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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 as environmental policy tools. 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. The role of budget balancing is recast as a policy intervention for correcting environmental market failures. 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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Keywords: Private provision of public goods; impure public goods; green markets; incentives; preference revelation; environmental regulation; mechanism design

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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). 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. From a broad perspective, these problems are not new. In the context of privately provided impure environmental goods, however, several policy-relevant questions deserve our attention. In particular, is there a normative rationale for regulation in the private provision of impure public goods? Do standard solutions to free-riding problems apply to the class of privately provided goods that have private and public consumption benefits? Can we say anything new about the role of incentives for voluntarily supplied public goods that correct environmental market inefficiencies?

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).[1] 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 yet been extended to the realm of public goods for which consumers receive private, or "warm glow," benefits from their own contribution. Further,

[1] Unlike Kotchen (2005, 2006), I consider an impure environmental public good explicitly, rather than modeling the private and public characteristics of an environmental good independently. Doing so disallows the potential for substitution possibilities between public and private characteristics of environmental goods, which is not a central focus of this analysis.

my model contains pure public goods provision and "warm glow" only provision as special cases.

Not surprisingly, consumer preferences for impure environmental goods have an unknown distribution across the population. Several studies have attempted to quantify these tastes 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). 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. Despite the consumer providing the public good at least cost, the optimal level of 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, truthful revelation of preferences is not a dominant strategy equilibrium. But, 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 abatatement 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.

In this analysis, 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). Many of the mechanisms proposed either are difficult to implement in practice (Varian, 1994) or exhibit undesirable equilibrium properties (Kirchsteiger and Puppe, 1997). Falkinger (1996) proposes a simple mechanism that punishes or rewards individuals based on their deviation from the average provision. This mechanism balances the budget, by definition, and almost achieves Pareto efficiency in Nash equilibrium. A test of this mechanism in a laboratory experiment suggests that it performs well in practice (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.[2]

Additionally, I reframe the role of budget balancedness in the context of policy incentives for correcting inefficiencies in environmental markets. A topical issue in environmental policy is the role of government intervention to close the "energy efficiency gap." Allcott and Greenstone (2012) outline the potential "win-win" scenario from increases in energy efficiency investments characterized by cost savings to consumers and lessened environmental damages from electricity generation. Thus, the regulator in this context finances subsidies that may correct environmental market failures by inducing optimal public goods provision.

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 consider the efficiency properties and incentive compatibility of various incentive 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 general 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 aggregate environmental benefits. Thus, consumers have preferences over their own provision of the clean good and the aggregate level of a cleaner environment.

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

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.[3] The budget constraint is satisfied with equality since any residual wealth is allocated to the numeraire good.

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

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

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}.[4] In Equation 1, the first argument of U_i determines the consumption level

[3] 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 costs isolates the role of preferences in the provision of public goods.

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

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

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.

As noted in Andreoni (1990), the impure public goods 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, which states that 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. Corresponding implications of transfers as they relate to budget balancedness is discussed in further detail in a following subsection.

To simplify the analysis, I assume all consumers exhibit quasi-linear preferences over x_i, such that net utility for consumer i can be written

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

where V is a twice-differentiable, weakly concave ($V''(\cdot) \leq 0$) preference function common to all consumers. By defining the consumer's problem as an unconstrained maximization program over own provision, concavity of V is sufficient to ensure that interior solutions to Equation 2, as well as all optimization programs that follow, will be local maxima. Further, I assume V has increasing differences, which implies that V satisfies the Spence-Mirrlees single-crossing condition (SCC) in own provision.[5]

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, $\theta_g > \theta_n$, such that

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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).

[5]Increasing differences ensures that the marginal benefits of c_i are increasing in θ_i. Mathematically, this is equivalent to $\partial V(c_i, c_i + C_{-i}|\theta')/\partial c_i - \partial V(c_i, c_i + C_{-i}|\theta)/\partial c_i \geq 0$ for all $\theta' > \theta$, since V is differentiable.

$V(c_g, c_i{+}C_{-i}|\theta_g) \geq V(c_n, c_i{+}C_{-i}|\theta_n)$ by the single-crossing condition. Thus, heterogeneity in environmental preferences arises through the individual-specific parameter, θ_i. I model green preferences as tastes for an impure environmental good, rather than a pure public good, to capture the private benefit that green consumers reap from their provision (Kotchen, 2006). Models with heterogeneous preferences for pure public goods can be solved with standard mechanisms, such as Lindahl taxation (Lindahl, 1919) or Clarke-Groves incentive structures (Cornes and Sandler, 1996). These mechanisms, however, have not been extended to the realm of impure environmental public goods.

Since V defines a general structure of public goods provision, it is worth noting special cases. In particular, if we place zero weight on the first term of V, we are left only with preferences over $c_i + C_{-i}$, which is the canonical model of private public goods provision, or "purely altruistic" provision (Bergstrom et al., 1986). Further, by placing some weight on both arguments of V, we have "warm glow" preferences for an impure public good in the sense of Andreoni (1989, 1990), in which there is utility derived from the contribution itself that is separate from direct consumption of the public good. If we place no weight on consumption of the public good, we have "purely egoistic" preferences. Further, V could take on social-welfare or social-efficiency preferences in the sense that consumers contribute to the public good in the direction of the socially efficient outcome (Charness and Rabin, 2002). The most natural interpretation of consumer heterogeneity in this framework given the assumptions on V, however, is that of "warm glow" preferences (Andreoni, 1989, 1990). That is, consumers share common values for consumption of the public good, but there is variation in preferences over own provision.

The consumer's objective function is thus defined as

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

where net utility, u_i, 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, 1977a).

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

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

From the structure of this first-order condition, the single-crossing condition implies the following:

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 the single-crossing condition. 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.[6]

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, who can be thought of as a government, is able to freely distribute income among consumers via lump-sum transfers and faces no budget constraint. Free distribution of income reflects the assumption of quasi-linear preferences, enabling lump-sum transfers between agents, which is important for the

[6]For this proposition, and others when applicable, I provide intuition for whether the results for two consumer types scale to an economy composed 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.

mechanisms considered in the following sections. The lack of budget constraint implies that the government need not raise tax revenue directly to finance subsidy-transfer schemes.[7] While not realistic in practice, the solution to the social planner's problem will define the optimal level of public goods provision from each type.

The social planner's problem (SPP) takes the following form for a two-person economy,

$$\max_{c_i} \left\{ \sum_i u_i | c_i \geq 0 \right\} \text{ for } i = g, n. \tag{5}$$

Net utility for each type (u_i for $i = g, n$) is given by the functional form in Equation 3. 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*,

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

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

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, (i) green consumers will provide as least as much of the public good as non-green consumers, that is, $c_g^* \geq c_n^*$. And, (ii) the inequality is strict for interior solutions.*

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

[7] The budget constraint of the government is revisited in subsequent sections.

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 will under-provide the public good relative to the socially optimal level. That is, including external benefits in the consumer's problem shifts the aggregate willingness to pay for the public good outward, such that the social equilibrium allocation is greater than that of the private equilibrium. 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 private equilibrium, the public good is provided at least cost to each consumer, which is a positive result. A normative solution is to correct this market failure through bargaining or government intervention. As such, free riding is illustrated by the gap between the private equilibrium and the socially optimal provision. Since it is unlikely that consumers possess enough information to bargain in a decentralized fashion, a corrective regulatory instrument is a more realistic device to increase public goods provision. Information limitations now arise as a problem between a regulator and the consumer, since the consumer holds private information about her preferences. This line of reasoning encapsulates the motivation for designing contracts to elicit true preferences for public goods (Green and Laffont, 1977b; Groves and Ledyard, 1977).

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 the system in Equations

[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 the SCC) an ordered marginal value of contributions. Thus, for a more general economy, provision of the public good is increasing in preferences over own provision.

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. This approach to solving free-riding problems is not new. But, the application of mechanism design in the provision of environmental goods with private and public characteristics is novel and the debate on ways to obtain efficient private provision of impure public goods remains unclear (Falkinger et al., 2000).

Myerson's revelation principle (Myerson, 1979) allows for a convenient methodological tool within this analysis. Particularly, it obviates the need to consider all possible feasible mechanisms; rather, we can simply focus our attention on finding direct mechanisms with incentive compatible equilibria. In this section, 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). Quasi-linearity in private consumption is a generally restrictive, but useful, assumption to make in this context. 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). However, for ease of illustration and to remain consistent with other applications of Clarke-Groves mechanisms, I maintain the assumption that preferences over the numeraire are quasi-linear.

Generally, Clarke-Groves mechanisms are structured to account for the social externality induced by an individual's reported value for a public project. By internalizing this social benefit, it is a dominant strategy for each consumer to reveal her true value for the public good (Clarke, 1971; Groves and Loeb, 1975). The archetypal Clarke-Groves mechanism defines a transfer for individual i as the sum of everyone else's valuation of the public good evaluated at the socially optimal level with and without i's presence, plus an arbitrary function of everyone else's reported valuation. However, the structure imposed on V in this paper deviates from traditional public goods models since consumer i's valuation is implicitly included in consumer j's valuation of the public good for some $i \neq j$. Thus, within the class of privately provided public goods, an individual's valuation of the public good is linked to the provision from other consumers. Due to this interdependence of agents' valuation and provision of the public good, truth revelation is not a dominant strategy (Varian, 1994; Falkinger, 1996; Kirchsteiger and Puppe, 1997).

This section presents a series of mechanisms that are variants of Clarke-Groves mechanisms adapted to the structure of privately provided public goods. 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 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 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), 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 be identified by enrollment in a green electricity program where, subject to some pecuniary or non-pecuniary incentive, 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* might be constructed in concert with community-based rewards programs that subsidize environmental protection (Jacobsen et al., 2013); however, on a more practical level, these 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 preferences, 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 $\mathscr{C} = [c_i(\tilde{m}_i), T_i(\tilde{m})]$ from Θ into $\mathbb{R}^+ \times \mathbb{R}$ where $c_i(\tilde{m}_i) : \Theta \mapsto \mathbb{R}^+$ are individually enforceable consumption contracts and $T_i(\tilde{m}) : \Theta \mapsto \mathbb{R}$ 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. In the example of clean electricity consumption as an economic good with private and public environmental benefits, the strong assumption on individually enforceable consumption contracts is justifiable in practice by considering the potential regulatory role of smart-metering technology at the household level. That is, individual consumption is feasibly observable to a regulator, notwithstanding practical, informational, and privacy constraints.

The timing of the mechanism in this subsection works as follows. First, consumers learn their type. Second, the regulator offers a contract conditional on reported types, $\tilde{m}$. 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. This timing represents a standard procedure for implementing direct mechanisms under adverse selection (Laffont and Martimort, 2002).

To facilitate the mechanism, the regulator specifies a payment scheme, $T_i(\tilde{m})$, 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 $T_g(\tilde{m})$ into her net utility function via her budget constraint. Thus, net utility for consumer i sending message $\tilde{m}_i$ can be written

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

which indicates that a consumer can send a message $\tilde{m}$ that does not 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

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

where T_i is a variant of a Clarke-Groves transfer with individually enforceable consumption contracts. Equation 9 specifies the transfer a consumer receives if she sends the message $\tilde{m}_i$, which is conditional on the report of other consumers, m_{-i}. Individual enforceability ensures that the regulator can observe, and contract upon, individual consumption.

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. As such, explicit structure would need to be placed on the preferences of all consumers. However, 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 a given environmental benefit in a given place and time.

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 net utility for both types, the transfers are chosen to mimic the social equilibrium without consumer i's presence, thus capturing the external effect of her provision. 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.[9]

For the example regulator that may be 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 abstract 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.

[9] 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 preferences 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.

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 $\mathscr{C}^R = [c_i^R(\tilde{m}_i), T_i^R(\tilde{m})]$ 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*. The practical motivation for this mechanism is that a regulator cannot enforce individual provision under the contract; rather, he conditions transfers only on the reported distribution of consumer types. For this mechanism, the timing remains the same as in the previous subsection.

In the two-consumer economy, define individual transfers

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

which are incorporated into consumer utility via the budget constraint,

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

The consumption bundle that maximizes u_i^R is a set of *reported consumption contracts*, $(c_g^R(\tilde{m}_i), c_n^R(\tilde{m}_i))$. In the working example, let reported consumption be some level of consumption that an electricity customer promises to consume in a goal-setting framework (Harding and Hsiaw, 2014). The incentive to meet the consumption goal could be reflected by the transfers specified in Equation 10, such that reported consumption would equal ex post realized consumption in expectation, absent any market, behavioral, or informational frictions.

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.

To fix ideas, assume residential electricity customers could receive some subsidy by indicating that they are participants in an environmentally friendly program, such as one that induces more renewable energy generation. Many customers would report they are participants to receive whatever benefit is provided to the green customers. However, since the regulator cannot observe who is actually in the program, no customers can be held accountable for falsely asserting that they are program participants. As such, the optimal level of environmentally friendly consumption cannot be obtained since this example simply describes a classic case of free riding and, thus, under-provision of the public good.

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, which has been motivated primarily by Alchian and Demsetz (1972) and Hölmstrom (1979, 1982). This method 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 $\mathscr{C}^{GR} = [\{c_i^R(\tilde{m}_i), C(\tilde{m})\}, T_i^{GR}(\tilde{m})]$, 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 a) reported messages and b) 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).

The primary objective of this mechanism is to elicit true preferences without relying on individual consumption contracts. 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,

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

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,

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

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 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.*

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.[10]

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 results in the consumer's problem coinciding with the social planner's problem.

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, and is less prone to overreaching informational constraints on the regulatory authority than previous mechanisms put forth.

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 the differential treatment of information available to a regulator in each context.

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

[10]Similarly to Proposition 3, this result scales to a general case in which there are a finite number of ordered preference types. However, this also 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.

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

The previous mechanism $\mathscr{C}^{GR}$ in the two-person economy provides a stylized illustration of the incentives that arise when consumers have heterogeneous preferences for providing a public good. In this section, I generalize the economy to that of I consumers, but restrict consumer types to being either green or non-green. Further, 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,

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

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

$$[c_g] : \frac{\partial V}{\partial c_g}(c_g, c_g + c_n | \theta_g) + \left(\frac{I_n}{I_g} \right) \frac{\partial V}{\partial c_g}(c_n, c_n + c_g | \theta_n) = a \tag{15}$$

and

$$[c_n] : \frac{\partial V}{\partial c_n}(c_n, c_n + c_g | \theta_n) + \left(\frac{I_g}{I_n} \right) \frac{\partial V}{\partial c_n}(c_g, c_g + c_n | \theta_g) = a \tag{16}$$

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 individual 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

$\mathscr{C}^{GR\star} = [\{c_i^{R\star}(\tilde{m}), C(\tilde{m})\}, T_i^{GR\star}(\tilde{m})]$. The properties and timing of this mechanism remain the same as those of $\mathscr{C}^{GR}$.

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

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

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. In this context, it is useful to think of the regulator as being a government with a plausibly large budget to finance the transfers. This mechanism, however, 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).

My abstraction from the government's budget constraint in this paper is acknowledged as a nontrivial omission. Any of the subsidy schemes proposed in the preceding sections must be financed by a government through raising taxes, which do not come without their own ramifications. 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 the mechanisms remains.

As a practical albeit unsatisfactory example, the transfers outlined in the previous mechanisms could represent subsidies for household energy efficiency investments. Since the energy efficiency gap is a substantial market inefficiency, there is justification for government intervention to increase the level of public goods provision. In fact, 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, arising from the 2009 economic stimulus package. While this analysis abstracts from potential general equilibrium effects of these taxes, these numbers provide a concrete justification for reframing the budget balance constraint as a discussion about correcting environmental market inefficiencies 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. Particularly, I affirm that environmental public goods are under-provided relative to the social optimum in general. 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.

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

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,* $c_g \geq c_n$.

Proof: Under the assumption that $\theta_g > \theta_n$, $c_g \geq c_n$ follows directly from the single-crossing condition of V in c_i that implies marginal utility is nondecreasing in type. $\square$

Proposition 2 *In the social equilibrium, (i) green consumers will provide as least as much of the public good as non-green consumers, that is,* $c_g^* \geq c_n^*$*. And, (ii) the inequality is strict for interior solutions.*

Proof: To prove (i), choose $\bar{c}_g \geq \bar{c}_n$, corresponding to some $\bar{\theta}_g > \bar{\theta}_n$, respectively, as solutions to the SPP

$$\bar{c}_i = \arg\max_{c_i} \left(u_g + u_n | c_i \geq 0\right) \text{ for } i = g, n.$$

Increasing differences implies

$$\frac{\partial V}{\partial \bar{c}_i}(\bar{c}_i, \bar{c}_i + C_{-i}|\bar{\theta}_g) - \frac{\partial V}{\partial \bar{c}_i}(\bar{c}_i, \bar{c}_i + C_{-i}|\bar{\theta}_n) \geq 0 \text{ for } \bar{\theta}_g > \bar{\theta}_n.$$

Thus, we have the following inequalities

$$\frac{\partial V}{\partial \bar{c}_g}(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) - \frac{\partial V}{\partial \bar{c}_g}(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) \geq 0$$

and

$$\frac{\partial V}{\partial \bar{c}_n}(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) - \frac{\partial V}{\partial \bar{c}_n}(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) \geq 0.$$

Adding the previous two inequalities provides

$$\frac{\partial V}{\partial \bar{c}_g}(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) - \frac{\partial V}{\partial \bar{c}_g}(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) + \frac{\partial V}{\partial \bar{c}_n}(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) - \frac{\partial V}{\partial \bar{c}_n}(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) \geq 0.$$

And, by rearranging terms

$$\frac{\partial V}{\partial \bar{c}_g}(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) - \frac{\partial V}{\partial \bar{c}_n}(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) \geq \frac{\partial V}{\partial \bar{c}_g}(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) - \frac{\partial V}{\partial \bar{c}_n}(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) \geq 0. \quad \text{(A.1)}$$

Now, let $\bar{c}_g = c_g^*$ and $\bar{c}_n = c_n^*$ such that the previous equation defines relationships within the first-order conditions to the SPP. Equation A.1 states that both terms that implicitly define the marginal contribution of the green consumer in the social equilibrium are at least as great as that of the non-green consumer. Hence, the green consumer will contribute at least as much to the public good as the non-green consumer, which provides the desired result.

To prove (ii), note that the first two terms in the inequality in Equation A.1 are strictly positive with $\bar{c}_g, \bar{c}_n > 0$. If $\frac{\partial V}{\partial \bar{c}_g}(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) - \frac{\partial V}{\partial \bar{c}_n}(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) = 0$, then the marginal benefits of g's own provision would have to equal those of n's. But, this would imply that $\theta_g = \theta_n$, which is a contradiction. Hence, $\bar{c}_g$ must be strictly greater than $\bar{c}_n$. $\square$

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.*

Proof: To show (i), assume arbitrary preference parameters $\bar{\theta}_g > \bar{\theta}_n$. The regulator solves the SPP for optimal contributions

$$\bar{c}_i = \arg\max_{i=g,n}\{V(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g) + V(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n) - a(\bar{c}_g + \bar{c}_n)|\bar{c}_g, \bar{c}_n \geq 0\}$$

with $\bar{c}_g > \bar{c}_n > 0$, indicating an interior solution. Under the transfer scheme in Equation 9, the payoff for g if she sends m_g is

$$V(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g, \tilde{m}_{-i}) + V(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_n, \tilde{m}_{-i}) - a\bar{c}_g \tag{A.2}$$

And, the payoff for g if she sends m_n is

$$V(\bar{c}_n, \bar{c}_n + \bar{c}_g|\bar{\theta}_g, \tilde{m}_{-i}) + V(\bar{c}_g, \bar{c}_g + \bar{c}_n|\bar{\theta}_g, \tilde{m}_{-i}) - a\bar{c}_n \tag{A.3}$$

Assume n sends m_n truthfully. If g prefers to report m_n, this would imply Equation A.3 is at least as large as Equation A.2, but this means that $\bar{c}_n$ cannot be different from $\bar{c}_g$ in the arbitrary social equilibrium, which is a contradiction. Hence, g can do no better than 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 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. $\square$

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

Proof: Consider a green consumer's payoff under the transfers in Equation 10 if she sends m_g truthfully and acts green

$$V(c_g, c_g + c_n|\theta_g, \tilde{m}_{-i}) + V(c_n, c_n + c_g|\theta_n, \tilde{m}_{-i}) - ac_g$$

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

$$V(c_g, c_g + c_n|\theta_g, \tilde{m}_{-i}) + V(c_g, c_g + c_n|\theta_g, \tilde{m}_{-i}) - ac_g.$$

By inspection, the latter payoff is strictly larger than the former; hence, sending a truthful message is not incentive compatible in this mechanism. □

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

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

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

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

$$\Omega_g = V(c_g, c_g + c_n|\theta_g, \tilde{m}_{-i}) - V(c_n, c_n + c_g|\theta_n, \tilde{m}_{-i}) - \tau(|C(m_j) - C^R|).$$

Now, choose τ, such that $\tau(|C(\tilde{m}) - C^R|) > V(c_g, c_g + c_n|\theta_g, \tilde{m}_{-i}) - V(c_n, c_n + c_g|\theta_n, \tilde{m}_{-i})$. 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. □

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.*

Proof: The proof follows from applying the envelope theorem to the first-order conditions in Equations 15 and 16. That is, let c_i^* maximize the SPP in the I-consumer economy for consumer type i. Then, $\partial c_i^*/\partial I_i = -I_j I_i^{-2} \partial V(c_j, c_j + c_i|\theta_j)/\partial c_i \leq 0$ for $i \neq j$ since V is nonnegative and $I_i, I_j > 0$, which proves (i). And, $\partial c_i^*/\partial I_j = I_i^{-1} \partial V(c_j, c_j + c_i|\theta_j)/\partial c_i \geq 0$ for $i \neq j$ since V is nonnegative and $I_i, I_j > 0$, which proves (ii). □

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.*

Proof: 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

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

which simplifies to

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

Now, choose τ such that $\tau(|C(\tilde{m}) - C^R|) > V(c_g, c_g + c_n|\theta_g, \tilde{m}_{-i}) - V(c_n, c_n + c_g|\theta_n, \tilde{m}_{-i}) - a(c_g + c_n)$. 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. □