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Private provision of environmental public goods: Household participation in green-electricity programs

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Abstract

Green-electricity programs provide an opportunity to study private provision of an environmental public good 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.

JEL classification: H41; Q42

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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% 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

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markets, suppliers of green electricity are competing with suppliers of conventional electricity; there are 29 green-electricity suppliers currently competing in eight 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 finance 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% 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 of green electricity (in the form of new generating capacity) implies a reduction in demand for conventional electricity, participants in green-electricity programs are responsible for a reduction in pollution emissions—a public good.[2] 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 [e.g., 1,3], while the latter are consistent with theory on private provision of an *impure* public good [9,10]. 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 Edison's "SolarCurrents," is based on a VCM. Participating households choose to lease 100-W 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% 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 [26], conjoint analysis [16,26], and contingent valuation [5,15,25]. In several cases, estimates from stated-preference techniques are compared to those from revealed-preference techniques [5,25,26]. 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 for green-electricity programs; (2) compare theoretical implications of the 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; and (4) interpret the results in the context of the theoretical models and previous empirical research on privately provided public goods.

The paper is of interest to environmental and public economists 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. [28] 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 [24] analyzes a sample of contributors to a VCM-based program and finds evidence that motives related to altruism and egoism underlie

[1]The basic facts reported here are taken from Bird and Swezey [4]. The information is periodically updated by the National Renewable Energy Laboratory of the US Department of Energy and is available online at http://www.eere.energy.gov/greenpower.

[2]The reduction in pollution emissions comes from a comparison in which demand for electricity is held constant, and a portion of the demand either is or is not met with green-electricity capacity.

contributions. Our study, in contrast, focuses on the primary mechanisms for participation in green-electricity programs (both VCMs and GTMs), 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.[3] 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 the finding of Smith et al. [31] that variables exert different effects on 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 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 $i = 1, \ldots, n$. 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 new 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. This follows because expanding new capacity of green electricity reduces demand for conventional electricity and thereby reduces pollution emissions, resulting in an environmental public good. All households thus benefit from the total amount of green-electricity capacity.[4]

We now consider different mechanisms for participation in a green-electricity program. We begin with the VCM and then consider the GTM. In both cases, we hold constant the number of households, their endowments, and their preferences. The objective is to contrast the two mechanisms in terms of how they elicit participation on both the extensive and intensive margins for private provision of a public good. The theoretical framework also motivates the subsequent empirical analysis.

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 the creation of new 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 purchase conventional electricity at the price p_c.

[3] Existing studies have focused on contributions to public radio [19], donations to a rural health care facility [31], and giving to colleges and universities [7,22].

[4] There is a technical relationship that translates green-electricity capacity into emission reductions. We simplify the analysis by measuring the public good in terms of new green-electricity capacity rather than emission reductions themselves. This assumption makes the model more direct but does not affect on any of the results.

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:

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

This setup is closely related to the standard model for private provision of a pure public good.[5] 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:

$$\max_{x_i, y_i, G} \{U(x_i, y_i, G; \theta) | x_i + p_c y_i + G = m_i + G_{-i}, G_{-i} \leqslant G\}, \tag{2}$$

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

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

where $f(\cdot)$ is an Engel curve as a function of full income (i.e., personal income plus spillins) ignoring the inequality constraint. We assume that G is a normal good, which implies that $f(\cdot)$ is strictly increasing.[6]

Let G^* denote an equilibrium level of aggregate contributions to finance green-electricity capacity.[7] Conditional on G^*, we can solve for each household's equilibrium contribution as function of its income m_i and tastes θ. This, as we will see, is useful for generating empirical predictions. We know by normality of G that $G^* > G^*_{-i}$ for at least one household. Using Eq. (3), we can invert $f(\cdot)$, add g_i^* to both sides, and solve for $g_i^* = m_i - f^{-1}(G^*; \theta_i) + G^*$. Now define a critical level of income $m^*(\theta) = f^{-1}(G^*; \theta) - G^*$. It follows that we can write each household's equilibrium contribution as

$$g_i^* = \begin{cases} 0 & \text{if } m_i \leqslant m^*(\theta), \\ m_i - m^*(\theta) & \text{if } m_i > m^*(\theta). \end{cases} \tag{4}$$

Several implications of the contribution function in (4) 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 the financing of new generation capacity 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. A household's effective contribution in support of green electricity is thus $\pi\alpha_i y_i$. Total capacity, still measured in financing expenditures, is now $G = \pi\sum_{i=1}^{n} \alpha_i y_i$, 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 its choice of α_i. In fact, the quantity

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[5] See Bergstrom et al. [3] for the standard model and Andreoni [1] for the extension to heterogenous preferences.

[6] The assumption in the standard model of private provision of a public good is that all goods are normal, and this is sufficient to guarantee existence of a unique Nash equilibrium. Here uniqueness is not important, so we make the weaker assumption that only the public good must be normal.

[7] Proving existence of a Nash equilibrium is relatively straightforward. Subtracting G_{-i} from both sides of (3) yields each household's best response function. Application of Brouwer's Fixed Point Theorem guarantees existence of at least one vector $(g_1^*, g_2^*, \ldots, g_n^*)$ that satisfies the best response function for all i. Then, conditional on this fixed point, maximization problem (1) yields unique values of x_i^* and y_i^*. The vector (x_i^*, y_i^*, g_i^*) for all i fully specifies each household's equilibrium strategy.

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).[8]

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

$$\max_{x_i, y_i, \alpha_i} \{U(x_i, y_i, \pi\alpha_i y_i + G_{-i}; \theta) | x_i + p_c y_i + \pi\alpha_i y_i = m_i\}. \tag{5}$$

Note that the objective function is the same as that for the VCM, but the constraints are different. The setup in (6) 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, consumers effectively have more than one way to obtain the private characteristic: conventional electricity (a pure private good) and green electricity (an impure public good).[9]

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 (5) in this way yields

$$\max_{x_i, y_i, G} \left\{ U(x_i, y_i, G; \theta) \middle| \begin{array}{l} x_i + p_c y_i + G = m_i + G_{-i} \\ G_{-i} \leqslant G \leqslant \pi y_i + G_{-i} \end{array} \right\}, \tag{6}$$

where the first constraint follows from adding G_{-i} to both sides of the budget constraint, and the additional constraints follow because $0 \leqslant \alpha_i$ implies $G_{-i} \leqslant G$, and $\alpha_i \leqslant 1$ implies $G(= \pi\alpha_i y_i + G_{-i}) \leqslant \pi y_i + G_{-i}$. In this case, let G^+ denote an equilibrium level of financing capacity.[10] We will now compare the VCM and GTM in terms of the set of possible equilibria that can emerge under the different mechanisms.

2.3. Comparison of the VCM and GTM

A useful observation is that maximization problems (2) and (6) are equivalent when the constraint $G \leqslant \pi y_i + G_{-i}$ is not binding or, what is the same thing, when the constraint $\alpha_i \leqslant 1$ is not binding. This observation leads to an important result about equivalence between the different financing mechanisms for green electricity: *if all households in a GTM choose to pay the voluntary premium on less than* 100% *of their electricity consumption, then the GTM and the VCM are equivalent mechanisms.* The VCM and the GTM can therefore generate equilibria in which all of the same households participate in the program, all households contribute the same amount, and the total capacity of green electricity is 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 contrast, when the constraint $\alpha_i \leqslant 1$ is binding, maximization problems (2) and (6) are not equivalent. In this case, the household faces an additional constraint with the GTM, whereby increasing the contribution level by increasing α_i is no longer possible. Admitting the possibility for such corner solutions leads to a more general result: *the GTM will generate a set of aggregate provision levels that are (weakly) lower than those generated by 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, $\pi \frac{m_i}{p_c + \pi}$ versus m_i. Thus, if the objective is to maximize aggregate provision, the GTM may be an inferior participation mechanism. The following example demonstrates a case in which $G^+ < G^*$.

Example 1. Assume there are two identical households with income m and preferences given by $U_i = q_i(1 + G)$, where $q_i = x_i + y_i$. Assume further that $p_c = 1$. With the VCM, it is straightforward to solve for the equilibrium level of provision $G^* = \frac{2(m-1)}{3}$. With the GTM, the equilibrium level of provision will

[8] See Cornes and Sandler [9,10] for the setup and analysis of the standard impure public good model.

[9] See , Kotchen [20] for extensions of the standard impure public good model that consider pure-private and pure-public substitutes for the impure public good. A game-theoretic approach for the case when both substitutes are available can also be found in Kotchen [33].

[10] Once again, it is relatively straightforward to prove existence of a Nash equilibrium. Maximization problem (6) produces a continuous demand function for G that mirrors Eq. (3) but includes the added constraint that $G \leqslant \pi \frac{m_i}{p_c + \pi} + G_{-i}$. Best response functions for g_i are derived in the same way, and Brouwer's Fixed Point Theorem guarantees a fixed point, $(g_1^+, g_2^+, \ldots, g_n^+)$, that implies a G_{-i}^+ for all i. Given this quantity, maximization problem (5) can be used to derive the equilibrium strategy $(x_i^+, y_i^+, \alpha_i^+)$ for all i households.

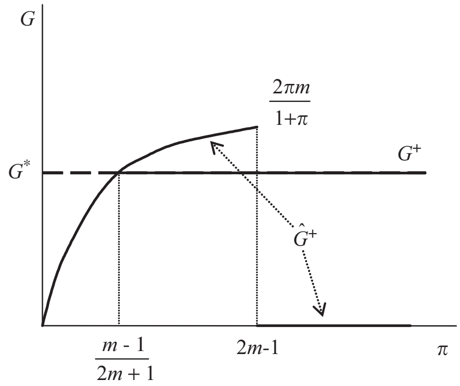

Fig. 1. Aggregate provision under different participation mechanisms.

depend on π such that

$$G^{+} = \begin{cases} \dfrac{2\pi m}{1+\pi} & \text{if } \pi < \dfrac{m-1}{2m+1}, \\ \dfrac{2(m-1)}{3} & \text{otherwise.} \end{cases}$$

This implies that $G^{+} < G^{*}$ for all values of $\pi < \frac{m-1}{2m+1}$; otherwise $G^{+} = G^{*}$. Fig. 1 shows this result graphically. At sufficiently low levels of π, the constraint $\alpha_i \leqslant 1$ is binding, and the GTM elicits a lower level of provision than the VCM. At sufficiently high levels of π, the constraint is not binding, and both mechanisms elicit the same level of provision.[11]

It is worth considering in more detail a restricted GTM in which households face an ''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% of their electricity consumption. Thus, the choice of α_i is constrained to the values of 0 or 1. We know that a household will participate in equilibrium if

$$V(p_c, \pi, m_i; \theta, G_{-i}, \alpha_i = 1) \geqslant V(p_c, \pi, m_i; \theta, G_{-i}, \alpha_i = 0), \tag{7}$$

where $V(\cdot)$ is the indirect utility function that equals the maximized value of (5) with the additional constraint. Note that the only difference between the two sides of the inequality is whether $\alpha_i = 1$ or 0.

It is clear that the all-or-nothing GTM is *not* equivalent to either the VCM or the flexible GTM. But how does the all-or-nothing GTM differ in terms of the level of public-good provision? We have the following result: *the all-or-nothing* GTM *can generate either a higher or lower level of provision than either the* VCM *or the flexible* GTM. We can demonstrate the different possibilities by modifying the previous example.

Example 2. Assume the setup is identical to that in Example 1. With an all-or-nothing GTM, the equilibrium level of provision, denoted $\hat{G}^{+}$, will depend on π such that

$$\hat{G}^{+} = \begin{cases} \dfrac{2\pi m}{1+\pi} & \text{if } \pi \leqslant 2m-1, \\ 0 & \text{otherwise.} \end{cases}$$

Fig. 1 demonstrates how the level of provision changes with π. At levels of $\pi \leqslant \frac{m+1}{2m-1}$, there is participation, the upper bound on provision is binding, and $\hat{G}^{+} = G^{+} \leqslant G^{*}$. At levels of $\pi \in (\frac{m+1}{2m-1}, 2m-1]$, there is participation and $\hat{G}^{+} > G^{+} = G^{*}$. The reason for the higher level of provision is that, despite being forced to provide more than under the VCM or the flexible GTM, the households prefer ''all'' to ''nothing.'' This, however, is no

[11] In Fig. 1 we will consider the provision level $\hat{G}^{+}$ when discussing Example 2.

longer true at sufficiently high levels of π, in which case the households do not participate because Eq. (7) is not satisfied, and the level of provision drops to $\hat{G}^{+} = 0 < G^{+} = G^{*}$.

In order to motivate the empirical analysis, we further compare the VCM and the all-or-nothing GTM. The breakdown of equivalence between the two mechanisms raises an additional question: How might household characteristics affect participation differently in green-electricity programs that are structured with a VCM versus an all-or-nothing GTM? We have already investigated the influence of θ and m_i on participation with a VCM. To understand the influence of these variables on participation in an all-or-nothing GTM, we can consider the comparative statics of demand for G in the context of an impure public good. 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, a higher value of θ will make satisfying Eq. (7) easier, so we would expect households with higher values of θ to be more likely to participate. The effect of a change in m_i, however, is less clear. Cornes and Sandler [10] 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.[12] 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, it is unclear whether a higher value of m_i will make satisfying Eq. (7) easier or harder; therefore we have no clear predication about how income will affect participation in a program based on an all-or-nothing GTM.

3. Data and Variables

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 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-W 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 kW, 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. The vast majority of these households were enrolled from the beginning of the program, so it is reasonable to assume participation decisions were made to establish new generation capacity. 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 7000 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 kW h of electricity per year, or enough to meet the demands 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% 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

[12]Detailed explanations of this result can be found in Cornes and Sandler [10].

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.

limits. Again, nearly all the participating households were enrolled from the beginning, so we assume participation decisions were made to establish new capacity.

We conducted household mail surveys of participants and nonparticipants in both of the programs. The surveys were designed to collect data on socioeconomic characteristics and indicators of environmental concern and altruistic attitudes (described below).[13] 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 Total Design Method [11]. The utility companies provided the names and addresses.[14] 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.[15] The response rates were high: 75% and 70% for the Detroit Edison and TCL&P surveys, respectively.[16]

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 [12]. The scale has also been used in the economics literature to explain contingent valuation responses [21]. 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, 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 Table A1, 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 [29,30] 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.[17] 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

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

[14]Surveys were addressed to the person whose name appeared on billing statements. We assume this person is the household decision-maker with respect to electricity.

[15]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.

[16]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.

[17]For example, Eckel and Grossman [15] conduct an experiment that uses a multi-item altruism scale to explain charitable contributions in a 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 ($1000s)	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 (kW h/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.

Clark et al. [6].[18] The specific items are listed in Table A1, 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. 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 mean NEP score, 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 respondent, and has more people living in the average household. The final variable, average electricity consumption, measured in kilowatt-hours per day (kW h/day), is available for only the TCL&P population and indicates daily consumption of about 18 kW h/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.

[18]For another application of the approach used by Clark et al. [6], see Cooper et al. [8], who use the NEP and altruism scales in the context of a contingent valuation study.

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

Variable	Model			
	(1)	(2)	(3)	(4)
	Tobit	Negative binomial	Probit	Truncated regression
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*
($1000s)	(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 dependent variables are the following: (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.

4.1. The SolarCurrents program

Eq. (4) 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. We estimate regression models to explain household contributions to the SolarCurrents program in terms of both 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 to the public good. 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.[19] 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 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

[19]The tobit model is commonly used for regressions of voluntary contributions with microdata. For examples see [19,31,7].

coefficient of 0.692 implies that a $1000 increase in annual income increases the annual contribution by roughly 70 cents. Despite differing from the theoretical prediction, the magnitude of this income effect is close to the results of other studies on voluntary contributions.[20] 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 assess 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 Eq. (4), it is possible that the explanatory variables influence voluntary contributions on the extensive and intensive margins in different ways. Smith et al. [31] 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 contribute, and a truncated regression model for the decision of how much to contribute.[21]

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.[22] The particular results for gender are consistent with findings by List [22] in a study of voluntary contributions to a university fund-raising campaign. He finds that males are less likely to make a donation, but that the evidence of a gender effect on the level of donations is weaker.

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 Eq. (7) 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

[20]For instance, comparable marginal effects are estimated to be 0.54 for contributions to public radio stations in the United States [19] and 0.01 for contributions to a green-electricity program in Zurich, Switzerland [24].

[21]Our approach differs from that of Smith et al. [31], 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 [17] notes that the appropriate decomposition of a tobit model is into a probit model and a truncated regression model.

[22]Although not reported here, we also estimated truncated count data models and found the same result—that income was the only statistically significant explanatory variable.

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

Variable	Model	
	(1)	(2)
NEP scale	0.074***	0.073***
	(0.015)	(0.015)
Altruism scale	0.076***	0.075***
	(0.017)	(0.018)
Household income ($1000s)	0.001	0.002
	(0.002)	(0.002)
Age	−0.006	−0.006
	(0.005)	(0.004)
Gender (1 = male)	0.109	0.119
	(−0.029)	(0.116)
Household size	−0.029	0.015
	(0.046)	(0.048)
Effective price ($s/year)	–	−0.003***
	–	(0.001)
Constant	−4.644***	−4.464***
	(0.512)	(0.508)
Observations	528	525
Log likelihood	−533.434	−524.341

Notes: The dependent 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.

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 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 [5,28] or other public goods [7,31]. 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 several survey questions, the approach is more reliable for measuring general attitudes [32], 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, an important insight of the theoretical framework is that income may affect participation with a VCM differently than with an all-or-nothing GTM. Now, consistent with this insight is the empirical finding that income affects participation in the SolarCurrents program but not the Green Rate program.[23] 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.

[23]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.

Household size has a statistically significant effect 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. In particular, we calculate an effective price by multiplying the price premium of 1.58 cents per kW h by the household's average annual electricity consumption.[24] Model (2) in Table 4 is another probit model of the participation decision that differs by the inclusion of the effective price (reported in $s per year) as an explanatory variable.[25] As expected, the coefficient on the effective price 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 [5] 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 −0.83, suggesting that the probability of participation is inelastic with respect to the effective price. With inclusion of the 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, a flexible GTM, and an all-or-nothing GTM. First, a GTM is equivalent to a VCM if all households choose to pay the tariff on less than 100% of their electricity consumption. Second, a flexible GTM will result in (weakly) less privately provided capacity of green electricity 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 either a VCM or a flexible GTM.

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

[24]For example, a household that consumes an average of 18 kW h/day will have an annual effective price of 18 kW h × 365 days × \$0.0158 ≅ \$104.

[25]There is a potential endogeneity concern with including the effective price as an explanatory variable. Upon entering the Green Rate program and paying the voluntary tariff, households may change their electricity consumption. 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; we use only months when the household was *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).

contribute, but only household income affects the decision of how much to contribute. The results pertaining to the different ways that gender affects contributions are consistent with prior research in both the field and laboratory [e.g., 13,22].

In the program based on an all-or-nothing GTM, fewer variables influence the participation decision. The probability of participation is increasing in environmental concern and altruistic attitudes, yet it is decreasing in the effective price of participation. Household income does not significantly influence participation; this result is particularly interesting because, according to the theoretical models, the effect of income is one of the potential differences that may occur between VCMs and all-or-nothing 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 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 that further advancement of the theory on voluntary contributions is also necessary. Following Smith et al. [31], 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 et al. [23] 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 understand how considerations such as the buying-in mentality [27], warm glow [2], and prestige [18] may operate differently at the extensive and intensive margins of contributions. To the extent that these same considerations interact differently with VCMs relative to GTMs, they may also be important to more fully understand participation in green-electricity programs.

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Appendix A

Item-total correlations and Cronbach's alpha for the NEP and altruism scales are shown in Table A1.

Table A1
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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