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Green Electricity Markets as Mechanisms of Public-Goods Provision: Theory and Experimental Evidence

by

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Abstract

Utility-based green electricity programs provide market opportunities for consumers to reduce the carbon footprint of their electricity use. These programs deploy three types of public-goods contribution mechanisms: voluntary contribution, green tariff, and all-or-nothing green tariff (Kotchen and Moore 2007). We extend the theoretical understanding of the all-or-nothing green tariff mechanism by showing that an assumption of warm-glow preferences is needed to explain widespread participation in programs deploying this mechanism. We conduct the first experimental test to compare the revenue generating capacity of a pure public good (based on the voluntary contribution mechanism) and an impure public good (based on the green tariff mechanism). In experimental play, the voluntary contribution mechanism raises 50 percent more revenue than the green tariff mechanism. With the all-or-nothing green tariff, experimental play and regression estimates show that a warm-glow preference positively affects participation, as predicted by the theory.

Keywords: impure public good, laboratory experiment, voluntary environmental program, warm-glow altruism

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1. Introduction

A suite of markets for green electricity products provides opportunity for U.S. households and businesses to reduce their carbon footprint from electricity consumption. These markets include utility-based green electricity programs, carbon offsets, and various green electricity products that exist in states with deregulated electricity markets.[1] In 2012, electricity-equivalent sales in these markets totaled 48.6 million megawatt-hours, or 1.3 percent of total U.S. electricity sales (Heeter and Nicholas 2013). On average, this translated into a reduction of roughly 37.8 million metric tons of carbon dioxide emissions from avoided generation of conventional electricity, or the equivalent of removing about 7.4 million cars from the roads for the year. Utility-based green electricity programs are a substantial segment of the overall market. Over 700 electric utilities and related companies offered these programs in 2012, with almost 550,000 residential customers enrolled (Heeter and Nicholas 2013). Program sales increased by 76 percent, from 3.4 million to 6.0 million megawatt-hours, between 2006 and 2012. As a voluntary approach, green electricity programs constitute one tool in a mix of voluntary and regulatory approaches to environmental management.

In this research, we study the theoretical and empirical properties of the three primary enrollment mechanisms used in green electricity programs: the voluntary contribution mechanism (VCM), green tariff mechanism (GTM), and all-or-nothing green tariff mechanism (A/NGTM). Electric utilities seem compelled to offer these programs to satisfy demand by their environmentally minded consumers. Overall, the average participation rate is 2.8 percent of eligible customers. Some utilities, however, achieve much greater success: participation rates at the top 10 programs vary from a low of 5.0 percent to a high of 18.2 percent (Heeter and

[1] These markets complement state-based regulatory programs for reducing CO_2 emissions from electricity generation. As of 2017, the federal government does not regulate CO_2 emissions from power plants, although such regulations are being developed by the U.S. Environmental Protection Agency.

Nicholas 2013). We address several interrelated theoretical and empirical questions within this general context of a large number of modestly performing programs. How do the different mechanisms compare in their capacity to enroll subscribers and to generate subscription revenues in support of green electricity provision? How do group contributions crowd out individual contributions? What is the role of warm-glow altruism in explaining program subscription? For these questions, we develop a theoretical prediction and then test or examine the prediction using data collected in experimental public-good games patterned after the enrollment mechanisms.

We first develop the theory of public-good provision in the context of the VCM, GTM, and A/NGTM mechanisms.[2] The VCM establishes a fixed program payment, typically monthly, that is independent of a household's electricity use. This could be accomplished, for example, by a household purchasing a fixed block of 100 kilowatt-hours per month at a green tariff, or premium, of two cents per kilowatt-hour. The GTM applies a price premium per unit of electricity use over some share of use. Here, for example, a household could pay a two cents per kilowatt-hour tariff on 50 percent of its monthly use; the payment thus would vary with use. The A/NGTM applies the tariff to 100 percent of electricity use for a participating household. Again, the payment would vary with monthly electricity use. Kotchen and Moore (2007) developed results on the relative capacity of the three mechanisms to generate aggregate provision revenues as a function of the magnitude of the green tariff.

We derive three new findings that add insight into these mechanisms.[3] First, we correct an important result on aggregate provision with the A/NGTM. Kotchen and Moore (2007)

[2] The VCM conforms to the theoretical framework of a privately provided public good (Bergstrom, Blume, and Varian 1986). The GTM and A/NGTM apply the theory of a privately provided impure public good (Cornes and Sandler 1984, 1994). Kotchen (2006, 2009) extends these theoretical frameworks to analyze markets for green products and carbon offsets, for which green electricity programs are commonly used as a motivating example.

[3] Unlike Kotchen and Moore (2007) who developed a three-good framework, we construct a two-good model. Two-good models are particularly useful for testing empirical validity of the predictions through laboratory experiments.

demonstrated that, under pure altruism, there exists a middle range of tariffs under which the A/NGTM will induce more aggregate provision than either a VCM or a GTM. We show that the extent of the range is smaller than previously understood, and that pure altruism is unlikely to generate any revenue for the A/NGTM. Second, we develop a new result on aggregate provision in a large economy. The standard result for both the VCM and GTM is that individual contributions decrease and total contributions increase as the number of participants grows.[4] The A/NGTM differs sharply, according to our second finding, with both individual and aggregate contributions decreasing to zero as the number of participants grows large. This result leads to a question: why do consumers participate in such a program? Our third finding proposes an answer to this: consumers with warm-glow preferences will participate at a higher rate in an A/NGTM program under conditions described in the paper.

In an empirical component, we implement laboratory experiments in which participants play symmetric public-good games with one good characterized as an environmental public good.[5] The experiments are used to compare the revenue generating capacity of the VCM and GTM, with parameters for the games chosen to test the theoretical prediction of identical revenue generation under the two mechanisms. We find that VCM raises 50 percent more revenue than the GTM. To our knowledge, this is the first experimental comparison of the revenue generating capacity between a pure and an impure public good mechanism.[6] In addition, the theory predicts that an increase in others' aggregate contributions under the VCM or the GTM crowd out

[4] In the paper, we interchangeably use the words contributions, provision, and revenues. This reflects the context of public-goods theory along with the practical setting of raising revenue to finance green electricity capacity.

[5] Rose et al (2002) used laboratory experiments to study a public-good provision point mechanism to analyze subjects' participation in and willingness to contribute to a green electricity program.

[6] Studying the VCM in a laboratory experiment follows a tradition of experiments on contributions to a pure public good (e.g., Andreoni 1995a, 1995b). Similar to our work on the GTM and A/NGTM, recent research uses laboratory experiments to study contributions to an impure public good (Munro and Valente 2009; Engelmann et al. 2011). However, using laboratory experiments to compare the pure and impure public good mechanisms is novel.

individual contributions at a 1:1 rate. The regression estimates suggest that crowding-out, while statistically significant, occurs at a smaller rate than 1:1.

The experiments also collect data on participants' environmental taste and altruistic taste, along with data on a warm-glow motive. Use of these data establishes a basis of comparison to earlier research. Oberholzer-Gee (2001) found evidence of an altruism effect and a warm-glow effect among participants in a green electricity program in Switzerland. Kotchen and Moore (2007) found that an environmental taste and an altruism taste affected whether to participate in an A/NGTM program in Michigan, and that the same two tastes affected the level of contribution to a (different) VCM program in Michigan. In our work, a variable representing the environmental taste of each participant helps to explain individual contributions in the VCM experiments. In the A/NGTM experiment, the results suggest that warm-glow altruism can explain participants' enrollment; this is consistent with the theory for the A/NGTM.

To examine robustness of the experimental results on the VCM and GTM, additional laboratory sessions are conducted using slight modifications of the original experimental designs. Results from the added sessions are consonant with the core set of results.

2. Theoretical Models

Consider an economy comprised of s individuals, n ($\leq s$) of whom participate in a green electricity program. Without loss of generality, the participants are indexed as i = 1, 2, …., n. Individual i is endowed with exogenously given money income M_i, and his/her utility function is given by $U_i = U_i(y_i,\ g,\ C_i)$, where y_i is a private good (e.g., conventional electricity or 'all-other-goods'), $(g_i + g_{-i}) = g$ is the total contributions to electricity generated from renewable sources ('green electricity'), g_i is the i^{th} individual's contributions, g_{-i} is the sum of all others' contributions, C_i is a constant that represents the i^{th} individual's (relative) concern for green electricity vis-à-vis the private good. U_i is assumed to be strictly quasiconcave and twice continuously differentiable in y_i and g_i. Both y_i and g_i are assumed to be normal goods. Since contributions result in production of green electricity which leads to a reduction in pollution, g is viewed as a (environmental) public good. Next, we introduce the three contribution mechanisms.

2.1 The Voluntary Contribution Mechanism (VCM)

Under the VCM, an individual voluntarily contributes a certain amount to the public good and spends the rest on the private good. Assuming each individual is identical in preferences and money income, the utility maximization problem for individual *i* can be written as

$$\max_{y_i, g_i} \; [U_i = U_i(y_i, g_i + g_{-i},\; C_i) \; s.t. M = y_i P_Y + g_i] \qquad (1)$$

where P_Y is the (relative) price of the private good. The setup in equation (1) is related to an individual choice problem in the presence of a *pure* public good (Bergstrom et al., 1986). The *symmetric* Nash equilibrium (SNE, hereinafter) solution (y_i^*, g_i^*) for (1) is given by (2) and (3)[7]

$$M = \; y_i^* P_Y + g_i^* \qquad (2)$$

$$\frac{\partial U_i(y_i^*,\; g^*,\; C_i)}{\partial y_i} \Big/ \frac{\partial U_i(y_i^*,\; g^*,\; C_i)}{\partial g_i} = P_Y \qquad (3)$$

2.2 The Green Tariff Mechanism (GTM) with Interior Solution

Under the GTM, an individual's contributions and her spending on the private good are directly linked. Individual *i* chooses a fraction $\alpha_i \in [0, 1]$ of her private good consumption on which she pays a (per unit) voluntary price premium (π), which is referred to as the "green tariff". Individual *i* contributes $\pi \alpha_i y_i$ and the total contributions by all *n* individuals is $\sum_{i=1}^{n} \pi \alpha_i y_i$. Individual *i* solves the following utility maximization problem.

[7] Equations (2) and (3) can be derived by using the standard Lagrange Multiplier Method of utility maximization. The symmetric Nash equilibrium is characterized by $(y_i^*, g_i^*) = (y_j^*, g_j^*) \; \forall \; i, j = 1, \dots, n$ and $i \neq j$. Existence of a Nash equilibrium is ensured by applying Brouwer's Fixed Point Theorem on individual best response functions g_i^*.

$$\max_{y_i,\ \alpha_i} [U_i = U_i(y_i, \pi\alpha_i y_i + g_{-i},\ C_i)\ s.t. M = y_i P_Y + \pi\alpha_i y_i \text{ and } 0 \leq \alpha_i \leq 1] \quad (4)$$

Equation (4) refers to an *impure* public good, where the quantity $\alpha_i y_i$ can be conceived as a combination of two different characteristics (Cornes and Sandler, 1994): a private characteristic (consumption of conventional electricity), and a public characteristic (contributions to green electricity, monetized as $\pi\alpha_i y_i$). Note that in comparison to the VCM, the present setup involves an additional constraint (on decision variable α_i). If this constraint does not bind (interior solution), the SNE (y_i^+, α_i^+) is given by (5) and (6)[8]

$$M = y_i^+ P_Y + \pi\alpha_i^+ y_i^+ \quad (5)$$

$$\frac{\partial U_i(y_i^+, n\pi\alpha_i^+ y_i^+, C_i)}{\partial y_i} \Big/ \frac{\partial U_i(y_i^+, n\pi\alpha_i^+ y_i^+, C_i)}{\partial g_i} = P_Y \quad (6)$$

A comparison of ((2) & (3)) with ((5) & (6)) implies $y_i^* = y_i^+$ and $g_i^* = g_i^+ = \pi\alpha_i^+ y_i^+$. The equivalence between the VCM and GTM follows from the fact that conditioning upon a direct donation (g_i^*) under the VCM, individual *i* can determine an optimal fraction α_i^+ that makes her contributions under the GTM equal to the same under the VCM (Kotchen and Moore, 2007). We test this theoretical proposition of *equivalent mechanisms* in the laboratory experiment.

At this juncture, an important result concerning individual preferences, others' contributions, and crowding out can be summarized in the following proposition.

<u>Proposition 1</u>: *Under pure altruism, an increase in g_{-i}^* (perfectly) crowds out g_i^* in 1:1 terms.*

Proof: See appendix.

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[8] There is a threshold level for the green tariff (π_L), below which an individual maximizes her utility by paying the green tariff on her entire consumption of the private good (corner solution). Put differently, when $\pi < \pi_L$, the constraint $\alpha_i \in [0, 1]$ binds at $\alpha_i^+ = 1$. As long as $\pi < \pi_L$, total contributions $(g^+ = nM/(P_Y/\pi + 1))$ continually rise with π, however, they also stay lower than the same under the VCM or the GTM with an interior solution. If g^* represents the total contributions to green electricity at the *symmetric* Nash equilibrium under the VCM or the GTM with an interior solution, then the solution to π_L is given by $g^*/g^+ = 1$, which implies $g^+ \begin{cases} < g^* \ if\ \pi < \pi_L \\ = g^* \ if\ \pi \geq \pi_L \end{cases}$.

The crowding out behavior arises due to the fact that an individual characterized by pure altruism (whereby he cares only about the total contributions) considers others' contributions as a perfect substitute for his own contributions. Given their equivalence, perfect crowd-out holds for both the VCM and GTM (Bergstrom et al., 1986).[9] We experimentally test this proposition.

2.3 The All-or-Nothing Green Tariff Mechanism (A/NGTM)

The A/NGTM requires a participating consumer to pay the green tariff on the entire electricity consumption. We investigate the A/NGTM in more detail as its theoretical properties are unstudied, yet utilities continue to use the mechanism to structure program enrollment. Under the A/NGTM, each consumer faces a binary choice set: not join $\left(\widehat{\alpha}_i^{\,+} = 0\right)$, or join $\left(\widehat{\alpha}_i^{\,+} = 1\right)$. Private consumption, individual and total provision under the two SNE are respectively given by

$$\widehat{y}_i^{\,+} = \begin{cases} M/(P_Y + \pi) & if\ \widehat{\alpha}_i^{\,+} = 1 \\ M/P_Y & if\ \widehat{\alpha}_i^{\,+} = 0 \end{cases} \tag{7}$$

$$\widehat{g}_i^{\,+} = \begin{cases} \pi M/(P_Y + \pi) & if\ \widehat{\alpha}_i^{\,+} = 1 \\ 0 & if\ \widehat{\alpha}_i^{\,+} = 0 \end{cases} \tag{8}$$

$$\widehat{g}^{+} = \begin{cases} n\pi M/(P_Y + \pi) & if\ \widehat{\alpha}_i^{\,+} = 1\ \forall\ i = 1, 2, \dots, n \\ 0 & if\ \widehat{\alpha}_i^{\,+} = 0\ \forall\ i = 1, 2, \dots, n \end{cases} \tag{9}$$

We develop additional insight into individual decision-making under the A/NGTM in the next two subsections.

2.3.1 Pure Altruism and the All-or-Nothing Green Tariff Mechanism

Under pure altruism, the A/NGTM will likely generate no contribution in an SNE, provided, (i) n is beyond a critical level and (ii) π is held constant. The payoff matrix below illustrates the argument. Recall that Section 2 began with the assumption that in an s-person economy, n ($\leq s$) individuals participate in a green electricity program. The matrix below is

[9] For an excellent discussion, see Andreoni (1989).

constructed by assigning three different values to n, which are $n = s$, $n = (s - 1)$, and $n = 0$. The two rows in the matrix represent individual *i*'s strategies ($\hat{\alpha}_i^+ = 1$ and $\hat{\alpha}_i^+ = 0$). Each strategy is evaluated at two extreme situations (which form the columns): (a) when *everyone* else in the economy participates and (b) when *no one* else participates. The first (second) argument in the indirect utility function in each cell represents individual i's private (green electricity) consumption.

	$\hat{\alpha}_j^+ = 1 \; \forall \; j, j \neq i$	$\hat{\alpha}_j^+ = 0 \; \forall \; j, j \neq i$
$\hat{\alpha}_i^+ = 1$	$V\left(\frac{M}{(P_Y+\pi)}, \frac{s\pi M}{(P_Y+\pi)}\right)$	$V\left(\frac{M}{(P_Y+\pi)}, \frac{\pi M}{(P_Y+\pi)}\right)$
$\hat{\alpha}_i^+ = 0$	$V\left(\frac{M}{P_Y}, \frac{(s-1)\pi M}{(P_Y+\pi)}\right)$	$V\left(\frac{M}{P_Y}, 0\right)$

Note that the strategy profile $\left(\hat{\alpha}_i^+ = 1, \hat{\alpha}_j^+ = 0 \; \forall \; j = 1, \ldots, s, j \neq i\right)$ indicates that only individual *i* participates in the program. A more *general* version of this situation can be denoted by a strategy profile $\left(\hat{\alpha}_i^+ = 1 \; \forall \; i = 1, \ldots, n, \hat{\alpha}_j^+ = 0 \; \forall \; j = (n+1), \ldots, s\right)$, where (without loss of generality) the first n individuals participate and the remaining $(s - n)$ individuals do not. Clearly, the $(s - n)$ nonparticipants do not make any difference to the program. As such, a comparative statics analysis of an SNE should focus exclusively on the participants. If there are n participants, the A/NGTM can generate positive total contributions under a symmetric equilibrium, if, conceptually, the following two inequalities are satisfied.

$$V(\hat{\alpha}_1^+ = 1, \ldots, \hat{\alpha}_i^+ = 1, \ldots, \hat{\alpha}_n^+ = 1) \geq V(\hat{\alpha}_1^+ = 0, \ldots, \hat{\alpha}_i^+ = 0, \ldots, \hat{\alpha}_n^+ = 0) \quad (10)$$

$$V(\hat{\alpha}_1^+ = 1, \ldots, \hat{\alpha}_i^+ = 0, \ldots, \hat{\alpha}_n^+ = 1) \leq V(\hat{\alpha}_1^+ = 1, \ldots, \hat{\alpha}_i^+ = 1, \ldots, \hat{\alpha}_n^+ = 1) \quad (11)$$

Equation (10) states that individual *i* must derive equal or more utility in an SNE in which everyone participates, compared to another SNE with no participant. Equation (11), which can be called the *free ride disincentive constraint* (FRDC), states that individual *i* must not be better off by free riding on others' contributions. Note that if the FRDC holds true, equation (10) becomes trivial. As such, under pure altruism, the FRDC holds the key to revenue generation. Using the above matrix and dropping the 'i' subscript, we can rewrite equation (11) as

$$V\left(\frac{M}{P_Y}, \frac{(n-1)\pi M}{(P_Y+\pi)}\right) \leq V\left(\frac{M}{(P_Y+\pi)}, \frac{n\pi M}{(P_Y+\ \pi)}\right) \tag{12}$$

Economic intuition suggests that under pure altruism, the restrictive binary choice set under A/NGTM results in a strong individual incentive to free ride. Unlike the VCM/GTM, an individual cannot adjust her contributions along a continuous curve in response to an increase in n under the A/NGTM. To overcome this problem, the electricity supplier must continuously reduce π to preserve the individual rationale for contributions. However, since electricity prices are often sticky (i.e., they are commonly set in state regulatory proceedings and are cost-based), this comparative static result shows the difficulty in administering the A/NGTM under pure altruism. Moreover, if U is concave in g, n does not need to be too large for the FRDC to fail if π is fixed (refer to Example 2 below). In sum, we have the following proposition.

<u>Proposition 2</u>: *Under the A/NGTM, if π is held constant and n is above a critical level $\left(n > n_C(\pi)\right)$, $\hat{g}^+$ will drop to zero if individual preferences are characterized by pure altruism.*

Proof: See the appendix.

Under pure altruism there exists a subtle distinction between the effect of an increase in n on (a) individual contributions under the VCM (g_i^*) or the flexible GTM (g_i^+), and (b) individual contributions under the A/NGTM ($\hat{g}_i^+$). We observe that when $n \to \infty$, $g_i^* \to 0$ and $\hat{g}_i^+ \to 0$ (assuming π is held constant). However, total contributions will be different between (a) and (b).

$$\lim_{\substack{n\to\infty \\ g_i^*\to 0}} n g_i^* > \lim_{n\to\infty} n\hat{g}_i^+ \Big|_{\pi=constant} = \lim_{n\to\infty} n * 0 = 0$$

The extreme left hand side of the above inequality shows the limiting level of total contributions under the VCM (or the flexible GTM), and the limit is positive. The adjacent expression stands for the limiting level of total contributions under the A/NGTM, when π is held constant. An increase in n in a regime of fixed π eventually leads individual (and total) contributions to drop to zero. *This result demonstrates a counterintuitive situation in which fewer participants are preferred for revenue generation*. As such, the classical result – that total contributions increase with n in an interior solution of the VCM and GTM –, will not hold under the A/NGTM.

Figure 2 goes here

2.3.2 Warm-Glow Preferences and the All-or-Nothing Green Tariff Mechanism

This subsection provides a plausible explanation for contributions under the A/NGTM. Consider a representative individual with a warm-glow utility function given by

$U_i = U_i(y_i, g_i, g, C_i)$, where $\frac{\partial U_i}{\partial g} > 0$ and $\frac{\partial^2 U_i}{\partial g^2} < 0$

The additional argument (g_i) implies that individual *i* derives utility from her own contributions. Given this, the equilibrium conditions in equation (12) can be modified as

$$V\left(\frac{M}{P_Y}, 0, \frac{(n-1)\pi M}{(P_Y+\pi)}\right) \leq V\left(\frac{M}{(P_Y+\pi)}, \frac{\pi M}{(P_Y+\pi)}, \frac{n\pi M}{(P_Y+\pi)}\right) \qquad (12')$$

The equation carries similar implications as before; however, an additional warm-glow component is introduced. The effect of an increase in *n* on individual contributions now hinges on two opposing individual incentives: the free riding incentive explained before, and the warm-glow motive that induces contributions. As a consequence of these opposing incentives, π does not necessarily need to be adjusted downward to preserve the individual rationale for contributions, which can *potentially* satisfy the FRDC for positive provision. Economic intuition suggests that under warm-glow preferences, others' contributions serves as an imperfect substitute for own contributions, and as such, free riding may lead to a loss in individual utility.

2.4 Examples

Three examples provide insight into the workings of the mechanisms.

Example 1: Suppose the price of the private good is P_Y and individual income is M. Assume that $C_i = C\ \forall\, i$ and individual preferences (pure altruism) are $U_i(y_i, g) = \sqrt{y_i} + C\sqrt{g_i + g_{-i}}$.

For these specifications, the SNE under the VCM is given by[10]

$$\left\{ y_i^* = \frac{nM}{(n + C^2 P_Y) P_Y}, \quad g_i^* = \frac{C^2 P_Y M}{(n + C^2 P_Y)}\ \forall\, i \right.$$

Under the GTM, the SNE is given by

$$\left\{ y_i^+ = \frac{M}{(P_Y + \pi)}, \quad g_i^+ = \frac{\pi M}{(P_Y + \pi)}\ \forall\, i \quad if\ \pi < \pi_L = \frac{C^2 P_Y^2}{n} \right. \text{ and}$$

$$\left\{ y_i^+ = \frac{nM}{(n + C^2 P_Y) P_Y}, \quad g_i^+ = \frac{C^2 P_Y M}{(n + C^2 P_Y)}\ \forall\, i \quad if\ \pi \geq \pi_L = \frac{C^2 P_Y^2}{n} \right.$$

The VCM and GTM are asymptotically equivalent (since as $n \to \infty, \pi_L \to 0$). Put differently, individual incentive to free ride increases with n and therefore the constraint $\alpha_i \leq 1$ does not bind, resulting in $\pi_L \to 0$. If we let $C = 1, M = 120$, $P_Y = 1, n = 4$, and $\pi \geq 0.25$, then $g_i^* = g_i^+ = 24$. At the SNE, each individual spends 20% of her budget on green electricity.

Example 2: Consider the A/NGTM when individual preferences are the same as in the previous example. In two steps, the FRDC (equation (12)) simplifies to

$$\frac{\sqrt{M}}{\sqrt{(P_Y + \pi)}} + C\frac{\sqrt{n\pi M}}{\sqrt{(P_Y + \pi)}} \geq \frac{\sqrt{M}}{\sqrt{P_Y}} + C\frac{\sqrt{(n-1)\pi M}}{\sqrt{(P_Y + \pi)}} \Rightarrow \frac{1}{\sqrt{\pi}} \geq \frac{\left[\frac{1}{P_Y} - C^2\left\{\sqrt{n} - \sqrt{(n-1)}\right\}^2\right]}{2C\left[\sqrt{n} - \sqrt{(n-1)}\right]} = \varphi(n)$$

Therefore, a representative individual's contributions at the SNE is given by

[10] Note that the marginal per capita return (MPCR) from the public good at the SNE under the VCM (or GTM with interior solutions) is given by: $MPCR = \mathrm{C}\sqrt{\mathrm{n g_i^*}} = \sqrt{120\mathrm{n}/(\mathrm{n}+1)}$, (assuming $\mathrm{C} = \mathrm{P_Y} = 1$ and $\mathrm{M} = 120$). Now if $\mathrm{n} = 4{,}5{,}6$ or 7, then $\mathrm{MPCR} = 9.80, 10, 10.14$ or 10.25. This formulation is in complete accord with treatment #3 (that states altering n also alters MPCR) on page 182 in Isaac & Walker (1988). We thank an anonymous referee for bringing our attention to this insightful paper.

$$\hat{g}_i^+ = \begin{cases} \frac{\pi M}{(P_Y + \pi)} \; if \; \frac{1}{\sqrt{\pi}} \geq \varphi(n) \\ \\ 0; \quad otherwise \end{cases}$$

Since $\varphi(n)$ is an increasing function of n, if n increases, π must decrease. If $C = 1$, $P_Y = 1, n = 4$ as before, the *highest* π that can sustain positive provision at the SNE is given by $\pi_H = 0.33$.

The line segments ADGH, ACFH, and ABEH in Figure 1 represent an individual's (leftward shifting) optimal decision function for n = 4, 8, and 16, respectively. When n = 4 (or n = 16), an individual chooses $\alpha = 100\%$ as long as $\pi \in (0, 0.33]$ (or $\pi \in (0, 0.07]$).

Figure 1 goes here

Example 3: Consider the A/NGTM when individual preferences (warm-glow) are $U_i(y_i, g) = \sqrt{y_i} + a(g_i) + C\sqrt{g_i + g_{-i}}$. Consider two different situations, (i) when $a(g_i)$ is concave, given by $a(g_i) = 0.5\sqrt{g_i}$ and (ii) when $a(g_i)$ is linear, given by $a(g_i) = 0.2g_i$.

(i) If $a(g_i) = 0.5\sqrt{g_i}$, individual i's contributions at an SNE are given by

$$\hat{g}_i^+ = \begin{cases} \frac{\pi M}{(P_Y + \pi)} \; if \; \frac{1}{\sqrt{\pi}} \geq \frac{\left[\frac{1}{P_Y} - \left\{C\left(\sqrt{n} - \sqrt{(n-1)}\right) + 0.5\right\}^2\right]}{2\left[C\left(\sqrt{n} - \sqrt{(n-1)}\right) + 0.5\right]} \\ 0; \quad otherwise \end{cases}$$

The condition attached with the positive provision is derived by using the FRDC. The constraint still reflects that π should be adjusted downward when n is growing. However, for the same parameter specifications as in Example 2, the highest π that can sustain positive provision at an SNE is 14.02; this is much more than 0.33 (as in pure altruism). Thus, strictly speaking, the warm-glow utility function *almost* eliminates the revenue generation problem.

(ii) If $a(g_i) = 0.2g_i$, individual i's contributions at an SNE are given by

$$\hat{g}_i^+ = \begin{cases} \frac{\pi M}{(P_Y + \pi)} \; if \; C\left(\sqrt{n} - \sqrt{(n-1)}\right) \geq -\frac{1}{\sqrt{\pi(P_Y + \pi)}}\left[0.2\pi\sqrt{M} + \left\{\sqrt{(P_Y + \pi)} - \sqrt{\left(1 + \frac{\pi}{P_Y}\right)(P_Y + \pi)}\right\}\right] \\ 0; \quad otherwise \end{cases}$$

Since the left hand side of the (simplified) FRDC above is positive and the right hand side of the same constraint would be negative (provided M and/or P_Y is not too small), we conclude that the revenue generation problem may not occur when the warm-glow component in the utility function is linear. If $M = 120,\ P_Y = 1$ as before, the above constraint reduces to

$$C\left(\sqrt{n} - \sqrt{(n-1)}\right) \geq -\frac{1}{\sqrt{\pi(1+\pi)}}\left[1.19\pi + \sqrt{(1+\pi)} - 1\right] = a\ negative\ number$$

Finally, if a representative individual is egoistic with a utility function $U_i = U_i(y_i, g_i)$, (where $\frac{\partial U_i}{\partial g_i} > 0$ and $\frac{\partial^2 U_i}{\partial g_i^2} < 0$), which indicates he treats own contributions as a private good, the revenue generation problem is completely eliminated.

In sum, economic theory can explain provision of green electricity under the A/NGTM in a large economy only when at least some participants have warm-glow or egoistic preferences. The VCM or GTM, in contrast, can explain provision without such a requirement on preferences.

Proposition 3: *In comparison to the situation where individual preferences are characterized by pure altruism, the revenue generation problem at a symmetric equilibrium under the A/NGTM is (a) almost eliminated if individual preferences consist of a concave warm-glow component, (b) eliminated if individual preferences consist of either a linear warm-glow component (assuming M and/or P_Y to be not too small) or an egoistic component.*

The critical question is: given the nature of preferences of the potential participants, which green electricity provision mechanism should a utility company offer? An insight into the potential participants' preferences can be developed by public opinion polls, surveys, or questionnaires (Oberholzer-Gee, 2001). As such, it is natural to compare the level of individual contributions (at an SNE) under all the mechanisms, in the presence of pure altruism or warm-glow.

Figure 2 demonstrates, for all three mechanisms, how individual contributions relate to the number of participants under pure altruism ('PA') and warm-glow ('WG').[11] In comparison to the base case of PA under the VCM/GTM, the individual contributions function shifts upward when a WG component is included in the utility function. Inclusion of a WG component in the utility function drastically increases individual contributions (which asymptote to a constant) under the A/NGTM, in comparison to the VCM/GTM. As such, the A/NGTM may generate more revenue in service areas with participants who derive a distinct pleasure from their own contributions, compared to the VCM/GTM. It follows that an electric utility company can exploit this feature by offering the A/NGTM to WG-type participants. Therefore, prior to deciding which mechanism to offer, a utility company may consider surveying its customers in an attempt to understand the nature of their preferences.

3. Setup of Experimental Games

The theoretical results frame two lines of inquiry for the laboratory experiments. First, the equivalence between the VCM and GTM raises the issue of whether, in reality, these two mechanisms generate the same revenue for an environmental public good.[12] Put in a more general context, how would the incidence of revenue generation compare between a pure public good mechanism and an equivalent impure public good mechanism? We develop the VCM game and the GTM game to test the prediction of equal revenue generation. Second, the theory for the

[11] The parameters used for Figure 2 are: $C = P_Y = \pi = 1$ and $M = 120$. As in Example 3(i), the warm-glow component in the utility function is assumed to be $0.5\sqrt{g_i}$. With these specifications, individual contributions under the VCM and GTM are given by: $g_i^* = g_i^+ = \left[120\left(0.5 + \frac{1}{\sqrt{n}}\right)^2\right] \Big/ \left[1 + \left(0.5 + \frac{1}{\sqrt{n}}\right)^2\right]$.

[12] Economists have long entertained the idea of experimental scrutiny of mechanisms that predict equal revenue generation in theory, particularly in the context of auction theory. Experimental studies, for example, on the equivalence of the Dutch auction and the first-price sealed-bid auction (Cox, Roberson and Smith, 1982; Lucking-Reily, 1999), and on the English auction and the second-price sealed-bid auction (Kagel, Harstad and Levin, 1987), developed a deeper insight into participants' decision making. In view of this literature, and also due to the lack of appropriate revenue data from naturally occurring markets, we investigate the predictions of the pure and the impure public good provision mechanisms (VCM and GTM) using experimental techniques.

A/NGTM predicts that, in a regime of a fixed green tariff, individual contributions will drop to zero (remain positive) provided preferences are characterized by pure altruism (warm-glow). We develop the A/NGTM game to assess the effect of individual preferences on contributions.

3.1 Description of the Three Games

Each participant[13] in the VCM game is endowed with a fixed income (M). Each participant simultaneously and independently determines the amount (y_i) to be spent on the private good. The rest (g_i) of the fixed income is donated as contributions to the environmental public good. After all participants have made their individual decisions, the total provision of the environmental public good (g) is calculated. Individual utility-payoff is then determined by y_i and g, according to the equation $U_i(y_i, g) = \sqrt{y_i} + \sqrt{g_i + g_{-i}}$.

The GTM game differs from the VCM game in only one aspect. Under the GTM each participant determines a percentage (α_i) of private consumption for contributions. The choice of α_i determines individual contributions (g_i) and individual spending on the private good (y_i).

In both games, each participant is endowed with an income of $M = 120$ units.[14] Price of the private good is given by $P_Y = 1$. The number of participants in each group is set at $n = 4$, which determines the size of the economy. For these parameter specifications, if the green tariff is 0.25 or above, the GTM and the VCM will lead to an identical outcome. In the GTM game, we set the green tariff at $\pi = 1$ to result in the prediction of identical outcomes across games.

The setup corresponds to a game with complete information, whereby each participant has information on others' utility-payoff and budget. The SNE is given by $g_i^* = 24 \,\forall\, i$ (under the VCM) and $\alpha_i^* = 25\% \,\forall\, i$ (under the GTM). In either case, at the SNE: (i) each participant

[13] In the context of the experiment, "participant" refers to a subject in the public-good games. In the theoretical models, in contrast, "participant" refers to an individual who makes a positive contribution to the public good.
[14] We deliberately choose M = 120 (and not 100). The choice of 100 is "focal" and can potentially lead a participant to a focal 50-50 allocation of her budget between y_i and g_i. See Goeree and Holt (2005) for a similar approach.

spends 96 units on private consumption and 24 units on contributions, (ii) total provision of the environmental public good in a four-person economy is 96 units, and (iii) each participant's utility-payoff is $19.60 \left(\cong \sqrt{96} + \sqrt{4 \times 24}\right)$. Note that if each participant contributes her entire income (under the VCM) to the environmental public good, then each will derive a utility-payoff of $21.91 \left(\cong \sqrt{480}\right)$. Likewise, if each participant chooses to pay the green tariff on 100% of her private consumption (under the GTM) to the environmental public good, she will receive a utility-payoff of $23.24 \left(\cong \sqrt{60} + \sqrt{4 \times 60}\right)$.

Moving on to the A/NGTM game, our objective is to select a fixed group size and a fixed green tariff such that the theory predicts zero (positive) contributions from individuals whose preferences are characterized by pure altruism (warm-glow/egoism). Accordingly, we modify two parameters of the previous games. Individual income, utility-payoff function, and price of the private good remain unchanged. However, the green tariff is set at $\pi = 0.4$ and the group size is set at $n = 5$. The choice of the green tariff and the group size are motivated by the theoretical prediction that (under pure altruism) the free ride disincentive constraint is not satisfied when $n = 5$. As such, the SNE for individual i is given by $\hat{\alpha}_i^+ = 0\%$ (pure altruism) and by $\hat{\alpha}_i^+ = 100\%$ (warm-glow/egoism). Since individual and total contributions drop to zero at the SNE under pure altruism, each individual derives a utility-payoff of 10.95 $\left(= \sqrt{120}\right)$ from private consumption. The zero contribution SNE originates from the prediction that, if everyone else contributes, an individual (characterized by pure altruism) gains 0.31 units from free riding.

3.2 Experimental Procedures

The experimental sessions were conducted at the University of Michigan, Ann Arbor. In what follows, we first describe the sessions under the VCM and GTM. After that, we discuss the A/NGTM sessions, highlighting the main differences.

We conducted three sessions each for the VCM and GTM games. The number of participants in each of the VCM sessions was 12. The number of participants in the three GTM sessions was 8, 16 and 16. No individual participated in more than one session. On average, each session lasted about 70 minutes. All participants were given sufficient time to understand the experimental instructions, and all of their questions were answered before they started making decisions.[15]

In each session, the same game was played for 12 decision rounds.[16] At the beginning of each round, participants were randomly matched to form groups of four participants. For each session we employed the stranger matching protocol, under which each participant was randomly matched with three other participants in each decision round. The four matched participants formed a group (termed an 'economy' in the previous sections); however, the composition of each group kept changing in each decision round. An average session with 12 participants had three groups in each round. At the end of each round, each participant was apprised of her private consumption, total provision of the environmental public good by her group, points she earned in that decision round, and cumulative total points she had earned through that round.

Each participant was rewarded in terms of points (equal to her utility-payoff) in each decision round. At the end of each session, all points earned by a participant were added and converted to US Dollar at the rate of $1 per 15 points. If each decision round in a session were played according to the SNE strategy, each participant would earn $15.68. In addition, each participant was given a lump-sum $5 for showing up.

[15] The instructions given to participants are available upon request from the corresponding author.

[16] Note that despite a finite repetition of the game, application of the backward induction principle will lead to the unique subgame perfect Nash equilibrium in each game which is identical to the unique Nash equilibrium in the one-shot game.

The experimental sessions were computerized with z-Tree (Fischbacher, 2009). Each participant received a sheet of experimental instructions upon arrival. To promote strict anonymity, we did not identify the participants by any registration number and let the computers identify each participant internally. In each round of the VCM sessions, each participant chose her private consumption by entering a number (up to two decimal digits) from the set [0, 120] on the computer screen. For the GTM sessions, each participant recorded the percentage of her private consumption she wanted to contribute by selecting a whole number from the set {0, 1, …., 99, 100}.[17] The same procedure was repeated for all 12 decision rounds. At the end of the 12th round of a session, each participant was privately paid the sum of money he/she had earned.

Moving on to the A/NGTM game, three sessions were conducted with five participants per group in each round. The number of participants per session was 15. As such, three different groups were formed in each round, in which each participant recorded from a binary choice set $\{100\%, 0\%\}$ the percentage of private consumption he/she allocated to environmental contributions. Participants who chose 100% contributed 34.29 units.

The experimental design applied the stranger matching protocol (Andreoni 1995a, 1995b), which retains the one-shot nature of a game, but allows participants to develop game-specific experience over the decision rounds. Since we were interested in the behavior of experienced participants, we repeated each game for 12 rounds. After each round, each participant was notified of the total contributions by her group, and no information was provided about any other group. Moreover, to minimize the chance of a participant making her decision in

[17] We let the participants choose numbers with decimal digits under the VCM because a corresponding percentage choice with a whole number under the GTM may actually result in a contribution with decimal digits.

any round based on her (or others') decisions in earlier rounds, we did not make the history of decisions available to the participants.[18]

4. Experimental Results

Section 4 reports the results in a series of sub-sections: summary of the VCM and GTM sessions, first-round play, average play, group-level play, summary of the A/NGTM sessions, and questionnaire results.

4.1 Summary of Experimental Sessions

Table 1 describes how group-level (environmental public good) provision, group-level private consumption, individual percentage choice, and individual earnings vary across the experimental sessions. On average, a group of four participants contributed 266.53 (175.20) units in a given decision round under the VCM (GTM) sessions. Therefore, (i) the average group-level contributions (private consumption) are significantly higher (lower) in the VCM sessions than in the GTM sessions, and (ii) for both VCM and GTM sessions, group-level average contributions are significantly higher than the SNE prediction of 96 units. Table 1 also shows that, interestingly, average individual payoff is almost invariant to the game with average individual earnings of $23.82 in the VCM and $23.33 in the GTM. At the same time, the dispersion of

Table 1 goes here

[18] In principle, cooperation among the participants can be one of the reasons (but certainly not the sole reason) behind greater than Nash equilibrium contributions in a public good game, as has been indicated in many studies, such as Andreoni (1995, 1995). Indeed, if the participants in an experimental public good game have warm-glow preferences (which our results are indicative of), cooperation is likely to occur (Andreoni, QJE, 1995). While it is difficult to completely remove the possibility of cooperation in a public good game that is repeated for multiple rounds, an experimenter can potentially nullify the impact of cooperation by adopting strategies that may include (i) a stranger matching protocol, (ii) limiting the number of rounds of play, (iii) comparing the first round data across the treatments, which does not result from any cooperative behavior, and examining evidence of any treatment effect during that first round, and (iv) in our context, running a questionnaire on environmental issues and examining whether more environmentally conscious participants contribute more to the environmental public good. Finally, after all these checks, if there still exists a doubt about the impact of cooperation, an experimenter may put forward a counter argument. If cooperation were to impact the outcome, it would impact each experimental game on a symmetrical basis, provided the sample size for each game is large. Therefore, any difference in the outcome across the experimental games should be attributable to the built-in features of those games.

individual contributions is larger with the VCM such that the heterogeneity of individual earnings is greater with the VCM relative to the GTM (Table 2).

Table 2 goes here

The superiority of the VCM over the GTM relates directly to a broader environmental implication. Without affecting individual welfare, the VCM would result in substantially more revenue for the environment and hence significantly lower pollution, relative to the GTM.

4.2 First Round Play

The set of decisions made in the first round of play is often regarded as the purest basis of comparison between two or more treatments, as it precludes any potentially confounding effect. Any statistical difference between the set of first round decisions across games is therefore attributable to difference(s) in the games, provided the sample size is large. In the first decision round, the average group (individual) level provision is 289 units (72.25 units) under the VCM sessions (with 9 independent groups and 36 independent participants). The corresponding average group (individual) level provision is 172.11 units (43.03 units) under the GTM sessions (with 10 independent groups and 40 independent participants). The null hypothesis of equality of the first round average group-level provision under the VCM and GTM (the alternative being the former was higher than the latter) is rejected at a 1% level of significance ($t = 4.69$ with equal variances not assumed in the test).

4.3 Average Play in the Sessions

Figure 3 shows the evolution of the average group-level provision for each session under the VCM and GTM. Focusing on the first two sessions under the VCM, the level of provision does not diverge much from a level of roughly 260 units for VCM S1 and 230 units for VCM S2. The average provision for the third session under the VCM stays close to 300 units from round six onwards, with the only exception of a sudden decline in decision round 12. This

Figure 3 goes here

decline can perhaps be explained by participants' increased propensity to free ride in the last decision round. The lower panel shows comparable data for the GTM sessions. Average group-level provision for the three GTM sessions stabilizes roughly at a level close to 180 units.

4.4 Group-level Play in the Sessions

For completeness, it is customary to document that the significant difference in average provision between the VCM and GTM sessions in Figure 3 is a general pattern for most of the groups, and it is not caused by some outlier groups. Figure 4 shows group-level total provision for each decision round. Considering all the VCM (GTM) sessions combined, there are nine (ten) group-level observations for each round. The scatter-triangles (scatter-squares) represent group-level provision under the VCM (GTM). In general, the VCM exceeds the GTM: for each round, a majority of the scatter-triangles are above the corresponding scatter-squares.

Figure 4 goes here

Overall, the results suggest that the VCM is a superior mechanism from the viewpoint of revenue generation for the environmental public good.

4.5 Summary of A/NGTM Sessions

Table 3 reports the summary statistics from the A/NGTM sessions. 29% of the participants' decisions were choices not to contribute. Recall that for a five-member group, the private incentive to free ride arises in equilibrium, which is supported by the empirical result that the fraction of contributing individuals lies between 0.63 and 0.78 over the decision rounds.

Table 3 goes here

4.6 Questionnaire Results

To gain further insight into the participants' motives for contribution, we developed a computer-based questionnaire for each participant to complete at the end of each session. The questionnaire (patterned after Kotchen and Moore (2007)) did not affect participants' previously determined earnings, and was primarily aimed at understanding participants' attitudes toward environmental as well as social/altruistic issues. Environmental aspects were captured by implementing the statements from the New Ecological Paradigm (NEP) (Dunlap et al., 2000), and social aspects were captured by using statements developed by Kotchen and Moore (2007), which follow the Schwartz model for altruistic behavior (Schwartz, 1970, 1977).

Five (six) statements were used for the NEP (Altruism) scale.[19] Each participant indicated his/her opinion with respect to each of the statements on a 5-point Likert scale, varying from strongly disagree to strongly agree. In each case, a higher value indicates more environmental (altruistic) concern. Table 2 reports the summary statistics of the summated NEP scale and the summated Altruism scale. Overall, we do not observe any statistically significant difference between participants' average NEP (or Altruism) scores under the VCM and GTM sessions.

5. Regression Results

5.1 Explaining Contributions in the VCM and GTM Sessions

We estimate ordinary-least-squares (OLS) regressions to explain individual contributions (g_{ijk}) using the specification:

$$g_{ijk} = \alpha + \beta_1 VCM_{ijk} + \beta_2 g_{-i,j,k} + \beta_3 NEP_i + \beta_4 ALT_i + \beta_5 GENDER_i + \gamma_j + \delta_k + \epsilon_{ijk}$$

where i indexes individuals, j indexes decision rounds, and k indexes sessions; *VCM* is the treatment effect variable for a VCM game (0 if GTM; 1 if VCM); g_{-i} is contributions by other group members; *NEP* is the NEP summated scale; *ALT* is the Altruism summated scale; *GENDER* is a dummy variable (0 if male; 1 if female); γ_j are decision round fixed effects; δ_k are session fixed effects; and ϵ_{ijk} is an idiosyncratic error term. We apply individual-level cluster-robust standard errors. Table 4 presents the corresponding regression estimates.

Table 4 goes here

[19] The Altruism scale should not be confused with the concept of pure altruism discussed earlier. The Altruism scale reflects generosity of an individual in reference to social issues.

In a specification without other explanatory variables, the treatment effect on individual contributions in a VCM round relative to a GTM round was, on average, a statistically significant increase of 30.50 units. This decreases to 20.58 units, still statistically significant, in a specification with other variables. The smaller number is close to what the summary statistics in Table 2 suggests, and it represents the preferred estimate of the treatment effect.

The coefficient on the NEP scale is statistically significant and positive – something one would ideally expect to observe. A one unit increase in NEP scale leads to 2.61 additional units of individual contributions. A one standard deviation increase of the NEP scale from its mean will result in approximately 5.19 units of additional contribution to the environmental public good. In contrast, individuals motivated by altruistic (social) concerns do not contribute more than others. *GENDER* is also not a significant determinant of individual contributions. We include total contributions by others as a regressor to assess whether an increase in others' contributions crowds out individual contributions, something Proposition 1 (above) predicts in 1:1 terms, i.e., the theory predicts a coefficient of –1. We find that an increase in others' contributions partially crowds out individual contributions. A one unit increase in others' contributions leads to a 0.1 unit decrease in individual contributions. This is consistent with a warm-glow motive for contributing.

The specification with other explanatory variables includes an interaction term between *GENDER* and the treatment effect to assess whether women and men behave with a distinct difference in the VCM game relative to the GTM game. We found no effect here. Note, in addition, that the sign, size, and significance of the coefficients on the other explanatory variables were virtually unchanged in a pooled OLS regression without the interaction term.

We also estimate two separate tobit regressions, one for the VCM sessions and the other for the GTM sessions. (The regression equation above can be modified to develop a corner solution model as a basis for a tobit regression (Wooldridge, Chapter 17, 2010).) The tobit regressions originate from the fact that individual contributions to the environmental public good are bounded within [0, 120] for the VCM sessions and within [0, 60] for the GTM sessions. In each case, a tobit model is estimated using the respective bounds. Estimated coefficients and marginal effects are reported in Table 4, with the marginal effects naturally smaller in absolute value yet showing the same pattern of statistical significance as the coefficients. In general, each included regressor in these two models impacts individual contributions in a manner consistent with the OLS regression.[20] In particular, the crowd-out effect continues as a statistically significant, yet small, negative number. The estimated coefficient on the NEP scale changes to insignificant in the GTM regression.

Overall, we observe that (i) environmental concerns motivate individual contributions in the VCM sessions, and (ii) the VCM sessions generate more contributions than the GTM sessions, despite the absence of any significant difference between the participants' environmental concerns in one game versus another (Table 2) and also after controlling for such concerns in the regressions.

5.2 Explaining Contributions in the A/NGTM Sessions

In Section 2, we reached the theoretical conclusion that individual preferences can play a more tangible role in shaping the binary participation decision under the A/NGTM, relative to

[20] As suggested by use of the tobit estimator, the OLS estimator might be inconsistent due to the bounds on contributions. Note, however, that the estimated marginal effects on the individual variables are quite similar in magnitude and significance across the three regressions. This suggests that any inconsistency is not severe.

the VCM or GTM.[21] To probe this empirically, the participants were asked in the questionnaire about their attitude toward contributions to an environmental project. The four possible answers were: (i) unconcerned, (ii) care about only the total group-level contributions (pure altruism), (iii) care about the total group-level contributions, as well as my own contributions (warm-glow) and (iv) care about my own contributions only (egoism). We converted these choices into a binary variable by assigning a value of 1 when a participant indicated that he/she cared about own contributions (choices (iii) and (iv)) and 0 otherwise (choices (i) and (ii)). Table 3 indicates that preferences were evenly distributed between the two categories.

Table 5 reports the estimates of a logit regression model in which the dependent variable (c_{ijk}) is a binary variable equal to 1 if the individual contributes ("all") and 0 otherwise ("nothing"). The estimator is:

Table 5 goes here

$$\text{Prob}(c_{ijk} = 1) = \Lambda(\boldsymbol{\beta}'\mathbf{x}),$$

where Λ (•) is the logistic distribution and

$$\boldsymbol{\beta}'\mathbf{x} = \alpha + \beta_1 NEP_i + \beta_2 ALT_i + \beta_3 GENDER_i + \beta_4 PREFERNC_i + \gamma_j + \delta_k$$

where *i* indexes individuals, *j* indexes decision rounds, and *k* indexes sessions; *PREFERNC* is a binary variable for the individual's expressed attitude toward environmental contributions (1 if warm-glow/egoism; 0 otherwise); γ_j are decision round fixed effects; and δ_k are session fixed effects. The other explanatory variables have the same meaning as before.

We report the marginal effects. The marginal effects for the NEP scale, Altruism scale, and the Gender variable are statistically significant. An interesting feature of the regression is the role of the *PREFERNC* variable, which distinguishes individuals by whether they derive utility

[21] When the number of individuals increases under the A/NGTM, individuals characterized by pure altruism are expected to contribute zero, whereas individuals with warm-glow or egoistic preferences are expected to contribute a positive amount. In contrast, under the VCM/GTM, individuals characterized by pure altruism are expected to lower their contributions along a continuous curve due to a similar increase in the number of individuals (g_i^* or g_i^+ is a continuous function of n). Therefore, the nature of preferences plays a more tangible role under the A/NGTM.

from their own contribution via warm glow or egoism, or instead, do not derive such utility. The theory predicts that individuals were likely to contribute 34.29 or zero in these sessions, depending upon their preferences. The marginal effect of *PREFERNC* is positive and statistically significant, implying that a participant whose self-reported preferences are characterized by either warm-glow or egoism is 28% more likely to contribute, in comparison to others. The experimental result that, in the A/NGTM, a warm-glow or an egoist individual is substantially more likely to contribute than others lends support to the theory.

6. Robustness of the Experimental Results on the VCM and GTM

This section addresses three issues related to features of the experimental design for the VCM and GTM games.[22]

The first issue is the use of "context" (or "framing") in the experimental instructions. To analyze the effect of participants' environmental concern on their contributions, we motivated the instructions using the context of renewable energy, and then used the NEP scale measure as a regressor. However, one could argue that such context may distort preferences, such that the significant difference in contributions across the two mechanisms may not emerge if context were eliminated. We conducted two additional sessions each for the VCM and GTM games to address this. Each session had 16 participants. Instructions for these sessions were identical to the original instructions, except being devoid of environmental context. Following Andreoni (1995), the new instructions described public-good contributions as "Investment in the Group". Figure 5 represents the group-level average provision for each new session. Overall, the VCM

Figure 5 goes here

[22] Each of the experimental sessions discussed in Section 6 was comprised of four practice rounds, followed by 12 decision rounds. Since participant confusion is a common phenomenon in experimental public-goods games (see Ferraro and Vossler, 2010), the practice rounds were meant to promote clarity in participants' understanding of the process of game playing and payoff calculation in each round.

still dominates the GTM in group-level contributions to the public good; the session-level averages for the VCM (GTM) are 242 and 227 (152 and 155). The difference in average group-level contributions across the mechanisms is 81 (234.5 minus 153.5). This is very similar to the difference in average group-level contributions in the original experiments, which equaled 91 (266.53 minus 175.20, from Table 1). Thus, the context of the original experiment does not dictate the results.

The second issue originates from the fact that participants in the GTM game chose a "percentage" of private consumption, whereas participants in the VCM game chose the level of private consumption. One could argue that this dissimilarity in experimental design might help to explain the observed differences in contributions under the two mechanisms. To address this, we conducted two additional sessions for the GTM game, each with 16 participants. Recall that if $\pi = 1$, individual contributions (private consumption) will lie in the range $[0, 60]$ ($[60, 120]$). As such, instructions for these new GTM sessions indicated that each participant would choose private consumption from the range $[60, 120]$, and the remaining income would be spent on renewable energy. Put differently, these instructions were identical to the VCM sessions described in subsection 3.1, except that private consumption now was chosen from the range $[60, 120]$. Figure 6 represents the group-level average provision for each new session. For the first (second) session, the overall group-level average is 167.30 (172.45) and the corresponding average individual provision is 41.83 (43.11). None of these averages is significantly different from the corresponding average from the earlier (percentage choice) GTM sessions reported in Tables 1 and 2.

Figure 6 goes here

The third issue relates to the magnitude of the green tariff. According to the theory, the VCM and GTM will result in identical provision at the SNE as long as $\pi \geq 0.25$. One could argue that the demonstrated difference in participants' contributions under the two mechanisms (Tables 1 and 2) might be sensitive to our choice of $\pi = 1$ and that the difference has not been shown to be robust to alternative choices of π. To address this, we conducted two additional GTM sessions, each with 16 participants: one session with $\pi = 1.5$, and the other with $\pi = 0.5$. Instructions in these sessions were identical to the GTM sessions described in subsection 3.1, except the new instructions specified $\pi = 1.5$ or $\pi = 0.5$. When $\alpha_i = 100\%$, individual (group) contributions attain a maximum of 72 (288) units under $\pi = 1.5$, and 40 (160) units under $\pi = 0.5$. Figure 7 represents the group-level average provision for the new sessions. For the session with $\pi = 1.5$, the overall group-level average is 179.57, which is not significantly different from the corresponding average (reported in Table 1) from sessions with $\pi = 1$. For the session with $\pi = 0.5$, the overall group-level average is 121.80, which is significantly lower than the corresponding average (reported in Table 1) from sessions with $\pi = 1$. This result is due to the fact that a 33% difference exists between the maximum possible individual contributions (= 60) when $\pi = 1$ and the same (= 40) when $\pi = 0.5$. Overall, the previously observed superiority of the VCM (over the GTM) in revenue generation is preserved when $\pi = 1.5$, and is magnified when $\pi = 0.5$.

Figure 7 goes here

7. Conclusion

This paper studies public-goods contribution mechanisms that are commonly employed by electric utilities in green electricity programs. We extend the theoretical results in Kotchen and Moore (2007) and test the results using laboratory experiments. Consistent with public-goods theory, our model predicts individual contributions to decrease and total contributions to increase as the number of participants rises; these results hold in a SNE for the VCM and the GTM with an interior solution. In contrast, the A/NGTM differs in an important way: as the number of participants rises under a constant green tariff, both individual and total contributions go to zero. This raises a question: what explains participation in actual A/NGTM programs? We show that warm-glow altruism can solve the problem of zero contribution. This is reminiscent of Andreoni's (1989) theory of warm-glow giving as a way to explain the presence of a large sector of the economy that relies on charitable contributions for financing. The A/NGTM, in theory, can be more effective at raising revenues than the VCM or GTM. We showed that the range of green tariffs over which this is true is smaller than characterized in earlier research (Kotchen and Moore, 2007).

We develop the first experimental evidence on the relative performance of two equivalent public-goods contribution mechanisms, a pure public-goods mechanism (the VCM) and an impure public-goods mechanism (the GTM). The VCM resulted in a 50 percent higher level of total contributions than the GTM, this despite the theoretical prediction of equal contributions.

By its nature, the A/NGTM generates a theoretical prediction of either 0 or 100 percent contribution in a symmetric game. In the experiment, participants enrolled even though the prediction under pure altruism was for 0 percent. The regression results suggest that a preference for warm-glow altruism influenced the observed enrollment by a substantial 28%, and this is consistent with our theoretical results when a warm-glow argument enters the utility function.

Following the tradition in experimental studies of offering a plausible explanation for deviations from Nash equilibrium predictions, we conjecture that a smaller upper bound for individual contributions for the GTM (60, as opposed to 120 for the VCM) might explain why the VCM generated larger contributions in the laboratory. Put differently, if pro-environmental motives are such that they lead individuals to contribute more than what the Nash equilibrium predicts, then such motives are faced with a more restrictive upper bound for contributions under the GTM; the VCM thus seems capable of generating more contributions than the GTM. We also conjecture that, as an impure public good, the GTM requires more complicated decision-making, and that this might help to explain its lower contributions relative to the VCM.

Two policy or program implications emerge from our overall analysis. First, the VCM is a preferable design for green electricity programs relative to the GTM. As future research, comparing the VCM and GTM for a variety of green products would generate important evidence on the environmental quality implications of these mechanisms in other contexts.

Second, the A/NGTM results point to the value of collecting data on the environmental preferences of consumers, including the presence of a warm-glow motive. Related research demonstrates that social prestige – which can enter the utility function as a warm-glow motive – plays a role in green consumption (Kotchen and Moore 2008) and can vary geographically (Kahn 2007; Sexton and Sexton 2013). Using consumer surveys to acquire data on the geographic variation in environmental warm-glow altruism could be a useful precursor to choosing a mechanism for a particular program. With a high rate of warm-glow altruism in a local population, for example, an electric utility should consider an A/NGTM with its potential to generate higher revenue. These considerations of impure and pure public good approaches to consumption of green products are important topics for future field experiments, with the ultimate goal of increasing provision of environmental public goods through private markets.

Appendix

Proof of Propositions

Proposition 1: In the symmetric Nash equilibrium, $\frac{dg_i^*}{dg_{-i}^*} = -1$.

Noting that $g^* = g_i^* + g_{-i}^*$, equation (3) can be rewritten as

$$\frac{\partial U_i(y_i^*, g_i^* + g_{-i}^*, C_i)}{\partial y_i} = P_Y \frac{\partial U_i(y_i^*, g_i^* + g_{-i}^*, C_i)}{\partial g_i} \quad \text{(A1)}$$

Differentiating both sides of (A1) w.r.t. to g_{-i}^* one obtains

$$U_{y_i y_i} \frac{dy_i^*}{dg_{-i}^*} + U_{g y_i}\left(\frac{dg_i^*}{dg_{-i}^*} + 1\right) = P_Y \left[U_{g_i y_i} \frac{dy_i^*}{dg_{-i}^*} + U_{g g_i}\left(\frac{dg_i^*}{dg_{-i}^*} + 1\right)\right],$$

Where $U_{y_i y_i} = \partial^2 U_i / \partial y_i^2$, $U_{g y_i} = \partial^2 U_i / \partial g \partial y_i$, $U_{g_i y_i} = \partial^2 U_i / \partial g_i \partial y_i$ and $U_{g g_i} = \frac{\partial^2 U_i}{\partial g \partial g_i}$.

Noting that $y_i^* = (M - g_i^*)/P_Y$ and simplifying the above equation one obtains

$$\left(-\frac{1}{P_Y} U_{y_i y_i} + U_{g_i y_i}\right)\frac{dg_i^*}{dg_{-i}^*} + \left(U_{g y_i} - P_Y U_{g g_i}\right)\frac{dg_i^*}{dg_{-i}^*} = -\left(U_{g y_i} - P_Y U_{g g_i}\right) \quad \text{(A2)}$$

If we differentiate both sides of (A1) w.r.t. to y_i and rearrange terms, we find

$$-\frac{1}{P_Y} U_{y_i y_i} + U_{g_i y_i} = 0$$

Using the above information in (A2) and rearranging terms one obtains

$$\frac{dg_i^*}{dg_{-i}^*} = -\frac{\left(U_{g y_i} - P_Y U_{g g_i}\right)}{\left(U_{g y_i} - P_Y U_{g g_i}\right)} = -1$$

Proposition 2 (also an illustration for subsection 2.3.1): Consider the FRDC as a function of n:

$$f(n) = V\left(\frac{M}{(P_Y + \pi)}, \frac{n\pi M}{(P_Y + \pi)}\right) - V\left(\frac{M}{P_Y}, \frac{(n-1)\pi M}{(P_Y + \pi)}\right)$$

Since indirect utility functions are continuous in M, $f(n)$ is continuous.[23] Now it must be that

$$f(1) = V\left(\frac{M}{(P_Y + \pi)}, \frac{\pi M}{(P_Y + \pi)}\right) - V\left(\frac{M}{P_Y}, 0\right) > 0,$$

because there must be at least one participant in the A/NGTM program. Now consider the limit:

[23] $f(n)$ is continuous in n because $n\pi M$and $(n-1)\pi M$ can be conceived as M' and M'', which basically represent two rescaled levels of income.

$$\lim_{n\to\infty} f(n) = \lim_{n\to\infty}\left[V\left(\frac{M}{(P_Y+\pi)},\frac{n\pi M}{(P_Y+\pi)}\right) - V\left(\frac{M}{P_Y},\frac{(n-1)\pi M}{(P_Y+\pi)}\right)\right] = V\left(\frac{M}{(P_Y+\pi)},\infty\right) - V\left(\frac{M}{P_Y},\infty\right) < 0$$

Since $f(n)$ is continuous and $f(1) > 0$ and $f(\infty) < 0$, by the intermediate value theorem, there must exist a critical value of $n > 1$, given by $n_C(\pi)$, such that if $n \geq n_C(\pi)$, $f(n) < 0$.

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Figures

Table 1: Summary of VCM and GTM Sessions

	VCM Sessions	GTM Sessions
Average Group-Level Contributions	266.53	175.20
Average Group-Level Private Consumption	213.47	304.80
Average Individual Percentage Choice	NA	66.50%
Average Individual Earnings	$23.82	$23.33

Table 2: Summary Statistics of VCM and GTM Sessions: Mean and Standard Deviation

	VCM Sessions	GTM Sessions	Combined
Individual contributions	66.63 (41.12)	43.80 (19.74)	54.62 (33.69)
Total contributions by others in own group	199.90 (66.85)	131.40 (32.18)	163.85 (61.89)
Number of Players * Number of Decision Rounds	432	480	912
NEP scale	21.36 (2.07)	21.23 (1.93)	21.29 (1.99)
Altruism scale	24.69 (2.33)	24.30 (2.60)	24.49 (2.47)
Gender	0.56 (0.50)	0.70 (0.46)	0.63 (0.49)
Number of Players	36	40	76

Notes: Standard deviations are provided in parentheses. NEP scale has 25 units possible. Altruism scale has 30 units possible. Gender is a binary variable, 1 if female and 0 if male.

Table 3: Summary Statistics of A/NGTM Sessions: Mean and Standard Deviation

	A/NGTM Sessions
Individual contributions	24.38 (15.56)
Fraction of observations with positive contributions	0.71 (0.45)
Number of Players * Number of Decision Rounds	540
Average Group-Level Contributions	121.92 (33.26)
Number of Groups	108
NEP scale	19.51 (3.00)
Altruism scale	22.96 (4.40)
Gender	0.56 (0.50)
Preference	0.58 (0.50)
Number of Players	45

Notes: Standard deviations are in parentheses. NEP (Altruism) scale has 25 (30) units possible. Gender is a binary variable, 1 if female and 0 if male. Preference is a binary variable, 1 if warm-glow or egoism and 0 if pure altruism.

Table 4: Regression Results: VCM and GTM Sessions

Dependent variable: Individual contributions	Combined: Pooled OLS		VCM: Tobit Model		GTM: Tobit Model	
Independent variables	Coefficient		Coefficient	Marginal Effect	Coefficient	Marginal Effect
Treatment effect (binary, 1 if VCM)	30.50*** (9.58)	21.71* (12.04)				
NEP scale		2.62** (1.09)	5.89** (2.84)	2.03** (0.98)	1.53 (1.79)	0.41 (0.49)
Altruism scale		–0.53 (0.99)	–1.76 (3.22)	–0.61 (1.11)	–0.43 (1.21)	–0.12 (0.33)
Total contributions by others in own group		–0.10*** (0.03)	–0.17*** (0.06)	–0.06*** (0.02)	–0.14** (0.06)	–0.04*** (0.01)
Gender (binary, 1 if female)		–2.39 (4.57)	–4.00 (14.56)	–1.37 (5.04)	–4.24 (8.79)	–1.13 (2.31)
Treatment effect*Gender		–1.88 (10.99)				
Intercept	45.29*** (3.99)	6.04 (31.89)	20.28 (86.33)		42.72 (54.88)	
Session fixed effects	YES	YES	YES		YES	
Round fixed effects	YES	YES	YES		YES	
R^2	0.14	0.18				
Log likelihood			–1728.42		–1522.87	
N	912	912	432		480	

Notes: (i) "Combined" include observations from both VCM and GTM sessions. (ii) Individual-level cluster-robust standard errors are in parentheses, (iii) ***, ** and * indicate significance at 1%, 5% and 10% level, respectively (iv) number of left (right) corner-solution observations for VCM [GTM] treatment is 52 (87) [37 (165)], and (vi) right-corner solutions occur for VCM (GTM) at an individual provision of 120 (60).

Table 5: Regression Results: A/NGTM Sessions

Dependent variable: Contribute (1 if yes, 0 if no) / Independent variables	A/NGTM (Logit)
NEP scale	0.027* (0.015)
Altruism scale	0.020** (0.008)
Gender	–0.21*** (0.07)
Preference (binary, 1 if warm-glow or egoism)	0.28*** (0.08)
Session fixed effects	YES
Round fixed effects	YES
Log likelihood	–263.36
N	540

Notes: (i) Marginal effects are reported, not estimated coefficients, (ii) individual-level cluster-robust standard errors are in parentheses, (iii) ***, **, * indicate significance at 1% level, 5% level and 10% level, respectively.