables which are classified as only recycling program, only Mandatory recycling policies/requirements, and both recycling program and mandatory requirements. Several states have made large investments in recycling programs and provide funding to localities and businesses to support market development, education campaigns and infrastructure improvement. For example, Massachusetts has a Pay-As-You-Throw program. In California, there are several grants and funding programs that are designed to encourage institutions to increase recycling. For example, the community composting for Green Space Grant, the Food Waste Prevention and Rescue Grant, Waste Reduction Grant and many others are put in place to encourage households and institutions to reduce waste. Also, in Arkansas, the Solid Waste Management and recycling grants program provides funding for a variety of recycling, composting and other waste reduction programs. In 2010 more than 4.1 million dollars was allocated to the 18 regional solid waste management districts.

There are also a number of U.S. states that have passed laws and regulations on recycling requirements. According to North American Electric Reliable Corporation (NERC), there are currently 25 states that have Mandatory recycling requirements. For example, in California, all businesses and public entities that generate four or more cubic yards of solid waste per week and multi family residential dwellings that have five or more units are required to recycle. There are other states that have both recycling programs and are mandated. Since 1989, Virginia has required localities to recycle. In 2006, the Mandate required high population densities areas or high unemployment rates to meet a recycle rate of 15 percent, while areas with low unemployment rates must meet recycling rate of 25 percent.

To capture the effects of these programs and mandatory recycling requirements, three dummy variables are introduced in the model. The dummies, $D1$, $D2$, and $D3$ represent states that have only recycling programs, states that have only mandatory requirements, and states that have both recycling programs and mandatory requirements, respectively. The description and descriptive statistics of the variables are presented in Table 1.

6. Estimation Results

6.1 Pooled, Fixed Effects and Random Effects Estimates

In order to provide empirical estimates of the variables derived from the theory, we estimated equations 8-10 one by one. The dependent variable in these equations is the recycling rate (RR). The fixed effects and the random effects models controlled for time-invariant and inter-state heterogeneity.

Table 1: Description of Variables and Descriptive Statistics

Variable	Description of Variable	Mean	Std. Dev.
RR	Recycle rate variable. The percentage, by weight, of MSW recycled from all waste generated.	38.93	10.19
V	The total volume of MSW generated by a state in a year (in tons)	2.20E+08	5.87E+08
N	The total yearly resource consumption in each state. It represents the yearly expenditures on resource exploitation (e.g. mining, agriculture, fishing, crude oil, and so on).	9.9E+06	1.41E+08
F	The total yearly volume of fresh (virgin) material resource consumption in each state. It represents the yearly expenditures on resource conservation or maintenance (in dollars).	1.22E+09	2.55E+09
R	The total yearly volume of recycled materials used by each state. It represents the annual expenditures on recycling ((in tons)	1.01E+06	1.55E+06
VSD	The percentage of society's solid waste disposal by a state in each year.	38.16	16.80
VPR	The percentage of private/industrial solid waste recycled.	77.95	6.90
POP	The yearly total population of a State (in millions).	1.33E+07	1.20E+07
EDU1	The percentage of the State population, 25 years and over who have not completed high school.	11.02	2.75
EDU2	The percentage of the state's population 25 years and over who have completed high school.	27.52	3.89
EDU3	The percentage of the State's population 25 years and over who have completed college.	34.11	6.84
MEDINC	The median income of the State (in dollars).	62,255	13,413
TF	The Tipping fee paid by the state to dispose waste in a landfill. (in dollars)	47.81	17.54
AGE	The median age of the state's population (in years).	38.68	2.78

D1	This is a dummy variable and indicates whether a state has a recycling program. It takes a value of 1 if the state has a recycling program, and 0 if it does not.	0.89	0.32
D2	This is a dummy variable that represents a recycling mandate by the state. It takes a value of 1 if the state has a recycling mandate, and 0 if it does not.	0.66	0.48
D3	State with Both recycle program and mandatory requirements	0.38	0.28
REVENUE1	Total revenue of the state from all sources	98.13E+06	1.22E+06
REVENUE	Total revenue on recycling	12.4E+10	2.1E+10
URATE	State's unemployment rate	4.2	0.32
TOTALCOST	Total cost on recycling (includes wages to recycling employees)	19.3E+10	3.6E+10
TOTALCOST-1	Total cost on recycling previous year	18.9E+10	2.8E+10
PAFFILIATION	Dummy; 1 for democratic leaning state, 0 for Republican state	0.5	0.002
DEPRATIO	States dependency ratio	48.6	3.2
INFLATION	Inflation rate	3.8	0.19
$(\hat{F})$	The predicted variable of the endogenous variable (V)	1.17E+09	1.92E+09
Selectivity $(\hat{\lambda})$	The predicted value of the sample selectivity variable	0.286	1.213
No. observations	Balanced data: Number of States (20) x number of years (17)= 20 x 17 = 340	--	--

Table 2 reveals that all the explanatory variables in equation 7 are statistically significant and with expected signs. Similarly, most of the demographic and policy variables are also statistically significant. The F-statistic indicates that the three regressions (models) fit the data well, and the R^2 indicates that 69 percent, 72 percent, and 70 percent of the explanatory variables explain the recycling rate in the pooled, fixed and random models, respectively. The Durbin-Watson statistic also indicates that autocorrelation is not significantly present in the residuals of the regressions.

Since we utilized a panel data, we performed three tests (Chow test, Hausman test, and Langrange Multiplier test) to choose the most appropriate model. The Chow test compares the Pooled effect (PE) with the fixed effect (FE) models; the

Hausmans test compares the fixed effect with the random effect (RE); and the Lagrange Multiplier compares the Pooled effect with the random effect (FE). The Chow test, the Hausman test and the Lagrange Multiplier test all reject the null hypothesis with a p-value of 0.004, 0.013 and 0.002, respectively. The test results clearly indicate that the fixed effect is the appropriate model for the data. Finally, since our variables are in logs, the Breusch-Pagan-Godfrey test reveal that there is no heteroskedasticity in the model. The p-value of the test is 0.314. Based on these tests results, we will concentrate our discussion on the estimates of the fixed effects model in Table 2.

Table 2: Estimates of the Pooled, Fixed effects and Random effects Models. The dependent variable is the recycling rate (RR). All variables Except (D1, D2 & D3) are in logs

Variables	Pooled Model	Fixed Effects Model**	Random Effects Model
Constant	13.8076 (6.0414)	2.7993 (0.8055)	0.8141 (1.2402)
V	23.1251 (8.7881)[a]	22.0241 (4.9078)[a]	19.1736 (3.2402)[a]
N	1.2241 (1.3270)	4.9968 (4.1619)[a]	3.5742 (1.8406)[c]
F	9.2265 (1.9865)[b]	18.6680 (2.0829)[b]	11.4654 (1.9511)[c]
R	1.7395 (1.9012)[c]	2.9227 (7.3304)[a]	1.9639 (2.1130)[b]
VSD	-3.8791 (-9.4276)[a]	-8.2287 (-10.6746)[a]	-3.1065 (-14.3529)[a]
VPR	0.8325 (6.7882)[a]	2.0947 (4.9890)[a]	1.0867 (3.7513)[a]
POP	-0.7792 (-4.8105)[a]	-0.1292 (-2.0237)[b]	-0.1171 (-1.6134)
EDU1	-0.0144 (-0.0150)	-0.0894 (-1.7439)[c]	-0.0464 (-9.6545)[a]
EDU2	0.0038 (1.8006)[c]	0.0068 (1.2199)	0.0092 (1.1624)
EDU3	-0.0507 (-1.5745)	-0.0126 (-2.1874)[b]	-0.0229 (-4.5001)[a]

MEDINC	0.1480 (0.9588)	0.0852 (1.7161)[c]	0.3719 (1.6280)
TF	3.2107 (6.9480)[a]	2.0983 (4.2684)[a]	1.0314 (13.1046)[a]
AGE	0.0646 (4.287)[a]	0.0383 (2.3586)[a]	0.0721 (1.9544)[c]
D1	0.1728 (2.4059)[a]	0.1055 (3.0615)[a]	0.1301 (6.6382)[a]
D2	0.2521 (1.1745)	0.1746 (2.7725)[a]	0.1668 (1.6595)[c]
D3	0.2631 (2.0062)[b]	0.2917 (4.8896)[a]	0.1422 (1.9844)[c]
R^2	0.6891	0.7173	0.6960
F-Statistic	84.95	107.27	113.56
Log-Likelihood	116.25	147.98	--
Durbin-Watson	1.482	1.596	1.522
No. of observations	340	340	340

t-scores in parentheses; [a] Significant at 1 percent level; b Significant at 5 percent level.
[c] Significant at 10 percent level. **Selected model for discussion

The results reveal that many of the variables presented in equation 7 have the predicted signs and play a crucial role in determining the recycling rates of the states in our study. In particular, one percent increases in the volume of solid waste generated (V) in the states, and the annual expenditures on recycling (R), will increase the recycling rate by 22 percent and about 3 percent, respectively. However, the percentage of solid waste disposed by society (VSD) has a negative effect of reducing the recycling rate 8.2 percent.
We found that the other three variables in equation 7 have a positive and significant effect on the state's recycling rate. Increases in the total natural resource consumption by each state (N), the total volume of virgin material resources consumption by each state (F), and the percentage of private/industrial solid waste recycled (VPR), all tend to increase the state's recycling rate. For example, a one percent increase in the volume of virgin material resource consumed will increase the recycling rate by about 18.7 percent. Similarly, a one percent increases in N and VPR will increase the recycling rate by 5 percent and 2.1 percent, respectively.
One thing that stands out in the results is that the socio-economic variables play a minimal role in influencing the recycling rate. While the state's population has a

negative and significant effect on the state's recycling rate, such effect is very small. A one percent increase in the state's population, will only reduce the recycling rate by about 0.13 percent. Also, the number of individuals with no high school education $(EDU1)$, and those with college education $(EDU3)$ have a moderate reduction effect on the recycling rate. This seems to suggest that these individuals in the population may have less incentive to recycle. On the other hand, the positive effect of individuals with high school education $(EDU2)$ on recycling rate is also very small and insignificant. We noted that increases in the state's median income (MEDINC), the tipping fees (TF), and the median age (AGE) of the state's population tend to increase the state's recycling rate by 0.08 percent, 2.1 percent and 0.04 percent, respectively.

Turning our attention to the policy and recycling program variables, we observe that the state's recycling programs $(D1)$, states with only recycling mandatory policies $(D2)$, and states that have both recycling programs and mandatory policies, tend to have a positive and significant effect on the recycling rate. We found that states with both recycling programs and mandatory policies $(D3)$ have the largest effect on the recycling rate. If other independent variables in the model are held constant, a unit increase in this variable will increase the recycling rate by 23 percent, while a similar increase in states with only recycling programs and only mandatory requirements will increase the recycling rate by about 11 percent, and 17 percent, respectively. This seems to suggest that enforcing state's recycling mandatory policies will undoubtedly increase the recycling rate substantially.

6.2 Probit and Resource Conservation Estimation Results

The second part of the empirical analysis examines situations where sample selection bias and endogeneity of explanatory variables may be present in the model. There are two possible estimation issues in our model. First, the selection of the states in our sample is non-random. The selection was based on the availability of information for states. Exclusion of states in the sample due to lack of data leads to a sample selection bias and OLS estimates will be biased and inconsistent.

Second, we posit that the total yearly volume of fresh(virgin) material resource consumption which is proxied by the state's yearly expenditure on resource conservation or maintenance (F), and the recycling rate (RR) are jointly determined. The argument is that if the government expenditure is primarily aimed at promoting sustainable development (which includes the recycling initiative), then a greater government spending will lead to higher rate of recycling. This would mean a lesser need to harvest more virgin resources. And a lesser recycling rate would lead to a greater harvesting of virgin resources and therefore a greater expenditures. Thus, changes in the recycling rate will lead to changes in the governments expenditures on recycling and vice versa. The Pearson's correlation coefficient between the government expenditures on recycling and the recycling rate is 0.8.

The variable (F) in equation (11) is the state's yearly expenditure on resource conservation or maintenance and it is jointly determined with the recycling rate,

RR (which is Y in equation 11. Equations 11-15 were estimated using the following steps: First, we estimate a probit model using equation 13 with Z as the dependent variable and m as the explanatory variables. The estimates of the probit model (δ) are used to calculate the inverse Mill's ratio (λ) for each observation. Second, using a two stage least squares approach (2SLS), we estimate the government expenditures on resource conservation (F), equation 12 with the exogenous variable (w) and the sample selection term $(\hat{\lambda})$. Using the mean values of the explanatory variables in equation 12, we predict a value for the F variable and replace it with its corresponding predicted value. This imputed variable $(\hat{F})$ serves as an instrument for the government expenditures on resource conservation (F). It must be noted that the instrumental variable technique is justified if appropriate instrument can be found. The correlation between the actual F variable and the imputed $\hat{F}$ was about 0.8. Third, we estimated the recycling rate equation 16 by including the predicted value of $\hat{F}$, and the inverse Mills ratio $(\hat{\lambda})$ as explanatory variable.

Table 3 presents the probit and the Expenditures on resource conservation equation 12 estimates. With the exception of the yearly expenditures on resource exploitation (N) and the percentage of industrial solid waste recycled (VPR), all the variables in the probit equation are statistically significant. The volume of municipal solid waste generated each year, the yearly expenditures on resource conservation, the state's population, the state's yearly revenue from all sources, the state's revenue from recycling, the state's unemployment rate, the total cost on recycling, and the tipping fees paid by the state are more likely to encourage the state government to participate in recycling programs or invest in recycling programs. However, the yearly expenditures on resource exploitation and the percentage of industrial solid waste recycled yearly do not influence the states' governments decisions to participate in recycling or invest in recycling programs.

Table 3: Probit and Government Expenditures on Resource Conservation (F) Estimates

Variable	Probit	F
Constant	0.0111 (2.402)[a]	0.1228 (1.9881)[b]
V	0.0422 (2.0321)[b]	0.0722 (2.7192)[a]
N	0.0027 (1.6428)	-0.0182 (-1.8921)[c]
F	0.0293 (1.9622)[b]	---
R	0.0633 (1.7642)[c]	-0.1934 (-2.0024)[b]
VSD	-0.3301 (-2.107)[b]	-0.0417 (-1.6921)[c]
VPR	-0.0051 (-1.0211)	-0.0097 (-1.6681)[c]
POP	0.0982 (3.2185)[a]	o.6218 (2.5926)[a]
MEDINC	0.0019 (1.7221)[c]	0.0245 (2.2212)[b]
TF	0.1674 (1.989)[b]	0.2153 (3.1182)[a]
UR	-0.0302 (-2.1322)[b]	---
REVENUE1	0.5182 (4.9124)[a]	0.7214 (5.8256)[a]
REVENUE	0.3142 (3.1183)[a]	----
TOTALCOST	-0.2105 (-2.3316)[a]	----
TOTALCOST-1	-0.0821 (-1.9623)[b]	-0.0051 (-1.9173)[c]

STATE POLITICAL AFFILIATION	0.0355 (1.9127)[b]	----
D1	---	0.3241 (2.6719)a
DEPRATIO	---	-0.0193 (-1.8874)[c]
INFLATION RATE	---	0.0362 (3.1342)[a]
$(\hat{\lambda})$	---	0.5236 (3.7412)[a]
N	340	340
F, R^2	---	37.6, 0.48
Log L	608.5	496.3

t-scores in parentheses
[a] Significant at 1 percent level, [b] Significant at 5 percent level, [c] Significant at 10 percent level

As expected, all the variables in the government expenditures on resource conservation equation are statistically significant. In particular, the volume of municipal solid waste generated yearly, the state's population, the tipping fees paid by governments, the state's yearly revenue, the state's recycling programs, and inflation rate in each state are major determinants of the states' decision to promote recycling initiatives. The sample selection bias variable is also significant.

6.3 The Adjusted Recycling Rate Equation

To assess the effect of the sample selection bias and the endogenous explanatory variable on the choice of the three models discussed in section 5, we re-estimated equations (8-10) by including the sample selection bias term $(\hat{\lambda})$ and the predicted $(\hat{F})$ variable. The Chow, Hausman and Lagrange Multipliers tests again indicated that the fixed effects model is the most appropriate model that fits the data. Our discussion of Table 4 will therefore be based on the adjusted fixed effects model estimates.

The results indicate that the sample selectivity bias term has a significant and positive effect on the recycling rate. This implies that there would be a positive sample selection bias in the recycling rate equation if the selection bias term had been omitted. We observed that with the exception of the population (POP) and individuals with college degree (EDU3) variables, all the signs of the estimated variables in the two Tables (2 and 4) are the same. While population and those with college degrees tend to reduce the recycling rate (Table 2), these same variables tend to increase the recycling rate when the sample selectivity bias term and endogenous explanatory variable (F) issues were addressed.

Table 4: Recycling rate (RR) Estimates adjusted for sample Selectivity Bias and Endogeneity in the F Variable. The dependent variable is the recycling rate (RR). All variables except (D1, D2 & D3) are in logs

Variable	Pooled Model	Fixed Effects Model**	Random Effects Model
Constant	9.1152 (3.6623)	1.0861 (1.7153)	0.7564 (1.3095)
V	18.1456 (3.7901)[a]	24.1922 (6.2977)[a]	20.7534 (3.9667)[a]
N	0.8743 (1.6183)	7.3398 (6.1823)[a]	3.8024 (1.9726)[b]
F	7.5491 (2.1533)[b]	20.1531 (1.9782)[b]	13.2754 (1.6833)[c]
R	2.1052 (1.6213)	3.1335 (5.2211)[a]	0.8722 (1.9885)[b]
VSD	-3.9977 (-4.6793)[a]	-8.9882 (-7.5635)[a]	-2.4217 (-9.0121)[a]
VPR	1.2146 (2.0215)[b]	2.8414 (5.2734)[a]	1.2773 (6.0941)[a]
POP	0.0822 (1.7442)[c]	0.0964 (1.1947)	0.0926 (0.5782)
EDU1	-0.0652 (-1.5983)	-1.0212 (-1.6859)[c]	-0.0973 (-2.1552)[b]
EDU2	0.0166 (1.5489)	0.0255 (1.4487)	0.0192 (0.9865)
EDU3	0.0215 (1.8332)[c]	0.9896 (3.6731)[a]	0.6007 (2.0445)[b]
MEDINC	0.2537 (1.6221)	0.1621 (1.6352)	0.0854 (1.5825)
TP	1.9582 (2.1382)[b]	2.4486 (2.2436)[b]	0.9996 (5.0542)[a]
AGE	0.0231 (1.9896)[b]	0.5289 (1.9784)[b]	0.2976 (1.6844)[c]
D1	0.1833	0.2324	0.1433

	(1.9975)[b]	(4.0295)[a]	(2.0870)[b]
D2	0.2542 (1.6622)[c]	0.1866 (1.9898)[b]	0.1648 (1.7312)[c]
D3	0.2749 (2.8451)[a]	0.2987 (3.0451)[a]	0.1697 (2.1728)[b]
$(\hat{\lambda})$	0.2563 (1.7216)[c]	0.9958 (2.1379)[b]	0.6275 (1.9841)[b]
R^2	70.5	74.9	69.8
F-statistic	86.99	120.63	118.6
Log-likelihood	121.1	176.3	----
Durbin-Watson	1.512	1.602	1.455
No. of observations	340	40	340

t-scores in parentheses, [a] Significant at 1 percent level, [b] Significant at 5 percent level, [c] Significant at 10 percent level.

Turning our attention to see how the inclusion of the sample selectivity bias term and addressing the endogenous explanatory issue in the model (adjusted model) affect the estimated coefficients, we observe that, in general, the adjusted fixed effects model coefficients are relatively larger than the estimates without the sample selectivity bias (Table 2). For example, the volume of MSW generated (V), the yearly expenditures on resource exploitation (N), and the predicted yearly expenditures on resource conservation $(\hat{F})$ increased by 2.2 percent, 2.3 percent, and 1.5 percent, respectively. Similarly, the yearly expenditures on recycling, the percentage of society's solid waste disposal, and the percentage of industrial solid waste recycled increased by a small percentage points after the adjustment.

A noticeable effect of the adjustment is seen when we examine the estimates of the policy variables. The results indicate that a one percent increases in the recycling programs, the recycling mandatory requirements, and a combination of recycling program and a mandatory requirements will increase the recycling rate by 23 percent, 18.7 percent, and 27.9 percent, respectively. By comparison, the adjusted regression estimates of the recycling program and mandatory policies variables $(D1)$, $(D2)$ and $(D3)$ increased by 12.7 percent, 1.5 percent and 6.7 percent, respectively. This is a clear indication that the adjustment was needed to improve the regression estimates.

7. Conclusion and Policy Applications

The current universal efforts to facilitate recycling is based on the recognition of the potential environmental adversities arising from continual use of natural resources, and the desire to minimize such adversities. In searching for ways to achieve greater efficiency in the recycling effort, we have offered a model that addresses the problem from both an optimal welfare approach and an equilibrium cost-benefit angle.

The welfare approach adopts a generalized welfare maximization setting to determine the optimal level of recycling in a world in which recycling and waste disposal are both costly. This is then used to deduce policy guidelines toward waste management and resource conservation. The cost-benefit analysis is premised on the existing situation of low private monetary cost of waste disposal, to show that independent agents will have no incentive to adopt more environmentally benign solid waste management. In such a system, the recycling effort is apt to yield an inefficient and sub-optimal outcome, with negative implications for the environment. Effort should be made to help identify a set of comprehensive criteria which will replace or complement the regulatory tools that are currently in use in natural resources and environmental management.

Solid waste disposal may seem "free" to an individual or firm, but from the social standpoint it is not costless. There is an element of "market failure" in waste disposal in a free-market setting. This is indicated by the fact that there is a gap between the private and social values of recycling. This gap can be removed only when an optimal level of recycling is reached in the society. This suggests that a key part of the recycling program is the proper pricing of waste disposal in society.

So far, the key policy implications for long term objective of an efficient recycling program, that emanate from this study, revolve around three main issues. These are that: (1) greater emphasis are to be placed on resource management towards more conservation and replenishment of current reserves of the stock of resources; in addition to this, (2) a deliberately initiated vigorous solid waste reduction drive would be a necessary condition, (3) a vigorously implemented mandatory reuse/recycling drive would be the sufficiency condition. In a market economy, these would call for the use of economic instruments that would place the cost of resource use and disposal more on the shoulders of the private sector than the public sector.

In the light of these policy implications, it is important to note that while some material resources and end-products can be reused/recycled many times, others do not lend themselves to reuse/recycling, and must be discarded upon initial use. Even for those that are recyclable, conversion losses and material wastage during initial consumption would mean that one cannot possibly operate a perfect recycling policy. The proposition of an optimal recycling program analyzed in this study does not suggest the achievement of a perfect one. Thus, society should cautiously focus on the quantity of virgin material resources it uses.

Resource conservation policies imply greater caution in the use of virgin materials.

Any serious measures to pursue this would mean the reduction of the rate of economic activity, or reduction of the materials intensity (the quantity of materials used per unit) of that activity. As the reduction of the rate of economic activity is bound to conflict with the society's longer term goals, targeting the materials intensity appears to be a more viable policy option. This can be done by shifting economic activity away from materials-intensive products (those that use relatively large amounts of materials, for example, tangible goods) to those that use relatively less amounts (for example, services). It can also be done by decreasing the materials intensity of particular products (for example, reducing the amount of packaging in finished products).

Since the harvesting of virgin natural resources lead to a variety of environmental (social) costs, economic and environmental efficiency would dictate that the prices paid by producers for these resources reflect these costs. Thus, the variety of public programs that lower the costs of virgin natural resources only succeed in artificially lowering their overall costs, thereby negating social efficiency.

Solid waste reduction in free-market economies has been a problem because of defects in the pricing systems that govern transactions and other economic activities. Producers design and market products on the basis of decisions consumers make and relay through the pricing mechanism. Producers make decisions on the total quantities of (virgin and recycled) materials they use, and consumers choose products that contain different types and amounts of these materials. Consumers also decide how to dispose of the various material by-products after consumption. For social and environmental efficiency, the externalities of solid waste must be reflected in disposal costs of the agents that make disposal decisions, namely private sector elements (producers and consumers). The usual "flat fees" levied on households/firms to cover the disposal costs of solid waste should be made flexible to reflect overall disposal costs (private plus social). These fees should not vary merely to reflect the scarcity of landfill space (as has been the case in many localities in Canada and the U.S.), but the unit-fees (fees per household or firm) should vary according to the amounts of material disposed per unit. This will ensure an incentive for these units to curtail the amounts of "solid waste" that they acquire and/or discard.

The disposition to use recycled materials would largely depend on their competitiveness with virgin resources. The producer (assumed to be profit-maximizing) will use recycled materials up to the point where its cost is equal to the price of virgin materials. Hence, it is necessary to ensure that recycled materials are assessed by producers at very low costs. Similarly, the reuse rate of consumers will depend on the relative costs of acquiring new products compared to reusing older ones. Making the prices of new products to reflect their true overall costs (social and private) is apt to make reusing of older products more attractive. Imposition of some sort of "environmental taxes" on new products could be considered.

ENDNOTES

1. ρ must be distinguished from the *recyclable ratio* of materials. Whereas ρ measures the rate at which the economy reuses its (used) materials (and therefore represents a measure of society's effort in recycling), the society's material recyclable ratio is the average proportion of solid waste materials that can be recovered through recycling. Assuming a society's recyclable ratio is *r*, then *1-r* is the measure of the *combustion ratio* in material recycling. For further details on recyclable and combustion ratios, see Tietenberg (1992).
2. The Lagrangean multiplier measures the sensitivity of the objective function (in this case social welfare) to the constraint (in this case N and V).
3. See EPA Report on the Environment; https://www.epa.gov/roe/
4. For more studies that found a significant and positive effect of income on the recycling rate, see Jared Starr (2014), page 26.
5. Starr, 2014, page 25.
6. For the theory behind this positive relationship, see Jared Starr (2014), page 25.
7. The Chow test states that, H_0: PE is appropriate (if p-value > 0.05) and H_1: FE is appropriate if p-value < 0.05). The Hausman test states that, H_0: RE is appropriate (if p-value > 0.05) and H_1: FE is appropriate (if p-value < 0.05). And the Lagrange Multiplier test sates that, H_0: PE is appropriate (if p-value > 0.05) and H_1: RE is appropriate (if p-value < 0.05).
8. Both the order and rank conditions for identification indicate that equation (12) is over-identified), and hence using 2SLS estimation approach is justified.
9. The dependent variable of the probit equation takes a value of 1 if the state's net benefit of recycling ≥ 0, and 0 if the net benefit is < 0. The net benefit equals total annual tax revenue from recycling employees minus total annual payroll of recycling employees. The argument here is that a state will consider participating in the recycling program if recycling is economically profitable. It is important to note that a participation in recycling involves different types of cost such as expenditures on resource conservation.
10. If the instrumental variable technique is to produce consistent parameter estimate, care must be taken in selecting instruments. First, the instrument selected must be strongly correlated with the variable to be instrumented. In most cases, it is difficult to find such variables. Second, it is also almost impossible to check the assumption that the instrumental variables are independent of the error term in the equation in which the instrumental variables become regressors. Thirdly, one cannot be sure that the chosen variables will yield the minimum asymptotic variance. Thus, the instrumental variable technique gives priority to consistency, and pays less attention to the possibility of high standard errors which the instrumental variables may produce. Therefore, the best instrument for a variable is the predicted value of that variable.
11. These figures were calculated by finding the difference in the $D1$, $D2$, and

$D3$ estimates in Table 4 and Table 2 for the fixed effects model. For example, the 12.7 percent = 0.2324-0.1053 = 0.1271.

12. The society's broad economic policy goals would mean a sustainable yield policy of natural resource use must be maintained. The sustainable yield in the harvesting of a replenishable natural resource biomass is the harvesting rate which equals the natural rate of growth of the biomass. T this rate of resource use, the resource stockpile would remain undiminished from period to period, thereby safeguarding the society the ever present fear of extinction of the resource. The question of whether or not this rate is consistent with the society's goal of economic growth and full employment arises.
13. Pursuing these policy options will have wide and varying sectoral repercussions in the economy. For example, materials intensity shifts would seriously affect the manufacturing sector; it would also lead to an economy re-aligning its structural composition, say, abandoning a resource-based economy for a high-tech or service-oriented one. All these have different (and sometimes conflicting) social and economic effects on society.
14. It can be viewed that this situation, together with those that increase the cost of recycled materials (for example, the advent of the large trash-compacting collection trucks), could lead to significant reduction in the proportion of materials recovered from the solid waste stream.

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