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Incentives, Green Preferences, and Private Provision of Impure Public Goods

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RESOURCES FOR THE FUTURE

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Abstract

Pro-environmental preferences are being used increasingly in environmental policy. In this paper, I consider the role of heterogeneous green preferences for private provision of environmental goods that have both private and public characteristics. Under different assumptions of information available to a regulator, I characterize equilibrium properties of several mechanisms. I find incentive-compatible Nash equilibria that provide socially optimal public goods provision when the regulator can enforce individual consumption contracts, as well as when reported consumption contracts are supplemented with group penalties. Throughout the paper, I ground the exposition with examples of consumer behavior in the context of green electricity programs and goal setting for energy conservation.

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1 Introduction

Environmental policy often appeals to an individual's attitude towards the environment by relying on social norms to influence behavior. By encouraging individuals to "do the right thing," voluntary provision of environmental public goods is acquiring a larger role as a policy instrument (Glaeser, 2014; Allcott, 2011; Ferraro and Price, 2013; Brennan, 2006). However, preferences for public goods are difficult to observe, free riding is a common problem in the provision of public goods, and mechanisms to induce socially optimal provision of impure public goods remain under-explored.

In this paper, I develop a general model of impure public goods provision that facilitates optimal provision under heterogeneous preferences for the environment. Specifically, I posit a model of consumer behavior in which individuals, in addition to their collective value of environmental quality, reap private benefits from their own provision to the public good. "Green" preferences are defined as the differential benefit that arises from both contributing to and consuming an environmental public good (Kotchen, 2005, 2006; Chan and Kotchen, 2014). Previous work has considered mechanisms for optimal voluntary provision of pure public goods (Varian, 1994; Falkinger, 1996; Kirchsteiger and Puppe, 1997; Falkinger et al., 2000), but this literature has not been extended to the realm of public goods for which consumers receive private, or "warm glow," benefits from their contribution. Further, my model contains pure public goods provision and "warm glow" only provision as special cases.

Several studies have attempted to quantify tastes for the environment by revealed preference indicators. For example, Kotchen and Moore (2007b) and Jacobsen et al. (2012) examine the conservation behavior of electricity customers who opt in to green electricity programs. Additionally, Kahn (2007) uses the proportion of Green Party voters within a county to examine fuel-efficient vehicle sales in California. Further, Sexton and Sexton (2014) characterize private signaling benefits that arise from green consumption for the case of hybrid vehicle purchases. Moreover, recent theoretical work emphasizes the potential cost-effectiveness of quantity over price regulation when heterogeneous preferences for the environment are present (Jacobsen et al., 2014). Other work, however, contends that regulatory tools that aim to affect environmental preferences confound our ability to measure their effectiveness (Brennan, 2006). Clean electricity, energy efficient and renewable energy technology adoption, and fuel-efficient vehicles are salient examples of economic goods that provide both private and public benefits. Throughout the study, I ground the conceptual analysis with examples of consumer behavior in the context of green electricity programs and goal setting for energy conservation.

In contrast to the existing literature in environmental and resource economics, I approach the policy relevance of green preferences as a problem of demand revelation among heterogeneous consumers. Optimal public goods provision is not attained in a laissez-faire economy. Thus, there are attainable efficiency gains by constructing policy instruments that elicit true preferences for the environment. In this effort, I consider the equilibrium and efficiency properties of several mechanisms that fall within the general class of Clarke-Groves mechanisms under different regulatory scenarios. In particular, I relax progressively the information available to a regulator. In the mechanisms considered, I find incentive compatible contracts that support Nash equilibria and induce socially optimal public goods provision when the regulator can contract upon either 1) individual provision or 2) individual reported provision paired with observable group output. I show that a contract conditional on individual reported provision alone is not incentive compatible.

The model I develop in this paper complements previous research that designs incentive contracts to regulate nonpoint source pollution. In particular, I draw insight from the general formulation of team production by Hölmstrom (1982), and its application to environmental regulation through collective penalties by Meran and Schwalbe (1987) and Segerson (1988). Both rely on group penalties that apply when realized emissions levels exceed some desired level of pollution. The parallels to public goods provision are in constructing contracts conditional on the observability of group provision of abatement and its deviation from individual reports. A primary distinction is that emission levels are determined exogenously for nonpoint source pollution, whereas optimal provision of the public good in this paper is constructed from consumer preferences.

I extend the literature on public goods by examining privately provided impure environmental goods in a mechanism design context. Several researchers have examined the implementability and comparative statics of privately provided (pure) public goods (Varian, 1994; Falkinger, 1996; Kirchsteiger and Puppe, 1997; Falkinger et al., 2000). Much of this research, however, relies on strong informational assumptions. I contribute to this literature by examining weaker informational constraints imposed on the regulator. Additionally, I model heterogeneous agents explicitly to provide intuition for incentive compatibility in the case of privately provided impure public goods when consumers exhibit heterogeneous preferences over their own contribution as well as total provision.[1]

While I use examples of green electricity markets to elucidate the results of this paper, the mechanisms put forth extend more generally to the class of goods for which there is a role for ex-post monitoring and enforcement in obtaining efficient private consumption and public goods provision. Some environmental contexts in which these mechanisms might

[1]While I motivate this model with environmental preferences, this model applies for the general case of privately provided impure public goods with heterogeneous preferences.

apply are: (i) fuel efficient vehicle purchases, and their corresponding usage; (ii) energy and water efficient technology adoption (e.g., compact fluorescent or LED light bulbs, Energy Star appliances, low-flow shower heads, rain barrels, etc.); (iii) installation of solar water heaters and photovoltaic panels; and so on. Common attributes of these goods include private benefits (e.g., reduced consumption costs of electricity), public benefits (e.g., cleaner air), and the ability for an external party to monitor usage (e.g., periodic utility bills). The latter point is key to allow regulators to construct incentive schemes based on observable provision to the public good. Other environmentally-friendly retail goods (such as shade-grown coffee, for example) do not provide a natural market characteristic that regulators can contract upon. Thus, while there are many privately provided public goods to which this model applies, it is not fully general to all impure public goods.

In the next section, I develop a general model of privately and socially optimal provision of impure public goods for two agents differentiated by their value over private and public aspects of an environmental good. I then consider the efficiency properties and incentive compatibility of various contracts under progressively weaker informational constraints on a regulator in the third section. In the last section, I conclude.

2 Private provision of impure environmental goods

I adopt a model of private provision of impure public goods similar to that of Andreoni (1989, 1990). In general, a consumer gains utility from a private good, x_i, an environmental public good, C, and her own private contributions to the public good, c_i. The public good is funded entirely by private contributions such that $C = c_i + C_{-i}$ where $C_{-i} = \sum_{j \neq i} c_j$. Utility over these commodities, U_i, is assumed to be strictly increasing and strictly quasi-concave. In the example of clean energy provision, c_i can be thought of as an individual's consumption of electricity generated from renewable sources; C_{-i} is the clean electricity consumption from everyone else in the economy; and C is aggregate clean consumption that maps to environmental benefits. Thus, consumers have preferences over their own provision of the clean good and the aggregate level of a cleaner environment.

Consumers face the budget constraint, $w_i = x_i + ac_i$, where w_i is i's exogenous wealth, x_i is a composite private good with its price normalized to unity, and c_i has a constant marginal cost of provision, a. The consumer faces a non-negativity constraint on individual provision $c_i \geq 0$. I assume homogenous costs to focus the analysis on heterogeneity arising from an individual's preferences.[2] The budget constraint is satisfied with equality since any residual

[2]The main results of this analysis hold for increasing marginal costs, but do not add insight into the problem. Common costs of environmental provision are not realistic, however, abstracting from heterogeneous

wealth is allocated to the numeraire good.

Thus, the consumer's problem can be defined generally as follows,

$$\max_{x_i,c_i,C} U_i(x_i, c_i, C|\theta_i)$$
$$\text{s.t. } w_i = x_i + ac_i$$
$$C = c_i + C_{-i}$$

where θ_i, lying in the space $\Theta \in \mathbb{R}_0^+$, is a green preference parameter known only to the consumer. We can rewrite the consumer's problem by substituting the budget constraint into the consumer's utility function and subsequently by imposing the Nash assumption, which implies that consumer i takes all other contributions, C_{-i}, as given. The result is an unconstrained maximization problem that takes own provision, c_i, as the only choice variable

$$\max_{c_i} U_i(w_i - ac_i, c_i, c_i + C_{-i}|\theta_i) \tag{1}$$

and treats other provision to the public good, C_{-i}, as exogenous. This model of public goods provision is formally equivalent to one in which consumers choose the total level of public goods rather than their own contribution; this duality can be seen by noting that $dc_i = dC$ for a given C_{-i}.[3] In Equation 1, the first argument of U_i determines the consumption level of the numeraire, the second argument captures the private benefit of providing the public good, and the third term defines the benefits of public good consumption.[4]

To simplify the analysis, I assume all consumers exhibit quasi-linear preferences over x_i, such that Equation 1 can be rewritten

$$u_i = w_i + V(c_i, c_i + C_{-i}|\theta_i) - ac_i = w_i + v(c_i, C_{-i}|\theta_i) - ac_i \tag{2}$$

where $V(c_i, c_i{+}C_{-i}|\theta_i)$ is defined without loss of generality as $v(c_i, C_{-i}|\theta_i)$. The first argument

costs isolates the role of preferences in the provision of public goods.

[3]Thus, one could also write the consumer's problem as a choice over the level of the public good, C,

$$\max_{C} U_i(w_i - a(C - C_{-i}), C - C_{-i}, C|\theta_i),$$

which is analogous to the canonical formulation of private provision of impure public goods with warm glow preferences, and all comparative statics results follow (Andreoni, 1989, 1990).

[4]This model can be viewed as a special case of the Cornes and Sandler (1984, 1985, 1996) model of public goods provision defined in characteristic- rather than commodity-space. The latter model has been employed by Kotchen (2005, 2006) and Chan and Kotchen (2014) to marry the concept of "green markets" with models of impure public goods provision that rely on the linear characteristics specification of Gorman (1980). Results from this literature, including the well-known neutrality theorem that states the total supply of a public good is independent of the distribution of wealth (Warr, 1983; Bergstrom et al., 1986), follow directly from the specification of preferences captured by Equation 1.

of v captures i's private benefit of contributing to the public good and the second captures i's benefit from consuming the public good. I assume v is twice-differentiable, weakly concave, and increasing in both arguments. I thus define the private marginal benefit from contributing to the public good as

$$\frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_i);$$

the marginal benefit from consuming the public good as

$$\frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_i);$$

and the warm glow component of marginal utility as

$$\frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_i) - \frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_i).$$ [5]

By defining the consumer's problem as an unconstrained maximization program over own provision, concavity of v is sufficient to ensure that interior solutions that maximize Equation 2, as well as all optimization programs that follow, will be local maxima.

I restrict the analysis to two types of agents—a green consumer, denoted by θ_g, and a non-green consumer, denoted by θ_n. I impose the ordering of preference types such that $\theta_g > \theta_n$ and make the following assumptions:[6]

Assumption 1 *(Increasing differences in warm glow provision) For $\theta_g > \theta_n$,*

$$\left[\frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_g) - \frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_g)\right] - \left[\frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_n) - \frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_n)\right] \geq 0.$$

This assumption implies that marginal benefits from the warm glow component of marginal utility are at least as large for green consumers as they are for non-green consumers.

Assumption 2 *(Increasing differences in total provision) For $\theta_g > \theta_n$,*

$$\frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_g) - \frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_n) \geq 0.$$

This assumption implies that the marginal benefits of consuming the public good are at least as large for green consumers as they are for non-green consumers.

[5]Note, in all notation henceforth, a partial derivative with respect to c_i refers to the first argument of $v()$ and a partial derivative with respect to C_{-i} refers to the second argument, regardless of the point at which this derivative is evaluated.

[6]These assumptions follow, roughly, from definitions in Milgrom et al. (1991).

Claim 1 *Increasing differences in warm glow provision (Assumption 1) and increasing differences in total provision (Assumption 2) imply that the marginal benefit from own provision for green consumers is at least as great as that for non-green consumers.*

To see this claim, note that Assumption 1 can be rearranged

$$\frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_g) - \frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_n) \geq \frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_g) - \frac{\partial v}{\partial C_{-i}}(c_i, C_{-i}|\theta_n)$$

and, Assumption 2 implies that the right-hand side of the previous equation is nonnegative and, hence,

$$\frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_g) - \frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_n) \geq 0.$$

Consumer i's optimal provision is thus defined by the solution to the following problem,

$$\max_{c_i}\{w_i + v(c_i, C_{-i}|\theta_i) - ac_i | c_i \geq 0\} \text{ for } i = g, n, \tag{3}$$

where the consumer's objective is a function of an individual's wealth and value of the public good less private costs incurred by providing the public good. An individual's valuation of the public good is independent of her wealth, which makes the application of modified Clarke-Groves mechanisms in subsequent sections convenient (Groves and Ledyard, 1976; Green and Laffont, 1977).

First-order conditions for Equation 3 implicitly define optimal contributions to the public good in the *private market equilibrium* for interior solutions,

$$\frac{\partial v}{\partial c_i}(c_i, C_{-i}|\theta_i) - a = 0 \text{ for } i = g, n. \tag{4}$$

From the structure of this first-order condition, we have the following result,

Proposition 1 *In the private market equilibrium, green consumers will provide at least as much of the public good as non-green consumers, that is,* $c_g \geq c_n$.

The proof for this proposition, and all others that follow, are contained in the appendix. This result follows directly from Claim 1. Intuitively, the preference parameter, θ_i, imposes an ordering of types such that the marginal valuation of provision to the public good is greater for green agents than for non-green agents. Further, under the assumptions given, this result generalizes to a finite number of ordered preference types.[7]

[7] For this proposition, and others when applicable, I provide intuition for whether the results for two consumer types scale to an economy comprised of a finite number of discrete consumer types. A formal analysis of the scalability of these results to a continuum of consumer types is left for future work.

The private market equilibrium defined in Equation 4 will be inefficient, however, since it fails to incorporate the external spillovers from any one individual's provision. To see this, we can introduce a social planner whose objective is to maximize social welfare—the sum of each individual's net utility. The social planner's problem (SPP) takes the following form for a two-person economy,

$$\max_{c_i} \left\{ \sum_i w_i + v(c_i, C_{-i}|\theta_i) - ac_i | c_i \geq 0 \right\} \text{ for } i = g, n. \tag{5}$$

The first-order conditions for Equation 5 implicitly define optimal contributions to the public good for each type (c_i^* for $i = g, n$) in the *social equilibrium*,

$$[c_g] : \underbrace{\frac{\partial v}{\partial c_i}(c_g, c_n|\theta_g)}_{g\text{'s private MB}} + \underbrace{\frac{\partial v}{\partial C_{-i}}(c_n, c_g|\theta_n)}_{g\text{'s external MB}} = a \tag{6}$$

$$[c_n] : \underbrace{\frac{\partial v}{\partial c_i}(c_n, c_g|\theta_n)}_{n\text{'s private MB}} + \underbrace{\frac{\partial v}{\partial C_{-i}}(c_g, c_n|\theta_g)}_{n\text{'s external MB}} = a, \tag{7}$$

ignoring non-negativity constraints and complementary slackness conditions. The first term in each equation is the consumer's private marginal consumption benefit, whereas the second term is the external marginal benefit from an individual's provision.

A direct implication of the first-order conditions for the social equilibrium is,

Proposition 2 *In the social equilibrium, green consumers will provide as least as much of the public good as non-green consumers, that is,* $c_g^* \geq c_n^*$.

The notion that socially optimal provision of the public good is greater for green agents than non-green agents is a straightforward result. Green agents have a higher marginal value for each additional unit of the public good provided than do non-green agents. Since costs are homogenous across consumer types, the demand curve of green agents for public good provision is situated farther from the origin than that of non-green agents, resulting in a greater level of equilibrium provision in the social optimum.[8]

Equations 6 and 7 are insightful for two reasons. First, they internalize the external benefits that arise from any one individual's contribution to the public good. As such, ignoring these benefits results in the well-known fact that the private market equilibrium

[8]This result also scales to the case of a finite number of preference types. To see this, take any pair-wise combination of preferences, which have (by Assumptions 1 and 2) an ordered marginal value of contributions. Thus, for a more general economy, provision of the public good is increasing in preferences over own provision.

will under-provide the public good relative to the socially optimal level. Second, any policy that induces privately optimal provision to replicate the socially optimal level of provision will be Pareto improving in the sense of Samuelson (1954). In the following sections, contracts are specified in an attempt to replicate the socially efficient provision of the environmental public good as it accords to maximand in the social planner's problem and thus results in the system in Equations 6 and 7.

3 Preference revelation and optimal provision

The primary function of this section is to explore different ways of eliciting information about consumer preferences through incentives. I approach the information asymmetry between an environmental regulator and a consumer in a mechanism design context. I rely on Clarke-Groves mechanisms, which are truth-revealing in the special case of pure public goods and quasi-linear utility (Groves and Ledyard, 1976; Clarke, 1971; Groves and Loeb, 1975). Quasi-linearity in private consumption is a generally restrictive, but useful, assumption to make in this context.[9]

I focus on three similar mechanisms under progressively weaker assumptions on a regulator's informational content. Particularly, I examine cases in which the regulator contracts upon 1) individual provision, 2) reported messages, and 3) reported messages and observable aggregate provision. In both the first and third cases, transfers are found such that preferences are revealed truthfully and the socially optimal level of public goods provision is supported by a Nash equilibrium. The second case, while not incentive compatible, motivates the use of transfers conditional on aggregate provision. Finally, the least restrictive contract is scaled up to a large economy limited to consumers with and without green preferences.

As a practical aside, I ground the following exposition and results with examples of consumer behavior in the context of green electricity programs and goal setting for energy conservation. The informational demands of a regulator in the mechanisms that follow can be supported, for example, by technological advances in the electricity grid. Specifically, smart meters that allow two-way communication between the supplier and consumer of electricity (Hledik, 2009) can be utilized to track individual usage of electricity for a given household. Many economic analyses of real-time pricing, informational interventions, social comparisons, and goal-setting initiatives for electricity demand and conservation have utilized rich data sets that permit novel insights into consumer behavior (Jessoe and Rapson, 2014; Harding

[9] Bergstrom and Cornes (1983) extend the applicability of demand-revealing mechanisms to incorporate non-zero income effects. Further, several papers implement noncooperative Nash strategies that do not require linear separability of private and public consumption (Varian, 1994; Falkinger, 1996; Kirchsteiger and Puppe, 1997; Falkinger et al., 2000).

and Hsiaw, 2014; Gilbert and Graff Zivin, 2014; Allcott, 2011). A complementary empirical literature explores the impact of signing up for green electricity programs, in which residential customers can opt in to receiving electricity generated by renewable energy sources. Analyses of these programs in accord with conceptual frameworks of private provision of impure environmental public goods have been performed by Jacobsen et al. (2012), Jacobsen et al. (2013), and Kotchen and Moore (2007a,b); Ma and Burton (2016), among others.

I use empirical research in this literature to ground abstract concepts in the mechanisms that follow. First, and most important for the conceptual framework put forward, green preferences can feasibly be identified by enrollment in a green electricity program where a consumer may assert her preference for environmentally friendly consumption (Jacobsen et al., 2012). If preferences are not identifiable at the individual level due to privacy or informational constraints, the distribution of consumer types may be accessible at an aggregate or community level (Jacobsen et al., 2013). Second, *individual consumption contracts* can be measured via administrative, micro-level electricity consumption records that nearly all large electricity utilities can access through their information systems (Loock et al., 2013). These data are often used for ex post program evaluation in the aforementioned literature. Third, *reported consumption contracts* are analogous, in principle, to incentivized energy conservation goals set by individuals in several novel demand-side management programs (Harding and Hsiaw, 2014; Loock et al., 2013). Finally, *group consumption contracts* could be defined by observing some level of aggregate clean electricity provision at the level of a community or electric utility. Formal definitions of these types of contracts are provided in the subsections that follow.

3.1 Individually enforceable consumption contracts

Consider a regulator who is assigned the task of maximizing social welfare (as in Equation 5) while ignorant of true preference types, θ_i. The role of the regulator is to design an incentive contract, $\mathscr{C}$, for individuals to reveal their true preferences such that the optimal level of public goods provision is obtained. The contract is formally defined as the mapping $\mathscr{C} = [c_i(\tilde{m}_i), T_i(\tilde{m}_i)]$ from Θ into $\mathbb{R}^+ \times \mathbb{R}$ where $c_i(\tilde{m}_i) : \Theta \mapsto \mathbb{R}^+$ are individually enforceable consumption contracts and $T_i(\tilde{m}_i) : \Theta \mapsto \mathbb{R}$ are continuously differentiable transfer functions conditioned on a consumer's strategy space, $\tilde{m}_i \in \{m_g, m_n\}$, which correspond to types. In this mechanism, the regulator can enforce individual contracts but he does not observe the distribution of types; he simply knows that consumers are either green or non-green.

The timing of this mechanism is as follows. First, consumers learn their type. Second, the regulator offers a contract conditional on reported types, $\tilde{m}_i$. Third, consumers report a value of their preference parameters through messages, $\tilde{m}_i$, that do not necessarily correspond to the value of their true θ_i. Fourth, the contract is executed.

The regulator specifies a payment scheme, $T_i(\tilde{m}_i)$, that individuals receive conditional on their report, $\tilde{m}_i$. That is, if an individual reports that she is a green consumer by sending m_g, she will incorporate the transfer $T_g(\tilde{m}_g)$ into her net utility function. Thus, consumer i's objective when sending message $\tilde{m}_i$ can be written

$$u_i^T = w_i + v(c_i, C_{-i}|\theta_i) + T_i(\tilde{m}_i) - ac_i, \tag{8}$$

which indicates that a consumer can send a message $\tilde{m}_i$ that does not necessarily correspond to her true type. The consumption bundle that maximizes u_i^T is a set of *individual consumption contracts* defined by $(c_g^T(\tilde{m}_i), c_n^T(\tilde{m}_i))$.

Transfers are specified as

$$T_i(\tilde{m}_i) = \begin{cases} v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) & \text{if } \tilde{m}_i = m_g \\ v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) & \text{if } \tilde{m}_i = m_n \end{cases} \tag{9}$$

where T_i defines the transfer a consumer receives if she sends the message $\tilde{m}_i$, which is conditional on the report of other consumers, $\tilde{m}_{-i}$. Individual enforceability ensures that the regulator can observe, and contract upon, individual provision.

In principle, the value of the transfers in Equation 9 is the external benefit of consumer i's contribution as it accrues to all other consumers in the economy. Practically speaking, if consumer i enrolls in a green electricity program or reduces her electricity consumption, one could think of the external value of that behavior, and thus the magnitude of the transfers, as the discounted stream of environmental benefits from reduced CO_2 emissions or benefits from reduced emissions of criteria pollutants. Of course, the crux is determining how all other consumers value the environment. These values could be taken from the non-market valuation literature and constructed to coincide with hedonic valuations—or marginal willingnesses to pay conditional on consumer type—for environmental protection.

Within this framework, we obtain the following result:

Proposition 3 *Under the transfers in Equation 9 and individually enforceable consumption contracts for the two-consumer economy, (i) there is an incentive-compatible Nash equilibrium in which preferences are revealed truthfully and (ii) the socially optimal provision of the public good is obtained.*

The intuition for Proposition 3 arises from the fact that the transfers in Equation 9 represent the externality arising from each type's provision in the social equilibrium. Since the social optimum maximizes welfare for both types, the transfers are chosen to decentralize the socially efficient outcome. In this structure, if the other consumer reports truthfully, the individual's maximization problem coincides with the social planner's problem. Thus, she can do no better than to report truthfully. These best responses conditional on truthful reporting imply socially optimal provision of the public good. This result, however, requires the regulator to fully observe, and contract upon, individual provision, which is a strong assumption in practice.[10]

For a regulator seeking to optimize environmental protection (e.g., reduction of emissions from the electricity industry), this result suggests that optimal provision of the public good can be obtained by observing consumer types (e.g., whether a household is enrolled in a green electricity program) and by contracting upon individual provision (e.g., facilitating a subsidy program that incentivizes socially efficient consumption of green electricity). By grounding this proposition with an application to residential electricity consumption, it is clear that the result is not infeasible to implement as policy; however, a variety of institutional and regulatory constraints would likely inhibit this mechanism from being adopted. Practically speaking, if the regulatory agency is a government and a consumer purchases electricity from a private utility, the regulator would not necessarily have direct access to the type of administrative data needed to construct and enforce the transfers in Equation 9. Hence, the subsequent contract mechanisms relax the informational needs of a regulator.

3.2 Reported consumption contracts

To relax the individual enforceability constraint, assume that the regulator can only condition transfers on reported levels of provision. Define $\mathscr{C}^R = [c_i^R(\tilde{m}_i), T_i^R(\tilde{m}_i)]$ as a mechanism with the same properties as $\mathscr{C}$ where $c_i^R(\tilde{m}_i) : \Theta \mapsto \mathbb{R}^+$ is a *reported consumption contract.*

In the two-consumer economy, define individual transfers

$$T_i^R(\tilde{m}_i) = \begin{cases} v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) & \text{if } \tilde{m}_i = m_g \\ v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) & \text{if } \tilde{m}_i = m_n, \end{cases} \tag{10}$$

[10]This proposition also scales to the case of a finite number of preference types. For illustration, let $(\theta_1, \theta_2, ..., \theta_N)$ represent an ordering of preference types for N consumers such that $\theta_1 > \theta_2 > ... > \theta_N$. Since some consumer i treats other provision as exogenous, the transfers in Equation 9 could be augmented to account for the external benefit of all other consumers. This would result in N unique transfers for each message in consumer i's strategy space. However, individual enforceability would ensure truthful reporting, and social optimal provision would obtain. The primary limitation of such a mechanism is that the number of transfers required is directly proportional to the number of preference types. So, as a practical mechanism, the more general case is difficult to justify. A formal proof of the implementability of a more general mechanism would follow that of Proposition 3.

which are incorporated into consumer utility,

$$u_i^R = w_i + v(c_i, C_{-i}|\theta_i) + T_i^R(\tilde{m}_i) - ac_i \text{ for } i = g, n. \tag{11}$$

The consumption bundle that maximizes u_i^R is a set of *reported consumption contracts*, $(c_g^R(\tilde{m}_i), c_n^R(\tilde{m}_i))$. Under reported consumption and the inability of the regulator to observe individual provision, we have the following result:

Proposition 4 *Under the transfers in Equation 10 and reported consumption contracts, reporting truthfully is not incentive compatible.*

In this mechanism, intuitively, the green consumer prefers to report that she is non-green to appropriate a larger payoff. But, it is not optimal for her to act as if she were non-green. Since the regulator cannot enforce individual consumption, g can send message m_n and consume according to her true preferences without penalty. Thus, the mechanism defined by the transfers in Equation 10 is not incentive compatible since there are profitable deviations from reporting the truth for the green consumer.

3.3 Group and reported consumption contracts

Now consider a regulator who can condition transfers on reported consumption contracts and observable aggregate provision of the public good. This mechanism borrows insight from team provision of a public good under moral hazard (Alchian and Demsetz, 1972; Hölmstrom, 1979, 1982), which has been adopted for environmental applications to provide group incentives for pollution reduction when firm behavior is unobservable (Meran and Schwalbe, 1987; Segerson, 1988; Xepapadeas, 1991). Meran and Schwalbe (1987), for example, construct incentives for meeting an emissions standard when a firm's pollution is not directly observable. Segerson (1988) extends these incentives to the case in which there is stochasticity in both the (unobservable) abatement actions taken by firms and ambient pollution levels. Both rely on group penalties that apply when realized emissions levels exceed some desired level of pollution. But, these models do not explicitly consider markets for public goods or consumer behavior.

Define the mechanism $\mathscr{C}^{GR} = [\{c_i^R(\tilde{m}_i), C(\tilde{m})\}, T_i^{GR}(\tilde{m}_i)]$, with $\{c_i^R(\tilde{m}_i), C(\tilde{m})\} : \Theta \mapsto \mathbb{R}^+$ representing a joint *reported-group consumption contract*. Within this mechanism, a regulator does not observe individual provision; however, he does observe group provision, C, from all consumers—that is, the total level of public good provision (e.g., aggregate energy conservation). Given these assumptions on observability, incentives for team provision of a public good apply in a standard moral hazard framework (Alchian and Demsetz, 1972; Hölmstrom, 1979, 1982).

For the mechanism $\mathscr{C}^{GR}$, the timing is as follows. First, individuals learn about their type. Second, the regulator specifies a menu of transfers conditional on reported messages and observable aggregate contributions to the public good. Third, consumers send a message $\tilde{m}_i$. Fourth, consumers choose privately optimal provision under the contract. Fifth, the contract is executed. The timing of this mechanism follows that of common moral hazard contracts (Laffont and Martimort, 2002).

We augment the transfers in Equation 10 by an increasing function τ, with $\tau(0) = 0$, that penalizes deviations from the truth conditional on observable characteristics. Define these new transfer functions,

$$T_i^{GR}(\tilde{m}_i) = \begin{cases} v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - \tau(|C(\tilde{m}) - C^R|) & \text{if } \tilde{m}_i = m_g \\ v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - \tau(|C(\tilde{m}) - C^R|) & \text{if } \tilde{m}_i = m_n, \end{cases} \tag{12}$$

where $\tau(|C(\tilde{m}) - C^R|)$ is a function of the absolute difference between observable contracted group provision, $C(\tilde{m})$, and aggregate reported provision, C^R.

In the two-person economy, let $C(\tilde{m})$ represent *group consumption contracts* defined by $C(\tilde{m}) = \sum_i c_i(\tilde{m}_i)$ for $i = g, n$ for a given contract. While individual consumption contracts are not enforceable, the level of aggregate contracted provision, $C(\tilde{m})$, is observable by the regulator. Finally, define *aggregate reported provision*, C^R, in the two-person economy as the optimal level of provision from both reported consumer types that solves the consumer's problem,

$$C^R = \sum_i c_i^R = \sum_i \arg\max_{c_i} \{v(c_i^R, C_{-i}^R; \theta_i, \tilde{m}_i) - ac_i^R | c_i \geq 0\} \text{ for } i = g, n \tag{13}$$

where $\tilde{m}_i$ is a consumer's reported type. Empirically, this value could be the sum total of individuals' electricity consumption goals, perhaps as an observable community-wide threshold that needs to be met to receive some payoff as in Jacobsen et al. (2013).

The τ function takes advantage of the concept illustrated in the previous subsection—while it is in g's best interest to report untruthfully, she will act according to her true preferences. This notion introduces a wedge between aggregate reported provision, C^R, and aggregate contracted consumption, $C(\tilde{m})$. Since τ is increasing when the two measures of aggregate provision diverge, this "tax" on misreporting provides a condition for which truthful reporting is a best response conditional on truthful reporting of others.

Proposition 5 *Under the transfers in Equation 12 and reported-group consumption con-*

tracts for the two-consumer economy, (i) there is an incentive-compatible Nash equilibrium in which preferences are revealed truthfully and (ii) the socially optimal provision of the public good is obtained.

As an illustrative proof, the payoff for the green consumer reporting truthfully is strictly greater than the payoff from reporting untruthfully if the non-green consumer reports truthfully. Thus, the green consumer, observing this, can do no better than to report truthfully if the benefit from misreporting is less than the penalty incurred from aggregate provision deviating from contracted provision. Thus, for a sufficiently large τ, the green consumer will report truthfully, which establishes the implementability of an incentive-compatible Nash equilibrium in which both consumers report preferences truthfully.[11]

Socially optimal provision is obtained by noting that with truthful revelation of preferences, aggregate reported provision will be identically equal to aggregate observed provision. Thus, τ will be zero, which decentralizes the social optimum.

This mechanism pairs the weaker informational constraints of reported provision (e.g., an electricity customer asserting that she is a participant in a clean energy program) with the practicality of observable output (e.g., total electricity conservation that could be empirically verified using program evaluation methods). By constructing a subsidy scheme that penalizes deviations from reported consumption, this mechanism could obtain efficient provision of the public good without requiring the regulator to observe individual provision from each agent, which might require the regulator to be privy to private administrative data on consumption and could be viewed as a privacy concern. These institutional constraints on earlier mechanisms make the weaker informational requirements in the mechanism proposed in this subsection relatively more practical.

From the development of transfers under different regulatory scenarios thus far, I make the following observation:

Remark 1 *The value of transfer payments made under optimal individually enforceable consumption contracts and reported-group consumption contracts are identical and each represents a Pigouvian subsidy in accordance with the social planner's problem in Equation 5.*

This conclusion is made by noting that a credible punishment, τ, will never be implemented in equilibrium. Thus, the level of transfers made under both scenarios will be monetarily equivalent—equal to the value of the external benefit of a given consumer's provision of the public good—under truthful revelation of preferences. This finding is noteworthy considering

[11]Similarly to Proposition 3, this result scales to a general case in which there are a finite number of ordered preference types. However, this comes with the caveat that the dimensionality of the transfers, and hence the informational burden on the regulator, grows with the number of consumer types in the economy. As such, it is difficult to defend the general mechanism in practice.

the differential treatment of information available to a regulator in each context. Practically speaking, Remark 1 suggests that it is optimal to subsidize individuals at the level of the external benefit they provide and that the level of these transfers do not depend on the informational constraints of a regulator.

To further substantiate the potential application of this mechanism, I note that each of the informational components required to implement this mechanism is already being used to promote energy conservation in practice. For example, Harding and Hsiaw (2014) and Loock et al. (2013) evaluate programs in which individuals report their incentivized reduction in electricity consumption; this information could be used to construct individual reported consumption contracts. Jacobsen et al. (2012) and Kotchen and Moore (2007b) examine green electricity programs, which can identify individual motivations to engage in environmentally friendly consumption; these analyses provide some structure for how one could identify green consumers and their consumption behavior in practice. Finally, Jacobsen et al. (2013) explore a community-based program that provides subsidization for environmental protection based on group contributions to a green electricity program. All of this is to say that 1) the information needed by regulator to facilitate the mechanisms proposed in this paper exist and this information has been used in practice, and 2) many of these programs involve subsidy schemes that could be reoriented to reflect the structure of the transfers developed in this paper. The latter point suggests that perhaps the budget balancing constraint of a regulator (e.g., raising tax revenue to finance subsidies) is less of a practical concern since these programs can be justified by their ability to correct market inefficiencies.

3.4 An I-consumer economy

In this section, I generalize the previous contract to a large economy, but restrict consumer types to being either green or non-green. Let I_g and I_n, known to the regulator, represent the number of green and non-green consumers, such that the economy is composed of $I = \sum_i I_i$ consumers, with $I_i > 0$, for $i = g, n$.

First, consider the social planner's problem that characterizes optimal provision of the public good under perfect information,

$$\max_{c_i} \left\{ \sum_i I_i \left(w_i + v(c_i, C_{-i}|\theta_i) - ac_i \right); c_i \geq 0 \right\} \text{ for } i = g, n \tag{14}$$

resulting in the first-order conditions for an interior optimum,

$$[c_g]: \frac{\partial v}{\partial c_i}(c_g, c_n|\theta_g) + \left(\frac{I_n}{I_g}\right)\frac{\partial v}{\partial C_{-i}}(c_n, c_g|\theta_n) = a \quad (15)$$

and

$$[c_n]: \frac{\partial v}{\partial c_i}(c_n, c_g|\theta_n) + \left(\frac{I_g}{I_n}\right)\frac{\partial v}{\partial C_{-i}}(c_g, c_n|\theta_g) = a \quad (16)$$

where the first term in each condition is the private marginal consumption benefit, and the second term is the weighted external marginal benefit of an individual's provision. An immediate implication of the previous first-order conditions is the following result:

Proposition 6 *Socially optimal provision in the I-consumer economy is (i) nondecreasing in the number of other types and (ii) nonincreasing in the number of own types.*

This result indicates an important crowding in or out effect. As the proportion of green consumers, for example, increases in the economy, the burden of providing the public good decreases for each green consumer. Contrarily, as the proportion of non-green consumers increases, it is optimal for the green consumer to provide more of the public good.

3.5 Group and reported contracts in a large economy

Consider the task of a regulator implementing an incentive scheme subject to the information constraints in Section 3.3. Here, the regulator observes individual reports and group provision. This subsection considers the ability of a regulator to implement incentive compatible contracts based on reported provision supplemented with a group penalty for deviating from the truth when there are I consumers in the economy. Denote this mechanism $\mathscr{C}^{GR\star} = [\{c_i^{R\star}(\tilde{m}_i), C(\tilde{m})\}, T_i^{GR\star}(\tilde{m}_i)]$. The properties and timing of this mechanism remain the same as those of $\mathscr{C}^{GR}$.

Define the transfer scheme $T_i^{GR\star}(\tilde{m}_i)$ as

$$T_i^{GR\star}(\tilde{m}_i) = \begin{cases} \begin{array}{l}(\tilde{I}_g - 1)\big[v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - ac_g\big] + \\ \quad +\tilde{I}_n\big[v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - ac_n\big]\end{array} & \text{if } \tilde{m}_i = m_g \\ \begin{array}{l}(\tilde{I}_n - 1)\big[v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - ac_n\big] + \\ \quad +\tilde{I}_g\big[v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - ac_g\big]\end{array} & \text{if } \tilde{m}_i = m_n \end{cases} - \tau(|C(\tilde{m}) - C^R|) \quad (17)$$

where $\tilde{I}_i$ for $i = g, n$ is the count of each reported type, which each consumer treats as exogenous since everyone moves simultaneously.

Under these transfers, which internalize both the external marginal benefits of an individual's provision on all other consumers in the economy, there is an analogous result to that of the simpler economy:

Proposition 7 *Under the transfers in Equation 17 and reported-group consumption contracts for the I-consumer economy, (i) there is an incentive-compatible Nash equilibrium in which preferences are revealed truthfully and (ii) the socially optimal provision of the public good is obtained.*

The intuition of this result is analogous to that of Proposition 5—the transfers in Equation 17 internalize the externality of an individual's provision, while a sufficiently high group penalty for misreporting induces truth revelation. In practical terms, the only additional requirement of this mechanism relative to the two-person economy is that the regulator knows the proportions of green and non-green consumers.

3.6 Budget balancedness

In general, the mechanisms proposed here will not satisfy budget balancing. In other words, since the transfers are structured as subsidies for optimal provision of the public good, the regulator needs to pay consumers the value of the transfers. These mechanisms, then, will never achieve Pareto efficiency since there will always be a need for the mechanism to be financed from an external source. Thus, the regulator in this context also serves to break the budget balancing constraint as in Hölmstrom (1982).

Andreoni and Bergstrom (1996), for example, examine several models of government behavior that could induce efficient public good provision by levying different tax schemes. In two of the three tax-subsidy schemes, an increase in government subsidies reduces private contributions to the public good. This crowding out of private contributions can be overcome by a mechanism proposed by Falkinger (1996), by rewarding and penalizing deviations from the mean contribution. In this context, the government's presence is required to facilitate and enforce these transfers, but not to finance them. However, this mechanism aligns most closely with the individually enforceable consumption contract model for the special case of pure public goods provision outlined in Section 3.1, which places the most restrictive set of informational constraints on the regulator. Thus, a formal analysis of the public finance side of less restrictive mechanisms is warranted.

As a practical example, the transfers outlined in the previous mechanisms could represent subsidies for energy efficiency investments. Because the energy efficiency gap is a substantial market inefficiency, there is justification for government intervention to increase the level of public goods provision. Allcott and Greenstone (2012) tabulate that the U.S. government spends roughly \$3.6 billion annually on demand-side management electricity programs, and \$5.8 billion on energy efficiency tax credits to homeowners. These numbers provide one justification for reframing the budget balance constraint as a discussion about correcting environmental market failures through government intervention without a coupled financing mechanism.

4 Concluding remarks

In this paper, I explore the role of incentives in optimal provision of impure public goods when consumers have heterogeneous preferences over private and public components of environmental goods. I contribute to the literature on impure public goods provision by identifying equilibrium properties of preference revelation mechanisms under varying degrees of informational restrictions on a regulator. Results are generally positive in that, with a combination of subsidy schemes and credible punishments, there are incentive-compatible Nash equilibria that obtain socially optimal public goods provision with group incentives.

These results contribute to a growing literature in environmental policy that considers the role of voluntary provision of environmental goods. While policy instruments for environmentally friendly programs already include subsidies or tax credits, the optimal policy depends critically on understanding individuals' preferences over both private and public characteristics of the environmental good. An empirical analysis measuring the distance between current levels of privately provided environmental public goods and the socially optimal level is important for designing effective policies. Specifically, more empirical work on the external benefits of provision to environmental public goods is necessary to identify levels of transfers that can induce efficient provision of public goods. Additionally, more research on the fundamental drivers of green consumer behavior would help inform the role of green preferences in regulatory design.

Fruitful areas for future work in this line include addressing the role of heterogeneous costs, examining a continuum of preference types, and exploring explicit forms of preferences for public goods. A natural extension of this research would be an analysis that considers government financing objectives and potential consumer responses.

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Appendix A. Proofs of main results

Proof of Proposition 1. Under the assumption that $\theta_g > \theta_n$, $c_g \geq c_n$ follows directly from Claim 1. Equation 4 states that we have first-order conditions,

$$\frac{\partial v}{\partial c_i}(c_g, c_n|\theta_g) = a$$

and

$$\frac{\partial v}{\partial c_i}(c_n, c_g|\theta_n) = a.$$

Since marginal costs are constant, the marginal benefits of own provision for g are weakly greater than for n, hence $c_g \geq c_n$. ■

Proof of Proposition 2. Choose c_g^* and c_n^* corresponding to $\theta_g > \theta_n$, respectively, as solutions to the SPP in the two-person economy

$$c_i^* = \arg\max_{c_i} \left\{ \sum_i w_i + v(c_i, C_{-i}|\theta_i) - ac_i | c_i \geq 0 \right\} \text{ for } i = g, n.$$

First-order necessary conditions for the SPP implicitly define c_g^* and c_n^*, respectively, as,

$$[c_g^*] : \frac{\partial v}{\partial c_i}(c_g^*, c_n^*|\theta_g) + \frac{\partial v}{\partial C_{-i}}(c_n^*, c_g^*|\theta_n) = a \tag{A.1}$$

and

$$[c_n^*] : \frac{\partial v}{\partial c_i}(c_n^*, c_g^*|\theta_n) + \frac{\partial v}{\partial C_{-i}}(c_g^*, c_n^*|\theta_g) = a \tag{A.2}$$

for interior solutions. By adding and subtracting the external benefit internalized by the *other* consumer to each first-order condition, we have

$$\left[\frac{\partial v}{\partial c_i}(c_g^*, c_n^*|\theta_g) - \frac{\partial v}{\partial C_{-i}}(c_g^*, c_n^*|\theta_g)\right] + \frac{\partial v}{\partial C_{-i}}(c_n^*, c_g^*|\theta_n) + \frac{\partial v}{\partial C_{-i}}(c_g^*, c_n^*|\theta_g) = a \tag{A.3}$$

and

$$\left[\frac{\partial v}{\partial c_i}(c_n^*, c_g^*|\theta_n) - \frac{\partial v}{\partial C_{-i}}(c_n^*, c_g^*|\theta_n)\right] + \frac{\partial v}{\partial C_{-i}}(c_g^*, c_n^*|\theta_g) + \frac{\partial v}{\partial C_{-i}}(c_n^*, c_g^*|\theta_n) = a \tag{A.4}$$

And, by subtracting equation A.4 from A.3, we have

$$\left[\frac{\partial v}{\partial c_i}(c_g^*, c_n^*|\theta_g) - \frac{\partial v}{\partial C_{-i}}(c_g^*, c_n^*|\theta_g)\right] - \left[\frac{\partial v}{\partial c_i}(c_n^*, c_g^*|\theta_n) - \frac{\partial v}{\partial C_{-i}}(c_n^*, c_g^*|\theta_n)\right] \geq 0,$$

where the last inequality follows directly from Assumption 1. Hence, the marginal benefits that arise because of g's presence in the economy will be at least as large as that of n, thus for constant marginal costs, $c_g^* \geq c_n^*$. That is, the green consumer will contribute at least as much to the public good as the non-green consumer in the social equilibrium, which provides the desired result. ■

Proof of Proposition 3. To show (i), assume arbitrary preference parameters $\bar{\theta}_g > \bar{\theta}_n$. The regulator solves the SPP for optimal, interior contributions (c_i) corresponding to $\bar{\theta}_i$ for $i = g, n$,

$$c_i = \arg\max_{c_i} \left\{ \sum_i w_i + v(c_i, C_{-i}|\bar{\theta}_i) - ac_i | c_i \geq 0 \right\} \text{ for } i = g, n,$$

and let $c_g > c_n$. Under the transfer scheme in Equation 9, the payoff for g if she sends m_g is

$$v(c_g, C_{-g}|\bar{\theta}_g, \tilde{m}_{-i}) + v(c_n, C_{-n}|\bar{\theta}_n, \tilde{m}_{-i}) - ac_g \tag{A.5}$$

And, the payoff for g if she sends m_n is

$$v(c_n, C_{-g}|\bar{\theta}_g, \tilde{m}_{-i}) + v(c_g, C_{-g}|\bar{\theta}_g, \tilde{m}_{-i}) - ac_n \tag{A.6}$$

Assume n sends m_n truthfully. If g prefers to report m_n, this would imply Equation A.6 is at least as large as Equation A.5. But, since consumption is individually enforceable, this means that c_g cannot be different from c_n in the arbitrary social equilibrium, which is a contradiction. Hence, g can do no better than to report m_g since doing so replicates the social optimum. A similar argument holds for n. Thus, reporting truthfully is incentive compatible for both types. The knife-edge case of $c_g = c_n$ does not change this result as incentive compatibility requires only a weak inequality.

The proof of (ii) is a direct implication of truthful reporting from both types, as the transfers in Equation 9 internalize the external marginal benefit of an individual's provision. As such, a consumer's optimal response coincides with solutions to the SPP. ■

Proof of Proposition 4. Assume arbitrary preference parameters $\bar{\theta}_g > \bar{\theta}_n$. The regulator solves the SPP for optimal contributions (c_i) corresponding to arbitrary preference types $(\bar{\theta}_i)$, where $c_g \geq c_n$ such that $v(c_g, C_{-g}|\bar{\theta}_g, \tilde{m}_{-i}) \geq v(c_n, C_{-n}|\bar{\theta}_n, \tilde{m}_{-i})$.

Now, assume n sends m_n truthfully. Consider a green consumer's payoff under the transfers in Equation 10 if she sends m_g truthfully and acts green

$$v(c_g, C_{-g}|\bar{\theta}_g, \tilde{m}_{-i}) + v(c_n, C_{-n}|\bar{\theta}_n, \tilde{m}_{-i}) - ac_g$$

and her payoff if she sends m_n untruthfully, but still acts green

$$v(c_g, C_{-g}|\bar{\theta}_g, \tilde{m}_{-i}) + v(c_g, C_{-g}|\bar{\theta}_g, \tilde{m}_{-i}) - ac_g.$$

By inspection, the latter payoff is at least as large as the former; hence, sending a truthful message is not incentive compatible in this mechanism. ■

Proof of Proposition 5. To prove (i), assume that n sends m_n truthfully. Now, define information rent for g under the transfers in Equation 12

$$\Omega_g = \underbrace{v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) + v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - ac_g - \tau(|C(\tilde{m}) - C^R|)}_{\text{Payoff if } g \text{ sends } m_n} - \big[\underbrace{v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) + v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - ac_g}_{\text{Payoff if } g \text{ sends } m_g}\big],$$

where the payoff if g sends m_g does not include τ since both consumers have reported truthfully. g's information rent simplifies to

$$\Omega_g = v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - \tau(|C(\tilde{m}) - C^R|).$$

Now, choose τ, such that $\tau(|C(\tilde{m}) - C^R|) > v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i})$. This value of τ is sufficient to ensure truthful reporting from g conditional on n reporting truthfully. A similar argument holds for n. With truthful reporting of both customer types, the rest of the proof for incentive compatibility follows that of Proposition 3.

To prove (ii), note that truthful reporting of both types implies that $\tau = 0$ and thus the individual's problem coincides with the social planner's problem. Hence, socially optimal provision of the public good obtains. ■

Proof of Proposition 6. The proof follows from applying the envelope theorem to the first-order conditions in Equations 15 and 16. That is, let c_g^* maximize the SPP in the I-consumer economy for consumer type g. Then, $\partial c_g^*/\partial I_n = I_g^{-1}\partial v(c_n^*, c_g^*|\theta_n)/\partial C_{-i} \geq 0$ for $g \neq n$ since v is increasing in C_{-i} and $I_g, I_n > 0$, which proves (i). And, $\partial c_g^*/\partial I_g = -I_n I_g^{-2}\partial v(c_n^*, c_g^*|\theta_n)/\partial C_{-i} \leq 0$ for $g \neq n$ since v is increasing in C_{-i} and $I_g, I_n > 0$, which proves (ii). A symmetric argument holds for non-green consumers. ■

Proof of Proposition 7. The proof follows that of Proposition 5. To show (i), assume all other consumers report truthfully. Now, fix $\tilde{I}_g$ and $\tilde{I}_n$ and define information rent for a green consumer under the contract in Equation 17 as

$$\bar{\Omega}_g = \underbrace{\begin{aligned} v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - ac_g + (\tilde{I}_n - 1)\big[v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - ac_n\big] \\ + \tilde{I}_g\big[v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - ac_g\big] - \tau(|C(\tilde{m}) - C^R|) \end{aligned}}_{\text{Payoff if } g \text{ sends } m_n} - \underbrace{\Big[\begin{aligned} v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - ac_g + (\tilde{I}_g - 1)\big[v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - ac_g\big] \\ + \tilde{I}_n\big[v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - ac_n\big] \end{aligned}\Big]}_{\text{Payoff if } g \text{ sends } m_g},$$

which simplifies to

$$\bar{\Omega}_g = v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - a(c_g + c_n) - \tau(|C(\tilde{m}) - C^R|).$$

Now, choose τ such that $\tau(|C(\tilde{m})-C^R|) > v(c_g, C_{-g}|\theta_g, \tilde{m}_{-i}) - v(c_n, C_{-n}|\theta_n, \tilde{m}_{-i}) - a(c_g+c_n)$. This value of τ is sufficient to ensure truthful reporting from g conditional on truthful reporting from all other types. A parallel argument holds for n. Thus, the transfers in Equation 17 are incentive compatible and support a Nash equilibrium.

To prove (ii), note that truthful reporting of both types implies that $\tau = 0$ and thus the individual's problem coincides with the social planner's problem. Hence, socially optimal provision of the public good obtains. ■