Household Recycling Behavior: A Labor Supply Approach

by

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Abstract
This paper focuses on household recycling behavior and their response to different waste management programs. The one-period mathematical model, based on the labor supply model of the labor-leisure tradeoff, explains how households maximize utility subject to consumption, leisure, garbage and recycling decisions. The model incorporates the opportunity cost of recycling and garbage production, and also includes the effects of recycling subsidies, technology, an excise tax on garbage and the market price received for recyclables. Using plausible assumptions and standard comparative statics techniques, we find recycling activity is directly related to a per unit subsidy on recyclables but its impact on leisure is indeterminate. An increase in the per unit excise tax on garbage production reduces leisure but its impact on recycling behavior is also ambiguous. The paper also includes a simple simulation exercise that supplements the comparative statics results.

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I. Introduction

This paper focuses on household recycling behavior and it analyzes how households respond to different waste-management programs. Decisions whether to recycle waste or just throw it away are analyzed in model similar to those that explain the labor-leisure tradeoff in labor-supply models. A one-period, mathematical model is developed where households maximize utility subject to consumption, leisure, garbage and recycling decisions.

Household utility is assumed to be a function of consumption and leisure. Consumption generates byproducts that can either be thrown away as garbage or recycled. The household maximizes its utility subject to a budget constraint that includes income from work, income from recycling efforts, and a tax on the production of garbage.

Given a fixed amount of time available, the budget constraint recognizes that time spent disposing garbage and time spent recycling reduces time available for consumption or leisure. Included in the budget constraint are production functions for the generation of garbage and the recycling of waste. If these production functions experience an improvement in technology, then less time is spent managing one's garbage and recyclables and more time is available for consumption and leisure.

Using standard comparative statics analysis, the paper describes how the endogenous variables - - leisure, time spent managing one's garbage and time spent recycling - - respond to changes in the model's exogenous variables. Of particular interest is how recycling efforts respond to changes in a per unit garbage tax, the income earned from recycling, and improvements in the technology of processing garbage and recyclables.

Given the complexity of the model, it is not be possible to sign all the comparative statics results unambiguously. Plausible assumptions result in both intuitive and unintuitive results. A simple simulation exercise is included to supplement the comparative static analysis.

As in most theoretical labor-leisure models, the results depend upon the relative strengths of the substitution and income effects. An increase in either the market price of recyclables or the subsidy on recyclables leads to an increase in recycling but the effect on leisure is ambiguous. An increase in the excise tax on garbage production decreases the optimal level of leisure but its impact on recycling behavior is surprisingly indeterminate. If households become more efficient in processing garbage, the optimal level of leisure increases, but the impact on recycling behavior is indeterminate. Finally, if household can process more recyclables in a given hour, the optimal level of recyclables will increase while the effect on the optimal level of leisure is less certain.

A brief literature review follows this introduction. Then the third section of the paper describes the model, the necessary first order conditions and the sufficient second order conditions. The comparative statics of the model are presented in the fourth section of the paper. A simple simulation exercise that provides a concrete example of the model is in the fifth section of the paper while the conclusion is in the sixth and final section.

II. Literature Review

Static and dynamic models of household and firm recycling have appeared frequently in the literature during the last thirty years. Some of the theoretical and empirical literature analyzed how the government can design incentives to encourage recycling and reduce the production of garbage. However, Baumol (1977) warns that recycling could result in a social loss as it may use more resources than it saves.

Many models have analyzed the proper design of incentive programs to reduce the production of garbage and to encourage increased recycling. Fullerton and Kinnaman (1995) develop a theoretical model where consumption can either be thrown away as garbage, recycled, or disposed of illegally, such as dumping or burning. Utility was assumed to be a function of consumption, household production, the production of garbage, the amount of burning and the stock of virgin materials. Obviously the level of utility was directly related to consumption and inversely related to the negative externalities of the generation of garbage, illegal waste disposal and the degradation of the country's natural resources. They find that when a third disposal technique such as illegal dumping or illegal burning is present, the use of a per unit garbage fee is no longer optimal. In this case, the proper fee structure would be a tax on all output and a refund if waste is properly disposed either as garbage or recyclables.

Wertz (1976) also develops a model of consumer utility maximization where utility is directly related to the goods consumed and inversely related to the amount of garbage accumulating between garbage pick ups. The model is analyzed to determine how the production of garbage responds to changes in income, the price of garbage service, how often garbage is picked up, the location of the garbage collection facility and the packaging involved.

Another theoretical model examining households' allocation of its waste between garbage and recyclables was the model developed by Lusky (1976). This paper examines the production of the consumption good, the production of recyclables, and the disposal of garbage. The interesting optimization problem is the allocation of a given amount of labor between the production of the composite good and its two waste byproducts while maximizing utility. However, leisure and labor supply decisions are not included in Lusky's analysis.

Aadland and Caplan (2003) estimate the social net benefits of curbside recycling from an econometric perspective, and their model includes leisure. Household utility is modeled as a function of a composite good, leisure, the amount of recyclables generated per month and the total amount of recycling in the community. A household receives a "warm glow" effect from the recycling efforts of others and utility is directly related to the total amount recycled. Each household will maximize utility subject to its budget constraint and choose the optimal level of consumption and recycling. The authors assume that waste is some proportion of the amount consumed and not all the waste can be recycled. Their econometric model predicts the net social benefit of curbside recycling is almost equal to zero. However, they warn that this result may be driven by their estimates of the cost of curbside recycling which they fear were too high.

Fullerton and Kinnaman (1996) examine in an econometric study how households respond to a per unit charge for each bag of garbage. They find that when households have to pay by the bag, they reduce the number of bags but the weight of the bags increases. A per unit fee gave households the incentive to compact or stomp their trash, resulting in fewer, but heavier bags. There was also evidence that charging households by the bag increased illegal dumping.

III. The Model

A modified labor-leisure model is used to examine how a utility-maximizing household determines its optimal recycling behavior and how it responds to different waste management programs. Economic agents either work or they enjoy leisure while consuming a composite good, purchased by the fruits of their labor.

<u>The household utility function</u>

Households maximize utility which is a function of the units of the composite good (C) consumed and the hours of leisure (L) enjoyed or

$$U = U(C,L) \; . \tag{1}$$

Since the marginal utility of consumption is positive, $\partial U/\partial C = U_C > 0$. Likewise, the marginal utility of leisure is also positive or $\partial U/\partial L = U_L > 0$. Given a total of T hours available, a household either works, consumes leisure and the composite good, or processes the waste of their consumption either as garbage (G) or recyclables (R).

Since consuming the composite good generates either garbage or recyclables, the consumption function becomes $C = C(G,R)$. The household determines the mix between garbage and recyclables. As households recycle more, less garbage is generated, so G is a function of R or $G = G(R)$ where $\partial G/\partial R = G_R < 0$. Given the inverse relationship between the production of garbage and recycling activity, the household's utility function becomes a function leisure and recycling activity where

$$U = U\{C[G(R),R],L\} \; . \tag{2}$$

The budget constraint

Households maximize the utility function in Equation (2) subject the constraint

$$w\left[T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L\right] + v + p_R R + s_R R - t_G G - p_C C[G(R),R] = 0 . \quad (3)$$

The budget constraint requires that the money earned from labor, recycling, and other nonlabor income equal the money spent on the composite good and paying taxes on the garbage generated.

Exogenous constants: w, p_C, p_R, s_R, and t_G

The wage rate is w, the price of the composite good equals p_C, and when recyclables are delivered to the recycling center, households receive a per unit price of p_R. All three of these prices are set by markets and households take these prices as given. Other exogenous variables that the consumer takes as given are s_R, the per unit subsidy that the government pays for recyclables, and t_G, the per unit tax that the government levies on the garbage disposed in the landfill. Both s_R and t_G are exogenously set by the government. The per unit subsidy on recyclables, s_R, is the government's attempt to encourage recycling, a positive externality, while the per unit tax on garbage generation, t_G, is the government's attempt to reduce landfill use, a negative externality.

Time spent working and processing garbage and recyclables

The time each consumer spends processing his or her garbage is denoted as $\frac{G(R)}{\alpha}$ where G(R) is the total amount of garbage produced and α is an exogenous constant measuring the units of garbage delivered to the landfill per hour spent processing garbage. Likewise, $\frac{R}{\beta}$ measures the time spent collecting, organizing and transporting the appropriate waste to the recycling centers as β is another exogenous constant measuring the units of waste than can be delivered to the recycling center per hour spent processing recyclables.

Nonwage income appears in the budget constraint and it is denoted by v. Consumers either work, process their garbage and recyclables or simultaneously consume both leisure and the composite good, so the time they spend working equals $T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L$. Since the exogenous wage per hour is w, the earnings from labor equal $w\left[T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L\right]$.

Deriving the necessary, first-order conditions

Each household faces a constrained optimization problem where it first determines the optimal levels of R and L which in turn determines the optimal levels of G, C, and U. The Lagrangian becomes

$$\Omega = U\{C[G(R),R],L\} + \lambda\left\{w\left[T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L\right] + v + p_R R + s_R R - t_G G(R) - p_C C[G(R),R]\right\} \quad (4)$$

where λ is the Lagrangian multiplier. The Lagrangian is a function of three endogenous variables: R, L and λ. The first-order conditions are found by partially differentiating the Lagrangian in Equation (4) with respect to each of these three endogenous variables and the three first-order conditions are[1]

$$\frac{\partial\Omega}{\partial\lambda} = \Omega_\lambda = w\left[T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L\right] + v + p_R R + s_R R - t_G G(R) - p_C C[G(R),R] = 0 \quad (5)$$

$$\frac{\partial\Omega}{\partial R} = \Omega_R = U_C(C_G G_R + C_R) + \lambda\left[p_R + s_R - t_G G_R - \frac{wG_R}{\alpha} - \frac{w}{\beta} - p_C(C_G G_R + C_R)\right] = 0 \quad (6)$$

and

$$\frac{\partial\Omega}{\partial L} = \Omega_L = U_L - \lambda w = 0. \quad (7)$$

Given Equation (7), $U_L = \lambda w$. Since U_L and w are both positive, λ must also be positive. Define θ as

$$\theta = p_R + s_R - t_G G_R - \frac{wG_R}{\alpha} - \frac{w}{\beta} - p_C(C_G G_R + C_R). \quad (8)$$

Substituting Equation (8) into Equation (6), and rearranging terms gives

$$U_C(C_G G_R + C_R) = -\lambda\theta. \quad (9)$$

[1] Following the notation used earlier, $C_G = \partial C/\partial G$ and $C_R = \partial C/\partial R$.

Equation (9) provides information about the signs of $(C_G G_R + C_R)$ and θ. Since U_C and λ are both positive, $(C_G G_R + C_R)$ and θ have opposite signs. If $(C_G G_R + C_R) > 0$, then $\theta < 0$. Conversely, if $(C_G G_R + C_R) < 0$, then $\theta > 0$.

Deriving the sufficient, second-order conditions

Since there are two endogenous variables (R and L) and the one constraint listed in Equation (3), the sufficient, second-order conditions require that the bordered Hessian from the system of equations in Equations (5) , (6), and (7) has a positive determinant. Let H denote the bordered Hessian. The elements of H equal the second partial derivatives of Equation (4). H is a symmetric, 3 x 3 matrix where[2]

$$H = \begin{bmatrix} \Omega_{\lambda\lambda} & \Omega_{\lambda R} & \Omega_{\lambda L} \\ \Omega_{\lambda R} & \Omega_{RR} & \Omega_{RL} \\ \Omega_{\lambda L} & \Omega_{RL} & \Omega_{LL} \end{bmatrix}. \tag{10}$$

Taking the second derivatives of Equations (5) – (7), the identities of interest are:

$$\frac{\partial^2\Omega}{\partial\lambda^2} = \frac{\partial\Omega_\lambda}{\partial\lambda} = \Omega_{\lambda\lambda} = 0$$

$$\frac{\partial^2\Omega}{\partial\lambda\partial R} = \frac{\partial\Omega_\lambda}{\partial R} = \frac{\partial\Omega_R}{\partial\lambda} = \Omega_{\lambda R} = p_R + s_R - t_G G_R - \frac{wG_R}{\alpha} - \frac{w}{\beta} - p_C(C_G G_R + C_R) = \theta$$

$$\frac{\partial^2\Omega}{\partial\lambda\partial L} = \frac{\partial\Omega_\lambda}{\partial L} = \frac{\partial\Omega_L}{\partial\lambda} = -w < 0 \tag{11}$$

$$\frac{\partial^2\Omega}{\partial L\partial R} = \frac{\partial\Omega_L}{\partial R} = \frac{\partial\Omega_R}{\partial L} = U_{CL}(C_G G_R + C_R)$$

$$\frac{\partial^2\Omega}{\partial L^2} = \frac{\partial\Omega_L}{\partial L} = U_{LL}.$$

Substituting some of the results from the set of equations in (11) into Equation (10) results in

[2] The convention used in earlier notation continues. If Y=f(X,Z), then $\partial^2Y/\partial X^2 = Y_{XX}$, $\partial^2Y/\partial X\partial Z = \partial^2Y/\partial Z\partial X = Y_{XZ}$, and $\partial^2Y/\partial Z^2 = Y_{ZZ}$.

$$H = \begin{bmatrix} 0 & \theta & -w \\ \theta & \Omega_{RR} & \Omega_{RL} \\ -w & \Omega_{RL} & \Omega_{LL} \end{bmatrix}. \qquad (12)$$

The sufficient, second-order conditions for a maximum requires that the determinant of H be positive or $\bar{H} = |H| = -(\theta^2 U_{LL} + 2w\theta U_{RL} + w^2 U_{RR}) > 0$. If $\bar{H}$ is positive, then $\theta^2 U_{LL} + 2w\theta U_{RL} + w^2 U_{RR}$ must be negative. Because $\bar{H}$ is nonzero, this implies that the necessary Jacobian to invoke the implicit function theorem exists, and using Equations (5) through (7), the optimal levels of R, L, and λ are functions of the eight exogenous variables. If the solutions are denoted as R^*, L^* and λ^*, then

$$R^* = R^*(p_C, s_R, p_R, t_G, v, w, \alpha, \beta)$$

$$L^* = L^*(p_C, s_R, p_R, t_G, v, w, \alpha, \beta) \qquad (13)$$

$$\lambda^* = \lambda^*(p_C, s_R, p_R, t_G, v, w, \alpha, \beta).$$

The endogenous and exogenous variables of the model are summarized in Table 1.

IV. Comparative Statics

Given that the economic agent maximizes utility and determines the optimal level of recyclables, garbage, consumption and leisure, the next question is to determine how the solution will change in response to a change in one of the exogenous variables. This section of the paper reports the results of a traditional comparative statics exercise and the assumptions used in determining the signs of the partial derivatives.

<u>**The income effect**</u>

In deriving the Slutsky-like equations that explain the response of R^* and L^* to a change in one of the exogenous variables, there will be a term analogous to the income effect. To find the income effect for both of these endogenous variables, one must partially differentiate both R^* and L^* with respect to nonwage income, v. In all of the comparative statics analyses that follow, three steps where followed. The first step involves evaluating all the first-order equations in Equations (5) through (7) at the solutions that are listed in the set of identities listed as Equation (13). The second step involves partially differentiating each of the equations with respect to the exogenous variable of interest, in this case, v. This step results in a system of three equations that is similar to Equation (14) below.

$$\begin{bmatrix} 0 & \theta & -w \\ \theta & \Omega_{RR} & \Omega_{RL} \\ -w & \Omega_{RL} & \Omega_{LL} \end{bmatrix} \begin{bmatrix} \partial\lambda^*/\partial v \\ \partial R^*/\partial v \\ \partial L^*/\partial v \end{bmatrix} = \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \qquad (14)$$

The third and final step in this comparative statics exercise is to solve for the partial derivatives using Cramer's Rule.

The partial derivative of R^* with respect to v is

$$\frac{\partial R^*}{\partial v} = \frac{1}{\bar{\bar{H}}} \begin{vmatrix} 0 & -1 & -w \\ \theta & 0 & \Omega_{RL} \\ -w & 0 & \Omega_{LL} \end{vmatrix} = \frac{1}{\bar{\bar{H}}} \left(\theta\Omega_{LL} + w\Omega_{RL} \right) . \qquad (15)$$

Since $\bar{H}$ is positive, if $(\theta\Omega_{LL} + w\Omega_{RL}) > 0$ then recyclables are a normal good or $\partial R^*/\partial v > 0$. Given this assumption, as nonwage income increases, the utility-maximizing consumer will recycle more.[3] A similar use of Cramer's rule finds the impact of an increase in nonwage income on leisure or

$$\frac{\partial L^*}{\partial v} = \frac{1}{\bar{\bar{H}}} \begin{vmatrix} 0 & \theta & -1 \\ \theta & \Omega_{RR} & 0 \\ -w & \Omega_{RL} & 0 \end{vmatrix} = -\frac{1}{\bar{\bar{H}}} \left(\theta\Omega_{RL} + w\Omega_{RR} \right) . \qquad (16)$$

Equation (16) indicates that leisure will be a normal good and $\partial L^*/\partial v > 0$ if $(\theta\Omega_{RL} + w\Omega_{RR}) < 0$.[4]

<u>The effect of a change in the exogenous wage</u>

To find the impact of a change in the exogenous, market wage on the optimal levels of recyclables and leisure the Equations (5) through (7) are evaluated at the solutions and then the three equations are partially differentiated with respect to w to obtain the following system of equations

[3] If there is diminishing marginal utility of leisure then $\Omega_{LL} < 0$ and as Equations (8) and (9) indicate, $\theta < 0$ if $(C_G G_R + C_R) > 0$. Even if $\Omega_{RL} < 0$, $(\theta\Omega_{LL} + w\,\Omega_{RL}) > 0$ as long as $\theta\Omega_{LL} > w\,\Omega_{RL}$.

[4] Leisure will be normal if $\theta < 0$, increased consumption of recyclables implies diminishing utility ($\Omega_{RR} < 0$) and $\theta\Omega_{RL} < -w\,\Omega_{RR}$.

$$\begin{bmatrix} 0 & \theta & -w \\ \theta & \Omega_{RR} & \Omega_{RL} \\ -w & \Omega_{RL} & \Omega_{LL} \end{bmatrix} \begin{bmatrix} \partial\lambda^*/\partial w \\ \partial R^*/\partial w \\ \partial L^*/\partial w \end{bmatrix} = \begin{bmatrix} -(T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L) \\ \lambda\frac{G_R}{\alpha} + \frac{\lambda}{\beta} \\ \lambda \end{bmatrix}. \quad (17)$$

Again, Cramer's rule is used to find $\partial R^*/\partial w$ and $\partial L^*/\partial w$. To determine the effect that higher wages has on the supply of labor and the optimal amount of leisure, one has to determine the sign of $\partial L^*/\partial w$ which equals

$$\frac{\partial L^*}{\partial w} = -\frac{\lambda\theta}{\bar{\bar{H}}}(\theta + \frac{wG_R}{\alpha} + \frac{w}{\beta}) + (T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L)\frac{\partial L^*}{\partial v}. \quad (18)$$

If leisure is a normal good, the second term on the right-hand side of Equation (18), then income effect, is positive. The labor supply curve will be upward sloping and $\partial L^*/\partial w$ will be negative if the substitution effect, $-\frac{\lambda\theta}{\bar{\bar{H}}}(\theta + \frac{wG_R}{\alpha} + \frac{w}{\beta})$, overpowers the income effect, $(T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L)\frac{\partial L^*}{\partial v}$. If leisure is normal and θ is negative, then $\theta + \frac{wG_R}{\alpha} + \frac{w}{\beta}$ must also be negative if $\partial L^*/\partial w < 0$ and the labor supply curve is upward sloping.

The effect of a change in wages on the optimal level of recycling equals

$$\frac{\partial R^*}{\partial w} = -\frac{\lambda w}{\bar{\bar{H}}}(\theta + \frac{wG_R}{\alpha} + \frac{w}{\beta}) + (T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L)\frac{\partial R^*}{\partial v} \quad (19)$$

where the first term on the right-hand side of Equation (19), $-\frac{\lambda w}{\bar{\bar{H}}}(\theta + \frac{wG_R}{\alpha} + \frac{w}{\beta})$, is the substitution effect and second term on the right-hand side of Equation (18), $(T - \frac{G(R)}{\alpha} - \frac{R}{\beta} - L)\frac{\partial R^*}{\partial v}$, is the income effect. If recyclables are normal, then $\partial R^*/\partial v$ is positive. If both θ and $\theta + \frac{wG_R}{\alpha} + \frac{w}{\beta}$ are negative then an increase in wages causes the rational economic agent to consume less leisure, to work more, to consume more, and to recycle more.

The impact of other exogenous variables on the optimal levels of leisure and recycling behavior

Table 2 lists the comparative statics results for the other exogenous variables. The results in Table 2 are based on the assumptions that leisure and recycling activity are both normal goods and the three terms listed in the first row of Table 2 have the signs indicated. Notice that the equations in Table 2 have either a plus (+) or minus (-) sign above each term. If economic theory or the assumptions in Table 2 imply the term is positive, a plus sign is placed above the term. Likewise, negative terms are indicated by the minus sign. According to the results listed in Table 2, given these assumptions, there is an inverse relationship between recycling activity and the price of the composite good. Equation (26) states that the partial derivative of recycling activity with respect to the price of the composite good is negative. As the price of the composite good increases, household buy less of it and recycling activity declines. Because the income and substitution effect have opposite signs, Equation (27) indicates that the partial derivative of leisure with respect to the price of the composite good is indeterminate.

If there is a technological improvement and the household can process more garbage in a given hour, Equation (21) implies that the economic agent will consume more leisure. Surprisingly, as shown in Equation (23), the impact of technological progress in processing recyclables has an ambiguous impact on the optimal level of leisure. In other words, $\partial L^*/\partial\beta$ can be positive, negative, or zero. Technological improvement in the process of garbage implies an increase in α, but Equation (20) indicates that the precise relationship between α and recycling activity is ambiguous. But technological progress in the processing of recyclables (an increase in β) is directly related to the amount of material recycled as Equation (22) indicates that $\partial R^*/\partial\beta > 0$.

Government regulation does influence how households dispose their waste. Equation (28) shows that recycling activity is directly related to the per unit subsidy on recycling while Equation (29) indicates that the effect of changing the subsidy has an indeterminate effect on leisure. Equations (24) and (25) imply that changes in the market price of recyclables, p_R, have a similar impact on the optimal levels of recycling and leisure. Finally, an examination of Equations (30) and (31) in Table 2 shows that higher taxes on garbage means less leisure, but the impact of garbage taxes on recycling activity is surprisingly ambiguous.

V. A Simple Simulation Exercise

Given the difficulty in signing the partial derivatives of the comparative statics and the loss of generality of making conclusions based on the assumptions of the previous sections, a simple simulation exercise is used to give the model a concrete example. The purpose of the simulation is to calculate the elasticity of endogenous variables with respect to the specific exogenous parameters. These simulation results are not a "proof by example" and they should be taken for what they are. Results will vary based on the magnitudes of the parameters and the types of the functions chosen for utility and the production of garbage and recyclables. If garbage and recycling are perfect substitutes, the numerical solutions may gravitate towards corner solutions. Why should the household produce any garbage if recycling costs less and takes less time?

Table 3 describes the functional forms used for utility, consumption and the allocation of waste between garbage and recyclables. Also included in Table 3 are the initial or "base case" values of the exogenous parameters. A key assumption in Table 3 is that both the utility function and the "production function" that allocates consumption between the production of garbage and recyclables take a Cobb-Douglas form. Table 3 also assumes that garbage is a linear function of recycling activity where the first derivative is negative and the second derivative equals zero. As recycling activity increases, the amount of garbage produced falls.

After calibrating this model, the first order conditions are solved using the base case values of these parameters. Then each exogenous parameter is either increased or decreased by 10 percent and the model is simulated again to obtain the new endogenous variables. The calculated elasticities are listed in Table 4. In this example, holding everything else constant, an increase in the wage leads to less recycling (a decline of 0.91 percent), more garbage (an increase of 1.28 percent) and more leisure (an increaser of 1.71 percent). An increase in nonwage income leads to more leisure, more recycling activity, but a decline in the production of garbage (it falls 0.20 percent).

The simulation exercise in Table 4 shows that a technological improvement in the processing of garbage leads to less recycling (a decline 0.62 percent), an increase in leisure (up 0.34 percent) and more garbage production (it increases 0.72 percent). Technological gains in the processing of recyclables generate symmetric results: the amount of leisure consumed and waste recycled increases while garbage production falls 4.17 percent.

Given an increase in the subsidy paid for recyclables, Table 4 shows that recycling activity increases, the production of garbage falls, and leisure increases by 0.60 percent. An excise tax on garbage reduces the production of garbage by 1.69 percent, the production of recyclables increases by 1.15 percent and leisure declines in this case by 0.60 percent.

VI. Conclusions

By introducing the time allocated to recycling and garbage disposal into a traditional labor supply model, this model of household recycling behavior includes policy instruments, technology, and the opportunity cost of spending time outside the labor market. Some of the comparative static results were impossible to sign and plausible assumptions had to be made which result in some results that were intuitively pleasing and other results that were surprising. If leisure and recyclables are both normal goods and if the labor supply curve is upward sloping, an increase in wages leads to less leisure, more consumption, and more recycling. Increasing the government subsidy on recyclables leads to more household recycling activity, but the impact on leisure is ambiguous. Increased excise taxes on garbage causes leisure to fall but the impact on recycling behavior is indeterminate. Technological improvement in the processing of garbage results in more leisure, but the impact of technological improvement in the production of recyclables on leisure could not be signed unambiguously. A higher market price on recyclables or technological improvement in processing recyclables causes households to recycle more.

Future work on this model could include the use of specific utility functions such as a Cobb-Douglas model or additive utility functions either in level form or log form. The model can be improved by adding terms to the utility function that capture the disutility related to total garbage production and the additional utility of the "warm glow" effect which is directly related to the total recycling effort. The model can be aggregated over all households to examine the social costs and benefits of various recycling schemes.

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Table 1
The Model's Endogenous and Exogenous Variables

Endogenous Variables		Exogenous Variables			
Symbol	**Definition**	**Symbol**	**Definition**	**Symbol**	**Definition**
L	Leisure	v	Nonwage Income	s_R	Per Unit Subsidy Paid on Recyclables
R	Recyclables	w	Market Wage Per Hour	t_G	Per Unit Tax Imposed on Garbage
$G = G(R)$	Garbage	p_C	Per Unit Market Price of the Composite Good	α	Amount of Garbage Processed per Hour
$C = C[G(R),R]$	Consumption of Composite Good	p_R	Per Unit Market Price of Recyclables	β	Amount of Recyclables Processed per Hour
$U = U\{C[G(R),R], L\}$	Utility Function				
λ	Lagrangian Multiplier				

Table 2
Comparative Statics Results: Assuming R^* and L^* are both Normal

Assumptions: (i) $C_G G_R + C_R > 0$, (ii) $\theta = p_R + s_R - t_G G_R - \frac{wG_R}{\alpha} - \frac{w}{\beta} - p_C(C_G G_R + C_R) < 0$, (iii) $\theta + \frac{wG_R}{\alpha} + \frac{w}{\beta} < 0$

α: Amount of Garbage Processed per Hour

$$\frac{\partial R^*}{\partial \alpha} = \frac{\overset{+}{\lambda}\,\overset{+}{w^3}\,\overset{-}{G_R}}{\underset{+}{\bar{H}}\,\underset{+}{\alpha^2}} + \frac{\overset{+}{w}\,\overset{+}{G}}{\underset{+}{\alpha^2}}\overset{+}{\frac{\partial R^*}{\partial v}} \qquad (20)$$

$$\frac{\partial L^*}{\partial \alpha} = \frac{\overset{+}{\lambda}\,\overset{+}{w^3}\,\overset{-}{\theta}\,\overset{-}{G_R}}{\underset{+}{\bar{H}}\,\underset{+}{\alpha^2}} + \frac{\overset{+}{w}\,\overset{+}{G^*}}{\underset{+}{\alpha^2}}\overset{+}{\frac{\partial L^*}{\partial v}} > 0 \qquad (21)$$

β: Amount of Recyclables Processed per Hour

$$\frac{\partial R^*}{\partial \beta} = \frac{\overset{+}{\lambda}\,\overset{+}{w^3}}{\underset{+}{\bar{H}}\,\underset{+}{\beta^2}} + \frac{\overset{+}{w}\,\overset{+}{R^*}}{\underset{+}{\beta^2}}\overset{+}{\frac{\partial R^*}{\partial v}} > 0 \qquad (22)$$

$$\frac{\partial L^*}{\partial \beta} = \frac{\overset{+}{\lambda}\,\overset{+}{w^2}\,\overset{-}{\theta}}{\underset{+}{\bar{H}}\,\underset{+}{\beta^2}} + \frac{\overset{+}{w}\,\overset{+}{R^*}}{\underset{+}{\beta^2}}\overset{+}{\frac{\partial L^*}{\partial v}} \qquad (23)$$

p_R: Per Unit Market Price of Recyclables

$$\frac{\partial R^*}{\partial P_R} = \frac{\overset{+}{\lambda}\,\overset{+}{w^2}}{\underset{+}{\bar{H}}} + \overset{+}{R^*}\,\overset{+}{\frac{\partial R^*}{\partial v}} > 0 \qquad (24)$$

$$\frac{\partial L^*}{\partial P_R} = \frac{\overset{+}{\lambda}\,\overset{+}{w}\,\overset{-}{\theta}}{\underset{+}{\bar{H}}} + \overset{+}{R^*}\,\overset{+}{\frac{\partial L^*}{\partial v}} \qquad (25)$$

p_C: Per Unit Market Price of the Composite Good

$$\frac{\partial R^*}{\partial P_C} = -\frac{\overset{+}{\lambda}\,\overset{+}{w^2}}{\underset{+}{\bar{H}}}\left(C_R \overset{+}{G_R} + C_R\right) - \overset{+}{C^*}\,\overset{+}{\frac{\partial R^*}{\partial v}} < 0 \qquad (26)$$

$$\frac{\partial L^*}{\partial P_C} = -\frac{\overset{+}{\lambda}\,\overset{+}{w}\,\overset{-}{\theta}}{\underset{+}{\bar{H}}}\left(C_R \overset{+}{G_R} + C_R\right) - \overset{+}{C^*}\,\overset{+}{\frac{\partial L^*}{\partial v}} \qquad (27)$$

s_R: Per Unit Subsidy Government Paid of Recyclables

$$\frac{\partial R^*}{\partial s_R} = \frac{\overset{+}{\lambda}\,\overset{+}{w^2}}{\underset{+}{\bar{H}}} + \overset{+}{R^*}\,\overset{+}{\frac{\partial R^*}{\partial v}} > 0 \qquad (28)$$

$$\frac{\partial L^*}{\partial s_R} = \frac{\overset{+}{\lambda}\,\overset{+}{w}\,\overset{-}{\theta}}{\underset{+}{\bar{H}}} + \overset{+}{R^*}\,\overset{+}{\frac{\partial L^*}{\partial v}} \qquad (29)$$

t_G: Per Unit Tax Imposed on Garbage

$$\frac{\partial R^*}{\partial t_G} = -\frac{\overset{+}{\lambda}\,\overset{+}{w^2}\,\overset{-}{G_R}}{\underset{+}{\bar{H}}} - \overset{+}{G^*}\,\overset{+}{\frac{\partial R^*}{\partial v}} \qquad (30)$$

$$\frac{\partial L^*}{\partial t_G} = -\frac{\overset{+}{\lambda}\,\overset{+}{w}\,\overset{-}{\theta}\,\overset{-}{G_R}}{\underset{+}{\bar{H}}} - \overset{+}{G^*}\,\overset{+}{\frac{\partial L^*}{\partial v}} < 0 \qquad (31)$$

Table 3
Simulation Exercise: Initial Conditions, Parameter Values and Functions Used in the Simulation

$U = C^{0.6}L^{0.4}$	$v = 10$	$t_G = 1.50$
$C = [G(R)]^{0.4}L^{0.6}$	$w = 5$	$T = 24$
$G(R) = 6 - 0.2R$	$p_R = 0.10$	$\alpha = 6$
$p_C = 7$	$s_R = 0.20$	$\beta = 6$

Table 4
Simulation Results

	Percentage Change in Exogenous Variable	Elasticities		
		Recyclables (R^*)	Leisure (L^*)	Garbage (G)
Nonwage Income (v)	+10%	0.12%	1.71%	-0.20%
	-10%	-0.17%	-1.62%	0.20%
Market Wage (w)	+10%	-0.91%	7.09%	1.28%
	-10%	2.63%	-8.54%	-3.69%
Market Price of the Composite Good (p_C)	+10%	-2.10%	-9.48%	2.73%
	-10%	0.80%	9.56%	-1.12%
Market Price of Recyclables (p_R)	+10%	0.40%	0.26%	-0.56%
	-10%	-0.45%	-0.26%	0.32%
Subsidy on Recyclables (s_R)	+10%	0.80%	0.60%	-1.16%
	-10%	-0.85%	-0.51%	1.20%
Excise Tax on Garbage (t_G)	+10%	1.15%	-0.60%	-1.69%
	-10%	-1.13%	0.77%	1.52%
Amount of Garbage Processed per Hour (α)	+10%	-0.62%	0.34%	0.72%
	-10%	0.69%	-0.34%	-1.28%
Amount of Recyclables Processed per Hour (β)	+10%	2.91%	2.22%	-4.17%
	-10%	-4.15%	-2.31%	5.82%