Private Provision of Environmental Public Goods:
Household Participation in Green-Electricity Programs*

By

Matthew J. Kotchen†
Department of Economics
Williams College

and

Michael R. Moore
School of Natural Resources & Environment
University of Michigan

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† Corresponding author: Department of Economics, Williams College, Williamstown, MA 01267; Email: mkotchen@williams.edu; Telephone (413) 597-2101; Fax (413) 597-4045.

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Abstract

Green-electricity programs provide an opportunity to study private provision of public goods in a field setting. The first part of this paper develops a theoretical framework to analyze household decisions about voluntary participation in green-electricity programs. We consider different participation mechanisms and show how they relate to existing theory on either *pure* or *impure* public goods. The models are used to examine the implications of participation mechanisms for the level of public-good provision. The second part of the paper provides an empirical investigation of actual participation decisions in two green-electricity programs—one based on a pure public good and the other based on an impure public good. The data come from original household surveys of participants and nonparticipants in both programs, along with utility data on household electricity consumption. The econometric results are interpreted in the context of the theoretical models and are compared to other studies of privately provided public goods.

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1 Introduction

The option to purchase "green" electricity is increasingly available to households across the United States. Green electricity is electricity generated from renewable sources of energy—such as solar, wind, geothermal, and biomass—and it is distinguished from conventionally generated electricity by its relatively low (or nonexistent) pollution emissions. Typically, green electricity is marketed at prices ranging from 10 to 30 percent above the price of conventional electricity. In states with regulated electricity markets, electric utilities are developing green-electricity programs as a distinct supply option that households can voluntarily choose; more than 350 utilities have implemented such green-electricity programs. In states with deregulated electricity markets, suppliers of green electricity are competing with suppliers of conventional electricity; there are 29 green-electricity suppliers currently competing in 8 states.[1]

Two primary mechanisms are available for households to participate in green-electricity programs. Some programs are based on a voluntary contribution mechanism (VCM), whereby households simply donate money to support the capacity for generating green electricity. Such contribution-based programs are structured so that payments for green electricity are independent of a household's electricity consumption. Other programs, in contrast, link payments for green electricity with household electricity consumption. Programs of this type are structured so that payments for green electricity are based on a green tariff mechanism (GTM), whereby households must pay a fixed tariff per kilowatt-hour of consumption. In some cases the tariff must apply to 100 percent of the household's consumption, while in other cases the tariff need only apply to a proportion of consumption that the household chooses.

The first part of this paper develops a theoretical framework to analyze household decisions about participation in green-electricity programs. We consider programs of both types, VCMs and GTMs. The theory begins with recognition that participants in green-electricity programs provide an environmental public good. Because increased production

[1] The basic facts reported here are taken from Bird and Swezey (2003). The information is periodically updated by the National Renewable Energy Laboratory of the U.S. Department of Energy and is available online at http://www.eere.energy.gov/greenpower.

of green electricity implies a reduction in demand for conventional electricity, participants in green-electricity programs are responsible for a reduction in pollution emissions—a public good. There is, however, an important distinction between programs based on VCMs or GTMs. As we will show, the former are consistent with theory on private provision of a *pure* public good (Bergstrom, Blume, and Varian, 1986; Andreoni, 1988), while the latter are consistent with theory on private provision of an *impure* public good (Cornes and Sandler, 1984, 1994). We consider this distinction explicitly in the theoretical analysis, and we examine its implications for program participation and the level of public-good provision.

The second part of the paper provides an empirical investigation of actual participation decisions in two different green-electricity programs. One program, Detroit Edision's "SolarCurrents," is based on a VCM. Participating households choose to lease 100-watt blocks of solar generation capacity at a centralized facility. Each block costs $6.59 per month, and households can choose to lease any number of blocks. The other program, Traverse City Light & Power's "Green Rate," is based on an all-or-nothing GTM. Participating households must agree to pay a premium of 1.58 cents per kilowatt-hour for 100 percent of their household's electricity consumption. Revenues are then used to finance capacity at a centralized wind turbine. We analyze participation in both programs using data from original household surveys of participants and nonparticipants, along with utility data on household electricity consumption.

Prior research on green electricity has focused primarily on estimating willingness-to-pay or willingness-to-donate. These studies have employed various techniques, including the hedonic price method (Roe *et al.*, 2000), conjoint analysis (Goett, Hudson, and Train, 2000; Roe *et al.*, 2000), and contingent valuation (Ethier *et al.*, 2000; Champ and Bishop, 2001; Poe *et al.*, 2002). In several cases, estimates from stated-preference techniques are compared to those from revealed-preference techniques (Roe *et al.*, 2000; Champ and Bishop, 2001; Poe *et al.*, 2002). The general findings are that many households are willing to pay a premium for green electricity and that, while stated preferences result in overestimates, calibration techniques based on revealed preferences can be used to adjust for the upward bias.

The objectives of this paper are different. We set out to accomplish the following:

(1) provide a theoretical basis for different participation mechanisms of green-electricity programs, (2) compare the theoretical implications of different mechanisms in terms of participation and public-good provision, (3) investigate empirically the factors that influence participation in green-electricity programs of different types, (4) interpret the results in the context of the theoretical models, and (5) compare the results to studies of other privately provided public goods.

The paper is of general interest because it analyzes private provision of a public good in a field setting. This perspective on green-electricity programs has been the focus of two other studies. Rose *et al.* (2002) test the use of a provision point mechanism to finance a green-electricity program and find that participation is responsive to the mechanism. Oberholzer-Gee (2001) analyzes a sample of contributors to a VCM-based program and finds evidence that motives related to altruism and egoism underlie contributions. Our study, in contrast, focuses on the primary mechanisms for participation in green-electricity programs, and we consider motives of both participants and nonparticipants in the two types of programs. We find, for example, that environmental concern and altruistic attitudes are important determinants of household decisions about green electricity.

Regarding other types of public goods, there have been surprisingly few studies that use microdata to analyze privately provided public goods in a field setting.[2] This paper reports on two case studies—one for a pure public good and one for an impure public good. After developing and comparing the theoretical models (Section 2), we further describe the empirical settings and data collection (Section 3). Three results of the econometric analysis (Section 4) contribute to the literature on private provision of public goods. First, we find that, while several household characteristics influence the decision of whether to contribute to a public good, only household income influences the size of a contribution. This result supports Smith, Kehoe, and Cremer's (1995) finding that different factors influence the extensive and intensive margins of charitable giving. Second, household income influences participation in a green-electricity program that provides a pure public good, but not one that provides an impure public good. This empirical finding, as we will show, is consistent

[2]Some existing studies have focused on contributions to public radio (Kingma, 1989), donations to a rural health care facility (Smith, Kehoe, and Cremer, 1995), and alumni giving to colleges and universities (Clotfelter, 2003).

with the theory. Third, using data on actual household electricity consumption, we find a significant price effect on participation in a green-electricity program that is based on an impure public good. We discuss these results and others, along with limitations and suggestions for future study, in the final section of the paper.

2 Theoretical Framework

Assume the economy consists of n households denoted $i = 1, ..., n$. Each household is endowed with exogenous income m_i and seeks to maximize a continuous and strictly quasi-concave utility function of the form

$$U_i = U(x_i, y_i, G; \theta),$$

where x_i is a numeraire consumption good, y_i is household electricity consumption, G is the generation capacity of green electricity, and θ is a vector of taste parameters that characterize heterogenous preferences. G has no subscript because it is a public good—that is, all households benefit from the total amount of green-electricity capacity.

2.1 The Voluntary Contribution Mechanism (VCM)

Consider a green-electricity program in which households have the opportunity to make a voluntary contribution to finance generation capacity. Total capacity, measured in financing expenditures, is determined by the aggregate level of contributions such that $G = \sum_{i=1}^{n} g_i$, where g_i is household i's contribution. An important feature of this program structure, as discussed previously, is that contribution levels are not a function of electricity consumption. While contributions are used to finance green electricity, households continue to consume conventional electricity at the price p_c.

Each household takes the contribution of all other households, denoted $G_{-i} = G - g_i$, as exogenously given (the Nash assumption) and solves the following utility maximization problem:

$$\max_{x_i, y_i, g_i} \{U(x_i, y_i, g_i + G_{-i}; \theta) \mid x_i + p_c y_i + g_i = m_i\}. \quad (1)$$

This setup is closely related to the standard model for private provision of a pure public good.[3] The only difference in (1) is the choice over two private goods, rather than one. The addition of the numeraire is useful, as we will see, for contrasting different participation mechanisms for green-electricity programs.

To analyze the model, it is convenient to add G_{-i} to both sides of the budget constraint in (1) and rewrite the household's problem with a choice over the aggregate level of G rather than g_i:

$$\max_{x_i, y_i, G} \left\{ U\left(x_i, y_i, G; \theta\right) \mid x_i + p_c y_i + G = m_i + G_{-i},\ G_{-i} \leq G \right\}, \tag{2}$$

where the additional constraint $G_{-i} \leq G$ follows from nonnegativity of g_i. The solution to this problem yields a continuous demand function for G that (after suppressing notation for p_c) can be written as

$$G = \max \left\{ f\left(m_i + G_{-i}; \theta\right), G_{-i} \right\}, \tag{3}$$

where $f(\cdot)$ is demand for G ignoring the inequality constraint. We assume that G is a normal good, which implies that $f(\cdot)$ is strictly increasing. Now subtracting G_{-i} from both sides of (3), we have each household's best-response function for a contribution:

$$g_i = \max \left\{ f\left(m_i + G_{-i}; \theta\right) - G_{-i}, 0 \right\}. \tag{4}$$

Using these best-response functions, it is relatively straightforward to prove existence of a Nash equilibrium (see the Appendix).[4]

Letting G^* denote an equilibrium level of contributions to finance green-electricity capacity, we can solve for each household's equilibrium contribution. Assume $G^* > G^*_{-i}$ in (3), invert $f(\cdot)$, and add g_i^* to both sides. Solving for the household's contribution yields $g_i^* = m_i - f^{-1}\left(G^*; \theta_i\right) + G^*$. Now define a critical level of income $m^*(\theta) = f^{-1}\left(G^*; \theta\right) - G^*$. We can then write each household's equilibrium contribution as

[3] See Bergstrom, Blume, and Varian (1986) for the standard model and Andreoni (1988) for the extension to heterogenous preferences.

[4] The results in this paper rely on existence and not uniqueness of a Nash equilibrium.

$$g_i^* = \begin{cases} 0 & \text{if } m_i \leq m^*(\theta) \\ m_i - m^*(\theta) & \text{if } m_i > m^*(\theta). \end{cases} \quad (5)$$

Several implications of the contribution function are worth noting. First, households with different tastes have different critical levels of income. If, for example, θ is defined such that greater values indicate a greater taste for G, then $m^*(\theta_i) < m^*(\theta_j)$ for $\theta_i > \theta_j$. Second, whether a household is a free-rider (contributor) depends on whether its actual income is less than (greater than) its critical level of income. Thus, households that free-ride are those with relatively low income, low θ, or both. Finally, households that are contributors contribute all of their income above their critical level, implying that households making larger contributions are those with relatively high income, high θ, or both.

2.2 The Green Tariff Mechanism (GTM)

Now consider a green-electricity program in which financing is based on a green tariff. Each household chooses a proportion of its electricity consumption, $\alpha_i \in [0,1]$, on which to pay a voluntary price premium (green tariff), $\pi > 0$, in excess of p_c. The effective contribution of a household in support of green electricity is therefore $\pi\alpha_i y_i$. Total capacity is $G = \pi\sum_{i=1}^{n}\alpha_i y_i$, and we carryover the notation $G_{-i} = G - \pi\alpha_i y_i$. Compared to the VCM, the GTM is distinct because a household's contribution is linked to its electricity consumption through the choice of α_i. In fact, the quantity of electricity consumption $\alpha_i y_i$ can be thought of as an impure public good because it generates a private characteristic (electricity consumption) and a public characteristic (green-electricity capacity).[5]

Each household's utility maximization problem with the GTM can be written as

$$\max_{x_i, y_i, \alpha_i} \{U(x_i, y_i, \pi\alpha_i y_i + G_{-i}; \theta) \mid x_i + p_c y_i + \pi\alpha_i y_i = m_i\}. \quad (6)$$

This setup is technically distinct from the standard impure public good model because α_i is a choice variable—that is, the private and public characteristics of the impure public good are not generated in fixed proportions. Furthermore, unlike the standard model, con-

[5] See Cornes and Sandler (1984, 1994) for the setup and analysis of the standard impure public good model.

sumers effectively have more than one way to obtain the private characteristic: conventional electricity and green electricity.[6]

In order to compare the GTM with the VCM, we once again write the household's problem with a choice over the aggregate level of G. Rewriting (6) in this way yields

$$\max_{x_i, y_i, G} \{U(x_i, y_i, G; \theta) \mid x_i + p_c y_i + G = m_i + G_{-i} \text{ and } G_{-i} \leq G \leq \pi y_i + G_{-i}\}, \qquad (7)$$

where the first constraint follows from adding G_{-i} to both sides of the budget constraint, and the additional constraints follow because $0 \leq \alpha_i$ implies $G_{-i} \leq G$, and $\alpha_i \leq 1$ implies $G\,(= \pi\alpha_i y_i + G_{-i}) \leq \pi y_i + G_{-i}$. Once again, it is relatively straightforward to prove existence of a Nash equilibrium (see the Appendix).

Note that maximization problem (7) is equivalent to maximization problem (2) if $\alpha_i < 1$, in which case the constraint $G \leq \pi y_i + G_{-i}$ is not binding. This observation leads to an important result about equivalence between different financing mechanisms for green electricity: *if all households in a GTM choose to pay the premium on less than 100 percent of their electricity consumption, then the GTM is equivalent to a VCM.* It follows that all of the same households will participate in the program, all households will contribute the same amount, and the total capacity of green electricity will be the same. Intuition for the equivalence follows from recognizing that, conditional on a household's choice of electricity consumption y_i, each household effectively chooses a contribution level with its choice of α_i.

In the case of a corner solution with $\alpha_i = 1$, however, the household faces an additional constraint with the GTM—whereby increasing the contribution level by increasing α_i is no longer possible—and equivalence breaks down. Admitting the possibility for such corner solutions leads to a more general result: *the GTM will generate a (weakly) lower level of public-good provision than the VCM.* This result follows from the simple fact that the GTM imposes a more restrictive upper bound on each household's level of provision, $\frac{\pi m_i}{p_c + \pi}$ versus m_i.

It is worth considering in more detail a restricted GTM in which households face an

[6] See Kotchen (forthcoming) for extensions of the standard impure public good model that consider pure-private and pure-public substitutes for the impure public good. In fact, the setup in (6) is equivalent to Kotchen's scenario involving a substitute conventional good.

"all-or-nothing" decision. Many green-tariff programs, including the one studied in the empirical portion of this paper, are structured so that participation requires households to apply the price premium to 100 percent of their electricity consumption. Thus, the choice of α_i is constrained to the values of 0 or 1. The model predicts that a household will participate in equilibrium if

$$V\left(p_c, \pi, m_i; \theta, G_{-i}, \alpha_i = 1\right) \geq V\left(p_c, \pi, m_i; \theta, G_{-i}, \alpha_i = 0\right), \tag{8}$$

where $V(\cdot)$ is the indirect utility function that equals the maximized value of (6). Note that the only difference between the two sides of the inequality is whether $\alpha_i = 1$ or 0.

We know that the all-or-nothing GTM is *not* equivalent to the VCM. But how do the two mechanisms differ in terms of the level of public-good provision? The answer differs from that for the more flexible GTM: *the all-or-nothing GTM can generate either a higher or lower level of public-good provision than the VCM.* We demonstrate this result with a simple example:

> **Example.** Assume there are two identical households with income m, $p_c = 1$, and preferences are given by $U_i = q_i\left(1 + G\right)$ where $q_i = x_i + y_i$. With the VCM, it is straightforward to solve for the equilibrium level of provision $G^{vcm} = \frac{2(m+1)}{3}$. With an all-or-nothing GTM, the equilibrium level of provision will depend on π. With participation, the level of provision will be $G^{\alpha=1} = \frac{2\pi m}{1+\pi}$; and without participation, the level of provision will be $G^{\alpha=0} = 0$.[7] Figure 1 demonstrates how the level of provision changes with π. At low levels of π, there is participation, the upper bound on provision is binding, and $G^{\alpha=1} \leq G^{vcm}$. At intermediate levels of π, there is participation, and $G^{\alpha=1} > G^{vcm}$; the reason for the higher level of provision is that, despite being forced to provide more than under the VCM, the households prefer "all" to "nothing" with the GTM. This is no longer true at sufficiently high levels of π, in which case the households do not participate, and the level of provision drops to $G^{\alpha=0} = 0$.

The breakdown of equivalence between the all-or-nothing GTM and the VCM raises a further question: How might household characteristics affect participation differently in the two types of green-electricity programs? We have already investigated the influence of θ and m_i on participation with a VCM. But how will changes in θ and m_i affect participation in an all-or-nothing GTM? To answer this question intuitively, it is useful to consider the

[7] The equilibrium is symmetric, and both households will participate if $q_i^{\alpha=1}\left(1 + G^{\alpha=1}\right) \geq q_i^{\alpha=0}\left(1 + G^{\alpha=0}\right)$, which is satisfied if and only if $\pi \leq 2m - 1$.

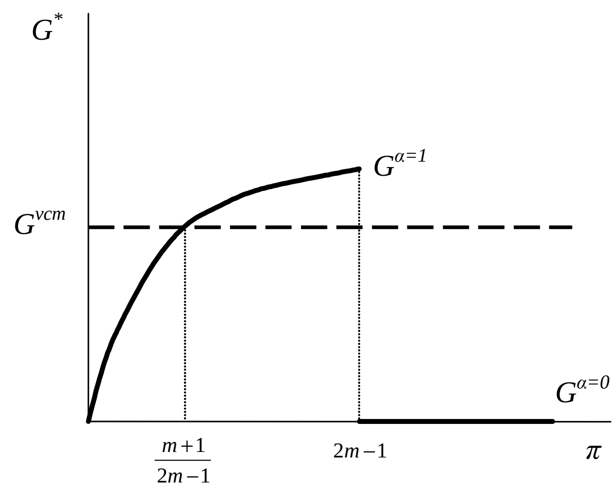

Figure 1: Example of provision with a VCM versus an all-or-nothing GTM

comparative statics of demand for G. Continuing to assume that greater values of θ indicate a greater taste for G, demand for G is nondecreasing in θ for given values of m_i and G_{-i}. Thus, an increase in θ will make satisfying the participation condition in (8) easier. The effect of a change in m_i is less clear, however. Cornes and Sandler (1994, 1996) show that demand for the joint products of an impure public good need not be increasing in income, even if one or both of the joint products satisfy normality.[8] Their result implies that demand for G can be either increasing or decreasing in m_i for given values of θ and G_{-i}. Thus, given a change in m_i, it is ambiguous whether satisfying the participation condition in (8) becomes easier or harder.

3 Data

Our empirical analysis assesses the influence of household characteristics on participation in the two types of green-electricity programs. We collected household data on participants and nonparticipants in two different programs in Michigan. One program was financed with a VCM, and the other was financed with an all-or-nothing GTM. This section describes the two green-electricity programs, the survey methods used to collect data, and the variables

[8] Detailed explanations of this result can be found in Cornes and Sandler (1994, p. 410; 1996, p. 264).

Table 1: Participation in Detroit Edison's SolarCurrents program

Number of Blocks	Annual Contribution	Number of Households
1	\$79.08	222
2	\$158.16	29
3	\$237.24	14
4	\$316.32	7
5	\$395.40	4
6	\$474.48	4
7	\$553.56	1

Note: Annual contribution is based on the price of \$6.59 per block per month.

for the econometric models.

The first program is Detroit Edison's "SolarCurrents" program. Detroit Edison is a large electric utility that serves over two million customers in southeastern Michigan. The SolarCurrents program began operating in August 1996. Solar energy is generated at two centralized photovoltaic facilities in the Detroit metropolitan area. Electricity produced at these facilities is fed directly onto the regional power grid and displaces an equivalent amount of electricity generated at conventional power plants. Participation is based on a VCM, whereby households agree to lease one or more 100-watt block(s) of solar capacity. Each block costs \$6.59 per month, and no limit is placed on the number of blocks a household can lease. Participating households must sign a two-year contract, and participation is completely independent of a household's metered consumption of electricity. The total capacity of the SolarCurrents program, 54.8 kilowatts, was determined according to the initial level of participation that resulted from 80,000 informational inserts in billing statements. In 1998, there were 281 households participating in the program at levels ranging from 1 to 7 blocks. Table 1 summarizes the distribution of participation levels based on the number of leased blocks and annual contributions per household.

The second program is Traverse City Light & Power's (TCL&P) "Green Rate" program. TCL&P is a municipal utility company that provides electrical service to approximately 7,000 residential customers in Traverse City, Michigan. In 1994, TCL&P began soliciting households to voluntarily finance a centralized wind turbine that would generate electricity and replace generation at the local coal-fired power plant. Based on the initial level of participation, TCL&P constructed a wind turbine in 1996. At the time, the turbine was the largest operating in the United States, producing roughly 800,000 kilowatt-hours of electricity per year, or enough to meet the demand of approximately 125 households. Participation in the Green Rate program is based on an all-or-nothing GTM. Participating households must purchase all of their electricity at a price premium of 1.58 cents per kilowatt-hour under a three-year contract. This translates into an average residential premium of $8.50 per month ($102 per year), or a 25-percent increase in the average household's electricity bill. In 2001, there were 122 households participating in the program, and 32 households were on a waiting list due to capacity limits.

We conducted household mail surveys of participants and nonparticipants in both of the green-electricity programs. The surveys were designed to collect data on socioeconomic characteristics and indicators of environmental concern and altruistic attitudes (described below).[9] The survey of Detroit Edison customers was conducted in 1998, while the survey of TCL&P customers was conducted in 2001. Both surveys were administered using the Dillman (1978) Total Design Method. The utility companies provided the names and addresses.[10] The sample sizes for the Detroit Edison and TCL&P surveys were 900 and 1000, respectively. Both samples were stratified to include all participants and a random sample of nonparticipants.[11] After accounting for undeliverable addresses, the response rates were 75 and 70 percent for the Detroit Edison and TCL&P surveys, respectively.[12]

A key feature of both surveys was the inclusion of questions designed to measure environmental concern and altruistic attitudes. The questions designed to measure environmental concern were taken from the New Ecological Paradigm (NEP) Scale, which is considered the standard instrument in the social and behavioral sciences for measuring concern about the environment (Dunlap, *et al.*, 2000). The NEP scale is based on a series of questions that ask respondents to indicate on a five-point scale the extent to which they agree or disagree with different statements. Responses to the questions are then checked for internal consistency,

[9] Copies of the survey instruments are available from the authors upon request.

[10] Surveys were addressed to the person whose name appeared on billing statements, and who we assume to be the household decision-maker with respect to electricity.

[11] For the Detroit Edison survey, questionnaires were sent to all 281 participants and a random sample of 619 nonparticipants. For the TCL&P survey, questionnaires were sent to all 122 participants, all 32 households on the waiting list, and a random sample of 846 nonparticipants.

[12] For the Detroit Edison survey, 624 questionnaires were returned and 72 were undeliverable. For the TCL&P survey, 677 questionnaires were returned and 28 were undeliverable.

after which they may be combined into a summated scale that provides a measure of general environmental concern. Five statements from the NEP scale were included in both surveys and comprise the scale used here. We report the specific statements in the Appendix Table, along with statistics to test for internal consistency (item-total correlations and Cronbach's alpha) for both surveys. The results indicate reasonable internal consistency and support combining the items into a summated scale.

The questions designed to measure altruistic attitudes followed the same format. Respondents were asked to indicate on a five-point scale the extent to which they agree or disagree with a series of statements that probed different aspects of the Schwartz (1970, 1977) model for the activation of altruistic behavior. While questions of this type are commonly used in experimental economics to explain private provision of public goods, they are less commonly used in the field where such data are more difficult to obtain.[13] This, however, was not a limitation for this study given the household mail survey. The scale that we use is based on a subset of the items used by Clark, Kotchen, and Moore (2003). The specific items are listed in the Appendix Table, along with the statistics to test for internal consistency. Based on these results, it is reasonable to combine the responses to form another summated scale that measures a general altruistic attitude.

The NEP scale and the altruism scale enter the econometric analysis as indicators of heterogenous tastes that may influence participation in a green-electricity program. The econometric analysis also includes variables constructed from data on annual household income, the number of people living in each household, and the age and gender of the respondents. A final source of data is for only the TCL&P customers. TCL&P provided data on actual household electricity consumption that we could match with the households in the survey. With these data, which span January 1994 through May 2002, we were able to create a variable for average daily electricity consumption. In the next section, we explain how this variable can be used to determine each household's effective price of participation in a program based on a GTM.

Table 2 compares descriptive statistics for the Detroit Edison and TCL&P populations.

[13] For example, Eckel and Grossman (2000) conduct an experiment that uses a multi-item altruism scale to explain charitable contributions in laboratory setting.

Table 2: Descriptive statistics for the
Detroit Edison and TCL&P populations

Variable	Detroit Edison	TCL&P	t stat.
NEP scale	17.175	17.303	0.472
	(0.206)	(0.177)	
Altruism scale	17.486	18.510	4.330***
	(0.180)	(0.153)	
Household income ($1,000s)	66.802	53.157	4.849***
	(2.411)	(1.450)	
Age	51.303	60.409	9.441***
	(0.720)	(0.642)	
Gender (1 = male)	0.698	0.525	5.310***
	(0.024)	(0.021)	
Household size	2.936	2.235	7.247***
	(0.079)	(0.056)	
Electricity consumption (kwh/day)	–	17.914	
	–	(0.424)	

Notes: Statistics are based on weighted survey data to represent the respective populations. Standard errors are reported in parentheses. One, two, or three asterisks indicate significance at the levels $p<0.10$, $p<0.05$, or $p<0.01$, respectively.

The NEP and altruism scales range from a minimum possible value of 5 to a maximum possible value of 25. While there is no significant difference between the two populations in terms of environmental concern as measured by the NEP scale, the TCL&P population scores significantly higher on the altruism scale. This difference may reflect the fact that Traverse City is a much smaller community, which may foster a greater sense of social capital. Annual household income is reported in 1997 dollars, and the mean is significantly higher for the Detroit Edison population. The two populations also differ significantly with respect to age, gender, and household size: the Detroit Edison population is younger, more likely to have a male name on the billing statement, and has more people living in each household. The final variable, average electricity consumption, measured in kilowatt-hours per day (kwh/day), is available for only the TCL&P population and indicates daily consumption of about 18 kwh/day.

4 Econometric Analysis

We use the data on participants and nonparticipants in the two green-electricity programs to estimate econometric models of the participation decision. We begin with the VCM of the SolarCurrents program. We then consider the all-or-nothing GTM of the Green Rate program.

4.1 The SolarCurrents Program

Equation (5) provides the theoretical foundation for analyzing household contributions to the SolarCurrents program. The theory predicts that a household's contribution will depend on tastes θ and income m_i. Specifically, households with different tastes will have different critical levels of income such that a household's contribution will be zero if income falls below the critical level; otherwise a household's contribution will be all of its income above the critical level.

We estimate regression models to explain household contributions to the SolarCurrents program in terms of income and heterogeneous tastes. The variables listed in Table 2 are included as regressors. The theory makes a clear prediction that contributions should be increasing in household income. We use the NEP and altruism scales as indicators of household tastes that may influence contributions. Formally, both scales are treated as elements of θ, and our hypothesis is that greater environmental concern and stronger altruistic attitudes will have a positive effect on contributions. The other variables of age, gender, and household size are also treated as elements of θ. While we have no strong priors about how age and gender may affect contributions, we hypothesize that household size will have a negative effect, as the amount of disposable income is likely to decrease with more members in a household.

We begin with a tobit model because of the large number of households that make no contribution to the SolarCurrents program.[14] The dependent variable is a household's annual contribution. The results are reported in the first column of Table 3. As predicted, both the NEP and altruism scales have a positive effect on contributions; both variables

[14] The tobit model is commonly used for regressions of voluntary contributions with microdata. For examples see Kingma (1989), Smith, Kehoe, and Cremer (1995), and Clotfelter (2003).

have coefficients that are positive and statistically significant. The positive and statistically significant coefficient on household income is also consistent with the theoretical prediction, as contributions do in fact increase with income. The marginal effect of income, however, is substantially lower than the theoretical prediction that contributions will increase with income one-for-one. The coefficient of 0.692 implies that a $1000 increase in annual income increases the annual contribution by roughly 70 cents. Despite differing from the quantitative prediction, the magnitude of this income effect is close to the results of other studies on voluntary contributions.[15] The effect of age is positive, but not statistically significant. The coefficient on gender is statistically significant, and the negative sign indicates that males tend to make smaller contributions than females. Finally, household size has a negative and statistically significant effect on contributions, suggesting the importance of considering disposable income.

To test the robustness of the tobit results, we also estimate count data models for the number of leased blocks of solar capacity. The count data models are motivated by the nature of the data on blocks, involving a preponderance of zeros and small positive integer values. We report the results of a negative binomial model in the second column of Table 3. A poisson model (not reported) generates very similar results, yet fails a specification test against the negative binomial model. With the exception of the statistical insignificance of gender, the qualitative results are robust to the count data specifications.

A common feature of the tobit and count data models is the restriction that explanatory variables influence the extensive and intensive margins of contributions in the same way. That is, an implicit assumption is made that the decision of *whether to contribute* is the same as the decision of *how much to contribute*. While this restriction is consistent with the theoretical foundation in equation (5), it is possible that the explanatory variables influence voluntary contributions on the extensive and intensive margins in different ways. Smith, Kehoe, and Cremer (1995) make this observation and find empirical support for it in a study of charitable contributions to a rural health care facility. We explore the same possibility here by decomposing the tobit model into a probit model for the decision of whether to

[15] For instance, comparable marginal effects are estimated to be 0.54 for contributions to public radio stations in the United States (Kingma, 1989) and 0.01 for contributions to a green-electricity program in Zurich, Switzerland (Oberholzer-Gee, 2001).

Table 3: Econometric models of household participation in Detroit Edison's SolarCurrents program

	Model			
	(1)	(2)	(3)	(4)
Variable	Tobit	Neg. Bin.	Probit	Trunc. Reg.
NEP scale	13.522***	0.100***	0.039***	1.659
	(3.758)	(0.031)	(0.011)	(3.569)
Altruism scale	16.651***	0.143***	0.048***	-3.167
	(4.214)	(0.040)	(0.012)	(4.354)
Household income	0.692**	0.009***	0.002**	0.612*
($1,000s)	(0.283)	(0.003)	(0.001)	(0.334)
Age	1.083	0.008	0.003	-0.537
	(1.003)	(0.008)	(0.003)	(0.846)
Gender (1 = male)	-44.081*	-0.274	-0.133*	33.192
	(26.366)	(0.227)	(0.077)	(29.499)
Household size	-31.182***	-0.224**	-0.091***	6.313
	(10.658)	(0.097)	(0.031)	(9.895)
Constant	-1473.893***	-9.891***	-4.22***	8.717
	(137.807)	(1.081)	(0.343)	(121.735)
Observations	521	521	521	235
Log likelihood	-2969.127	-1783.470	-1540.672	-1411.424
$\hat{\sigma}$	350.429			125.645
$\hat{\alpha}$		115.955		

Notes: The dependant variables are (1) annual contributions including zeros, (2) blocks of solar capacity including zeros, (3) the binary participation decision, and (4) annual contributions excluding zeros. All models are estimated with pseudo-maximum likelihood in which observations are weighted to correct for different sampling probabilities. Observations with missing data are excluded from the estimation. Robust standard errors are reported in parentheses. One, two, or three asterisks indicate significance at the levels $p<0.10$, $p<0.05$, or $p<0.01$, respectively.

contribute, and a truncated regression model for the decision of how much to contribute.[16]

We report the results of these two models in the third and fourth columns of Table 3. The qualitative results of the probit model mirror those of the tobit; all of the coefficients have the same sign and level of statistical significance. Thus, variables that influence only the extensive margin of contributions are the same as those that influence the extensive and intensive margins jointly. The results differ substantially, however, when considering only the intensive margin. In the truncated regression model, only household income is a statistically significant explanatory variable, which continues to imply that contributions increase with income. Nevertheless, the overall model explains little variation in contributions, as it fails a Wald test restricting all coefficients to zero $\left(\chi^2 = 4.42,\, p = 0.6\right)$. Although not reported here, estimates of truncated count data models generate an identical pattern of results, yet do not fail the Wald test restricting all coefficients to zero.

Together, these results provide evidence that the decision of whether to contribute is not determined in the same way as the decision of how much to contribute. Specifically, we find that environmental concern, altruistic attitudes, household income, gender, and household size influence the decision about whether to contribute to the SolarCurrents program, yet only household income influences the decision of how much to contribute.

4.2 The Green Rate Program

We now consider participation in TCL&P's Green Rate program. Because the program is based on an all-or-nothing GTM, the condition specified in equation (8) provides the theoretical foundation for analyzing household participation decisions.

We start with a probit model of participation that includes all of the same variables that were used to analyze the SolarCurrents program. The results are reported as model (1) in Table 4. The NEP and altruism scales have a positive and statistically significant effect on participation. These results are consistent with those for the SolarCurrents program. We therefore conclude that the NEP and altruism scales provide reliable measures of

[16] Our approach differs from that of Smith, Kehoe, and Cremer (1995), who examine the different margins with a Heckman selection model. We do not follow their approach because our sample includes all households that participated in the SolarCurrents program; therefore, the analysis of the intensive margin needs no correcting for sample-selection bias. For cases such as this, Greene (2000) notes that the appropriate decomposition of a tobit model is into a probit model and a truncated regression model.

Table 4: Probit models of household participation in TCL&P's Green Rate program

	Model	
Variable	(1)	(2)
NEP scale	0.074***	0.073***
	(0.015)	(0.015)
Altruism scale	0.076***	0.075***
	(0.017)	(0.018)
Household income	0.001	0.002
($1,000s)	(0.002)	(0.002)
Age	-0.006	-0.006
	(0.005)	(0.004)
Gender (1 = male)	0.109	0.119
	(-0.029)	(0.116)
Household size	-0.029	0.015
	(0.046)	(0.048)
Electricity consumption	–	-0.017***
(kwh/day)	–	(0.006)
Constant	-4.644***	-4.464***
	(0.512)	(0.508)
Observations	528	525
Log likelihood	-533.434	-524.341

Notes: The dependant variable in both models is the binary participation decision. Both models are estimated with pseudo-maximum likelihood in which observations are weighted to correct for different sampling probabilities. Observations with missing data are excluded from the estimation. Robust standard errors are reported in parentheses. One, two, or three asterisks indicate significance at the levels p<0.10, p<0.05, or p<0.01, respectively.

heterogeneous tastes with respect to preferences for participation in a green-electricity program. Other studies have attempted to measure environmental and/or altruistic attitudes to explain contributions to green-electricity programs (Champ and Bishop, 2001; Rose, *et al.*, 2002) or other public goods (e.g., Smith, Kehoe, and Cremer, 1995; Clotfelter, 2003). With mixed degrees of success, the typical approach in these studies is to employ a survey question about other charitable activities and/or a single-item question about a specific attitude. While the summated scales used here require more demanding survey questions, the approach is more reliable for measuring general attitudes (Spector, 1992), and both scales have a conceptual foundation in the social and behavioral sciences.

Inclusion of the NEP and altruism scales in the probit model is particularly compelling because not one of the other explanatory variables is statistically significant. Most notable is the insignificance of household income. Recall that the theoretical model accounts for this possibility because participation is based on provision of an impure public good. Indeed, the prediction that income may affect participation differently with a VCM or an all-or-nothing GTM is an important insight of the theoretical model. Now, consistent with this insight is the empirical finding that income affects participation in the SolarCurrents program but not the Green Rate program.[17] A similar pattern emerges from a cross-program comparison of the influence of household size, which we interpret as a proxy for disposable income after controlling for household income. Household size has a statistically significant affect on participation in the SolarCurrents program but not the Green Rate program.

An interesting feature of the all-or-nothing GTM is the way that, in general, households face different effective prices of participation. Even though participating households pay an identical price premium π, electricity demand y_i will vary across households. This implies that the effective price of participation, πy_i, will also vary across households. We hypothesize that, controlling for other factors, the effective price of participation will exert a negative effect on the probability of participating in an all-or-nothing GTM.

We test this hypothesis using utility-provided data on household electricity consumption as a proxy for the effective price of participation. Model (2) in Table 4 is another probit

[17] It is worth mentioning that the coefficient on income becomes positive and statistically significant at the 0.05 level if the NEP and altruism scales are dropped from model (1) in Table 4. Controlling for heterogenous tastes is therefore important for obtaining an accurate estimate of the income effect.

model of the participation decision that differs by the inclusion of average daily electricity consumption as an explanatory variable.[18] As expected, the coefficient on electricity consumption is negative and statistically significant, indicating that a higher effective price decreases the probability of participation in the Green Rate program. By way of comparison, Champ and Bishop (2001) find a negative price effect when soliciting participation in a green-electricity program with randomly assigned contribution levels. Their result, however, pertains to provision of pure public good, while our result pertains to provision of an impure public good. The magnitude of our estimated price effect implies an elasticity (evaluated at the mean of electricity consumption) of -0.83, suggesting that the probability of participation is inelastic with respect to effective price. With inclusion of effective price in the model, the coefficient estimates on the other explanatory variables remain virtually unchanged.

5 Conclusions

The increasing number of green-electricity programs combined with the diversity of their participation mechanisms raises two important questions: Why do households participate in green-electricity programs? And how does a program's structure affect participation? These questions can be addressed with economic theory on private provision of public goods. The first part of this paper extends models of privately provided pure and impure public goods to capture the primary participation mechanisms for green-electricity programs, namely VCMs and GTMs. The models show how participation in these programs will depend on income and heterogeneous tastes. The models also reveal several insights about public-good provision under a VCM versus a GTM. First, a GTM is equivalent to a VCM if all households choose to pay the tariff on less than 100 percent of their electricity consumption. Second, a GTM will result in (weakly) less privately provided capacity of green electricity

[18] There is a potential endogeneity concern with including average daily electricity consumption as an explanatory variable. Upon entering the Green Rate program and paying the voluntary tariff, households may change their electricity consumption. See Kotchen and Moore (2004) for a detailed investigation of this possibility. To address this concern here, we use the times series data on household consumption to calculate an alternative variable for each household's average daily consumption when *not* participating in the Green Rate program. When this variable is included instead, all of the results remain nearly identical to those in model (2).

than a VCM. Finally, depending on the size of the tariff, an *all-or-nothing* GTM can result in more or less privately provided capacity of green electricity than a VCM.

The empirical portion of the paper focuses on the influence of household characteristics on participation in two green-electricity programs—one based on a VCM and one based on an all-or-nothing GTM. The data come from a combination of revealed preferences for actual green-electricity programs and original surveys of both participating and nonparticipating households. In the program based on a VCM, several variables influence contributions in predicted ways. Models that combine the extensive and intensive margins of participation reveal that contributions are increasing in household income, environmental concern, and altruistic attitudes; yet they are decreasing in the number of people living in the household and whether a male name is on the electricity billing statement. Interestingly, the results differ substantially when the extensive and intensive margins are analyzed separately. All of the same variables affect the decision of whether to contribute, but only household income affects the decision of how much to contribute. In the program based on an all-or-nothing GTM—where there is only an extensive margin—fewer variables influence the participation decision. The probability of participation is increasing in environmental concern and altruistic attitudes; yet it is decreasing in household electricity consumption, which proxies for the effective price of participation. Household income does not significantly influence participation; this result is particularly interesting because, according to the theoretical models, it is one of the potential differences that may occur between VCMs and GTMs.

Our theoretical and empirical results have several implications for the design of green-electricity programs. The theory suggests that participation based on a VCM will induce more green-electricity capacity than participation based on a fully flexible GTM. However, the comparison between a VCM and an all-or-nothing GTM will depend on the size of the green tariff. While sufficiently low or high tariffs continue to favor the VCM, there exists a middle range of tariffs under which the all-or-nothing GTM will induce more capacity. The empirical results suggest ways to most effectively market green electricity. It appears that the greatest success will occur if marketing efforts can be targeted to households that have greater concern for the environment and/or stronger altruistic attitudes. Marketing green-electricity programs through environmental and charitable organizations may thus prove useful. Other suggestions are to target households with higher income when participation is based on a VCM, and to target households with lower electricity consumption when participation is based on an all-or-nothing GTM.

We conclude with remarks about limitations and suggestions for future studies. While we test some predictions of the theoretical model, the fact that our data set encompasses only two green-electricity programs limits the empirical scope of the research. Specifically, we cannot test for the effect of program structure on participation and the level of public-good provision. This would be possible with either microdata or aggregate data on many green-electricity programs, or even experimental data on participation in hypothetical programs with different participation mechanisms. This is a task for future research. Our empirical results suggest, however, that further advancement of the theory on voluntary contributions is also necessary. Following Smith, Kehoe, and Cremer (1995), we find that different variables influence the extensive and intensive margins of voluntary contributions; nevertheless, the theory does not account for this empirical finding. In a recent study, Murdoch, Sandler, and Vijverberg (2003) consider a two-stage game in which agents first choose whether or not to participate, and then they choose their level of participation. While the model accounts for different determinants at each stage, the natural application is to international treaties. Similar studies that focus on individual or household contributions and motives would be useful. For instance, models could be developed to further consider how notions such as the buying-in mentality (Rose-Ackerman, 1982), warm glow (Andreoni, 1990), and prestige (Harbaugh, 1998) may operate differently at the extensive and intensive margins of contributions. To the extent that these same considerations interact differently with VCMs and GTMs, they may also be important to more fully understand participation in green-electricity programs.

Appendix

Equilibrium existence with a VCM

Proof. Define $Z = \{z \in R^n : 0 \leq z_i \leq m_i \text{ for } i = 1, .., n\}$, which is clearly a compact and convex set. The best-response functions in (4) define a continuous function from the set Z to itself. By Brouwer's Fixed Point Theorem there exists at least one fixed point that can be denoted with g_i^* for all i. Then, conditional on g_i^* for all i, each household solves (1) for x_i^* and y_i^*, and the vector (x_i^*, y_i^*, g_i^*) for all i fully specifies a Nash equilibrium. ■

Equilibrium existence with a GTM

Proof. The proof is similar to that for the VCM. Write demand for G that arises from solving (7) as $G = \min\left\{G^+, \pi y_i^+ + G_{-i}\right\}$, where G^+ is the solution to (3), and y_i^+ is demand for y_i. Subtracting G_{-i} from both sides yields the best-response functions $g_i \left(= \pi\alpha_i y_i^+\right) = \min\left\{G^+ - G_{-i}, \pi y_i^+\right\}$. Now define $S = \left\{s \in R^n : 0 \leq s_i \leq \pi \frac{m_i}{p_c + \pi} \text{ for } i = 1, ..., n\right\}$, and note that the best-response functions map from the closed and compact set S to itself. By Brouwer's Fixed Point Theorem there exists at least one fixed point that can be denoted with g_i^* for all i. Then, conditional on g_i^* for all i, each household solves (6) for x_i^* and y_i^*, from which it is possible to use the relationship $g_i^* = \pi\alpha_i y_i^*$ to recover α_i^*. It follows that the vector $(x_i^*, y_i^*, \alpha_i^*)$ for all i fully specifies a Nash equilibrium. ■

Appendix Table: Item-total correlations and Cronbach's alpha for the NEP and altruism scales

	Detroit Edison	TCL&P
NEP scale		
1. Plants and animals have as much right as humans to exist.	0.604	0.562
2. The so-called "ecological crisis" facing humankind has been greatly exaggerated.	0.737	0.745
3. Human ingenuity will insure that we do not make the earth unlivable.	0.631	0.643
4. The earth is like a spaceship with very limited room and resources.	0.600	0.671
5. The balance of nature is strong enough to cope with the impacts of modern industrial nations.	0.738	0.772
Cronbach's alpha	0.680	0.707
Altruism scale		
1. Contributions to community organizations rarely improve the lives of others.	0.654	0.658
2. The individual alone is responsible for his or her well-being in life.	0.462	0.644
3. It is my duty to help other people when they are unable to help themselves.	0.678	0.608
4. My responsibility is to provide only for my family and myself.	0.716	0.755
5. My personal actions can greatly improve the well-being of people I don't know.	0.686	0.644
Cronbach's alpha	0.636	0.675

Notes: Responses are based on a five-point Likert scale ranging from "strongly agree" to "strongly disagree." Responses are coded from 1 to 5 such that higher numbers correspond to greater concern about the environment or altruism. Two minor changes were made to the wording of the altruism scale in the TCL&P survey: item 1 was adjusted to a positive statement by substituting "can greatly" for "rarely," and item 2 was adjusted by substituting "satisfaction" for "well-being."

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