Public Goods Provision in the Presence of Heterogeneous Green Preferences

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PRELIMINARY DRAFT

Abstract

This paper develops a model that incorporates heterogeneity across preference structures where some agents exhibit pro-social behavior – "green" preferences in our examples – and some do not. We compare the relative performance of various policies to increase public goods provision in the presence of this heterogeneity. We find that technology standards are almost always preferable to price instruments, working counter to the usual efficiency advantage of price-based policy. We then extend the model to allow heterogeneity in both green preferences and costs of provision: we show how the two effects compete to determine optimal policy. In the context of energy conservation policy we argue that heterogeneity in green preferences may importantly reduce the efficiency costs of existing consumer-facing technology mandates.

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1 Introduction

The private provision of public goods is playing an increasingly important role in overall public goods provision. Governments and NGOs, for example, rely on private provision and charitable giving to supplement shrinking city, state and federal contributions. In the context of energy conservation, social comparisons and advertising are similarly used to accentuate pro-social behavior on the part of consumers, increasing the private provision of energy conservation even in the absence of binding policy.[1] A growing literature models the underlying rationale for private provision of public goods.

We build on this literature, now asking the related policy question: In an economy where public goods are already being provided privately, but to insufficient levels, what are the merits of alternative policy instruments to further increase their provision? There are several reasons why accounting for private provision of public goods could affect the design of policy. First, there are a variety of results showing that different individuals in the economy have different values for their own public good provision (for example Costa and Kahn (2011) and Jacobsen, Kotchen, and Vandenbergh (2012)).[2] Second, reasons such as warm glow, moral suasion and impure altruism have all been shown to exist in both the lab and the field (Andreoni (1989), Levitt and List (2007)). Third, accounting for alternative preference structures can lead to dramatically different equilibrium outcomes for public good provision and the composition of who provides public goods (Andreoni (1991)).

We find that price-based policies can be significantly more costly than standards. Specifically, if agents have heterogeneous preferences for a public good then private provision of that public good combined with a minimum standard is always more efficient than a tax to reach the same aggregate level of provision. This result is the opposite of the usual policy prescription (deriving from heterogeneity in costs) but arises from a simple intuition: agents with stronger, pro-social, preferences for the public good will more pro-

[1] Allcott (2011) and Ferraro and Price (2011) for example show that high use households are significantly more responsive to pro-social appeals aimed at promoting conservation of energy and water. Kotchen and Moore (2007) consider green electricity programs.

[2] Survey evidence of heterogeneity is also available: Saphores, Nixon, Gounseitan, and Shapiro (2007) measure consumer willingness to pay for a green product with no outward differences. The find distinct groups in the population: 30% are unwilling to pay any price premium, for example, while 35% are willing to pay an added premium up to 10%.

vide more of it. This means the public good is provided asymmetrically across individuals, violating the equimarginal principal if marginal costs of provision are rising.[3] A uniform price incentive causes all agents to provide more of the good, preserving the equimarginal violation. Conversely, a binding standard helps equalize marginal costs across agents. To our knowledge our model is the first to show the superiority of standards under a simple, general source of pro-social preference heterogeneity with no additional constraints.[4]

While the scope of our model is broad, we motivate the discussion in the context of "green" preferences and the private provision of environmental goods like energy conservation. Some agents will care only about their own private returns while others care about environmental benefit both to themselves and others in the economy. In this regard, green preferences in our model will be in the spirit of efficiency preferences as modeled in Charness and Rabin (2002) or pro-social behavior as in Benabou and Tirole (2006). Rising marginal costs of provision, fundamental to the intuition behind our results, also accord well with the energy conservation setting: 41% of U.S. carbon emissions are either residential (largely via residential electricity use) or from personal vehicles meaning the provision of conservation rests largely on choices made by individual households. Marginal cost of improved energy-efficiency in durables like refrigerators, light bulbs, and cars will be rising for an individual choosing to increase their own contribution to conservation.

In this context, our result suggests an increased role for policy mandates like minimum standards on energy efficiency. Taxes or subsidies to encourage energy-efficient products will, in the presence of existing private provision, involve relatively greater cost. It is important to point out that a second, key source of heterogeneity is also likely in many settings: differences across individuals in the cost of provision. We extend our model to show how the two effects combine: greater heterogeneity in green preferences favors a standard while (relatively) greater heterogeneity in cost will favor a price-based policy.

The remainder of this paper is organized as follows: section two introduces the theo-

[3]Agents who provide more of the public good will pay a higher price on the margin, either in direct costs (coming through the technology for individual provision) or in opportunity costs (coming from decreasing marginal utility for an outside consumption good).

[4]In the existing literature standards instead tend to emerge as the preferred policy in behavioral models of limited attention or hyperbolic discounting: in these settings the policy mandate can improve decision-making or reduce later regret. For example Allcott, Mullainathan, and Taubinksy (2012) consider the case of fuel economy rules.

retical model and derives analytical results. Section three provides an algebraic example of the theoretical model. Section four discusses the theory in the context of light bulb efficiency and automobile choice, and section five concludes.

2 Public Goods Provision and Green Preferences

We outline a theoretical model of public goods provision that leads to heterogeneity in private provision of the public good. We then analyze the cost of alternative policies to increase public goods provision in this setting. Section 2.2 extends the model to allow a second form of heterogeneity: differences between agents in the cost of provision. We show how the two sources of heterogeneity compete in determining optimal policy choice. Proofs appear in Appendix A.

2.1 Modeling Preference Heterogeneity

We begin with a simple model of utility over a numeraire private good, c and a public good, X. Provision of X will be the sum across N members of the economy where x_i is the contribution of the ith member, $\Sigma_{i=1}^{N} x_i = X$, and $\Sigma_{j \neq i} x_j = X_j$. Individuals provide the public good subject to a strictly convex cost function $h(x_i)$ with $h'(x_i) > 0,\ h''(x_i) > 0$. We will consider the provision of energy conservation and environmental quality in our examples below, but the setting is generalizable to any public good.

Preferences over the two goods will be given by:

$$\begin{aligned} U_i(c_i, X|\Theta) &= c_i + \tilde{V}_i f(X) \\ &\qquad\qquad s.t.\ \ y_i = c_i + h(x_i) \\ \Rightarrow U_i(c_i, X|\Theta) &= y_i - h(x_i) + \tilde{V}_i f(X) \end{aligned} \tag{1}$$

In equation (1) utility is assumed linear in the numeraire good and the weakly concave function $f(\cdot)$ represents an agent's valuation of the public good.[5] It is equivalent to

[5]We will assume, as is common in the public goods literature, that $\lim_{x \to 0} f'(X) = \infty$ and $f'(X) \geq 0$ for all X.

write the model with decreasing marginal utility over the consumption good and a linear budget constraint following Andreoni (1989); this formulation appears in Appendix B. The heterogeneity we will study in the model appears in the term $\tilde{V}_i$, scaling each agent's preference for the public good.[6] For simplicity we will allow two types of agents, a share α with $\tilde{V}_i > 1$ and a share $(1-\alpha)$ with $\tilde{V}_i = 1$.

In practice, there are several interpretations of heterogeneity in $\tilde{V}$. First, the differences could be due to strict neoclassical preference heterogeneity. Indeed, there is significant evidence that agents have varying preferences for individually provided public goods (Saphores, Nixon, Gounseitan, and Shapiro (2007) and Costa and Kahn (2011)). Second, variation in $\tilde{V}$ could embed heterogeneity in social norms throughout an economy, such as in Benabou and Tirole (2006). Third, heterogeneity in $\tilde{V}$ allows generalized efficiency preferences, as in Charness and Rabin (2002).

The efficiency preferences interpretation accords particularly well with a form of green preferences, and can be represented in the following utility structure:

$$U_i(c_i, X|\Theta) = c_i + f_i(X) + s\Sigma_{j\neq i} f_j(X). \tag{2}$$

Added to the neoclassical specification is an additional term, multiplied by a weight s, that includes the sum of other agents' valuation of the public good. This is a green preference in the sense that the agent desires the socially efficient outcome as in Charness and Rabin (2002). The form implies that individual i will adjust their own provision of the public good toward social efficiency. In our setting the α "green" agents with $\tilde{V} > 1$ can be thought of as having utility as in (2). This is equivalent to setting $\tilde{V} = 1 + s(N-1)$ for these agents. The remaining $(1-\alpha)$ "non-green" agents will have strictly neoclassical utility (i.e., $s = 0$ and $\tilde{V} = 1$).

The standard first order conditions for the privately optimal provision of the public good are given in our model by:

$$h'(x_i^*) \geq \tilde{V} f'(x_i^* + X_{i\neq j}^*) \ \ \forall \ i \tag{3}$$

[6] For simplicity we assume that the shape of preferences for the public good given in $f(X)$ is common across agents, though other sources of heterogeneity at the margin can also produce our result.

with equality if $x_i > 0$. Combined with our assumption of common costs of provision (we will show how cost side heterogeneity enters in Section 2.2 below) this allows a straightforward summary of the difference across agents:

Proposition 1: Green agents provide more of the public good than non-green agents.

Intuitively, since the marginal benefit associated with each unit of the public good is higher for green agents than non-green agents, they will alway provide more of the public good. Figure 1 shows this graphically, indexing green agents as g and non-green agents as u. The privately optimal levels of provision (solving the first order conditions in (3)) are indicated by $\hat{x}_g$ and $\hat{x}_u$.

Further assuming increasing marginal costs (for example of energy conservation by individual households) the model immediately leads to the following:

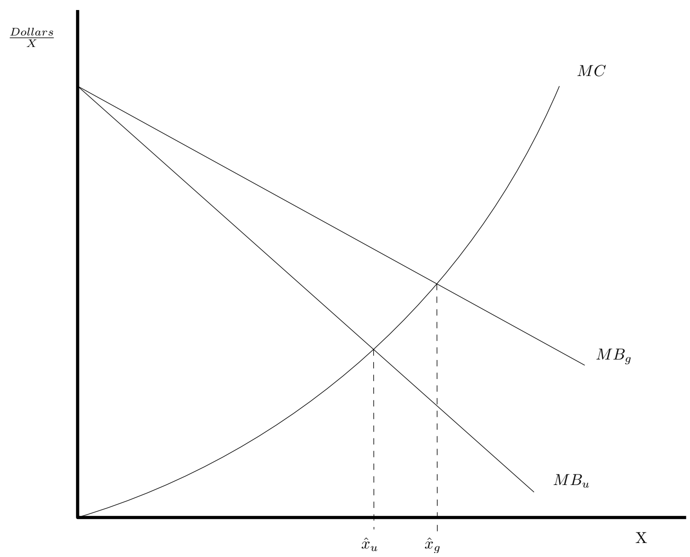

Figure 1: Basic Equilibrium

Proposition 2: For any level of public goods provision $\tilde{X}$, it is cost minimizing to have all agents provide identical quantities.

Corollary 1: Private provision of the public good is socially efficient (with respect to the direct benefits in each $f_i(X)$) if all agents have full social efficiency preferences.

Proposition 2 is simply the classic equimarginal principle in the context of our model: since the marginal cost of provision is increasing and symmetric across agents the minimum-cost provision of any aggregate $\tilde{X}$ will involve $x_i = x_j$. In Figure 1, the marginal cost of provision for green agents is larger than the marginal cost of provision for non-green agents. As a result, the private equilibrium cannot minimize cost due to the wedge in marginal costs across agents.

The assumption of increasing marginal costs accords well, for example, with energy conservation provided through lighting choices: the switch from incandescent to CFL bulbs may be relatively cheap, but if an individual wishes to provide even more conservation they begin moving up a marginal cost curve, perhaps switching to relatively expensive LED-based products. Our assumptions in this simple version of the model will be met to the extent consumers face similar costs in the marketplace and the technologies are close substitutes in providing a final good (household lighting in this case). We consider other examples and cases where cost heterogeneity enters in the discussion below.

Corollary 1 includes two important features that make it differ from the classic definition of equilibrium public goods provision (e.g. in Samuelson (1954)). First, each agent provides their own contribution of the public good through *independent* convex cost functions, $h(\cdot)$. These agents must therefore have the same preferences in order to guarantee provision of identical quantities as required by Proposition 2. Second, these preferences must place enough weight on the public good to bring the aggregate level of provision up to the efficient level. The weights needed are given in (2) where $s = 1$. Note that the social planner here implicitly only considers direct benefits of provision, contained in $f_i(X)$. If the planner also considers the feedbacks in the efficiency preference term we would again arrive at under-provision of the good in equilibrium. We will abstract from this distinction in what follows by considering the planner's problem as a cost-minimization subject to reaching a specified level of provision in aggregate.

We now turn to the motivating question about cost-minimizing policy. We will compare the performance of a price instrument (a subsidy to public good provision in this case) to

the performance of a standard that enforces a minimum level of public good provision.[7] For simplicity, we assume perfect enforcement of both policies:

Proposition 3: For any level of regulated public goods provision $\tilde{X}$ such that the standard binds for all agents, $\frac{\tilde{X}}{N} \geq \hat{x_g}$, a standard is always more efficient than a price instrument.

Proposition 4: For any level of regulated public goods provision $\tilde{X}$ such that the standard binds for non-greens but not for green agents, $\hat{x_g} \geq \frac{\tilde{X}}{N} \geq \hat{x_u}$, a standard is always more efficient than a price instrument.

The intuition behind Proposition 3 follows first from the equimarginal principle: if the standard binds for all agents then they all provide $\frac{\tilde{X}}{N} \equiv \bar{x}$ units of the public good and reach aggregate provision at minimum cost. A uniform price subsidy across types, on the other hand, preserves a wedge in the level of provision between greens and non-greens. The difference in provision, and therefore marginal cost, means that the price policy will always be less efficient. Subsidies targeted by type can still produce efficiency (shown below), though we will argue that these are infeasible in practice.

Proposition 4 is based on a similar intuition, though requires additional analysis since neither policy is able to satisfy the equimarginal condition. (The standard in this case is not binding for green agents so they will provide more of the public good under either policy.) The key intuition for the result is that the subsidy increases provision from both types of agents while the standard only increases provision from non-green agents, who have relatively low marginal cost. The concavity of benefits from the public good introduces an additional factor, which we find reinforces the result in the proposition: if the unconstrained "green" agents provide somewhat less of the good when the standard is in place (due to declining marginal benefits in the aggregate), this acts to further reduce the wedge between the two types of agents. The standard is therefore unambiguously preferred for any level of provision greater than the private optimal level.

[7] Note that to agents in a large economy, a quota on emissions will manifest as a price instrument. For example, an emissions quota applying to electricity production will appear as higher electricity prices to households.

The effect of price instruments and standards in the case considered by Proposition 4 is shown in Figures 2 and 3. In Figure 2, the subsidy for public good provision shifts each curve up by the level of the subsidy, τ. Each type sets private marginal benefit (now including the subsidy) equal to marginal cost, preserving a wedge in marginal cost across types: $MC(x_u(\tau)) < MC(x_g(\tau))$.

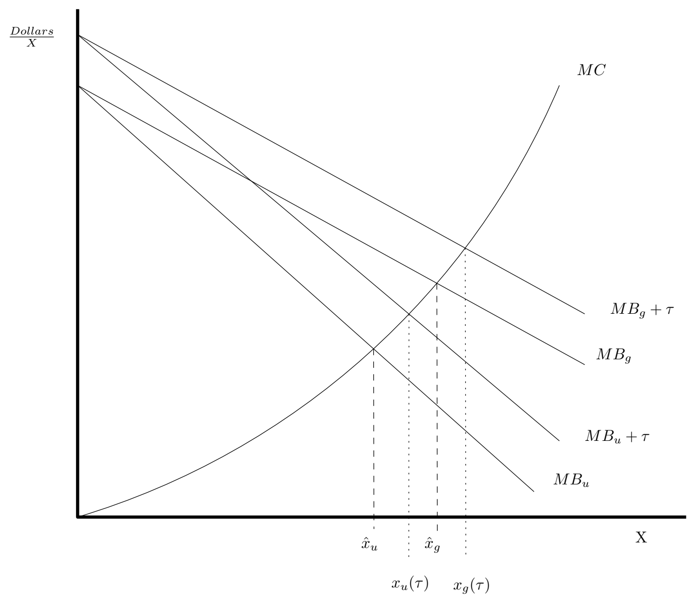

Figure 2: Equilibrium with a price instrument

Figure 3 shows the case where the standard binds only for the non-green type. In this case, the non-green agent must provide at a level greater than their private optimum ($\bar{x} > \hat{x}_u$). This brings the two types closer together (holding the choice of the green fixed), reducing aggregate cost. Further, a possible indirect effect of the standard on greens also appears in the figure: when non-greens are induced to provide more the marginal benefit of existing provision by greens may be lowered. Greens then provide (weakly) less than before ($x_g(\tilde{X}) \leq \hat{x}_g$). Both effects of the standard, then, act to narrow the wedge in marginal costs between non-green and green agents.

In addition to demonstrating the advantage of a standard, as in the propositions above, the model also permits consideration of the relative size of this advantage with respect to parameters. Corollaries 2 and 3 below are the first steps toward the comparison, and show how provision of each type of agent changes as a function of α, the proportion of green

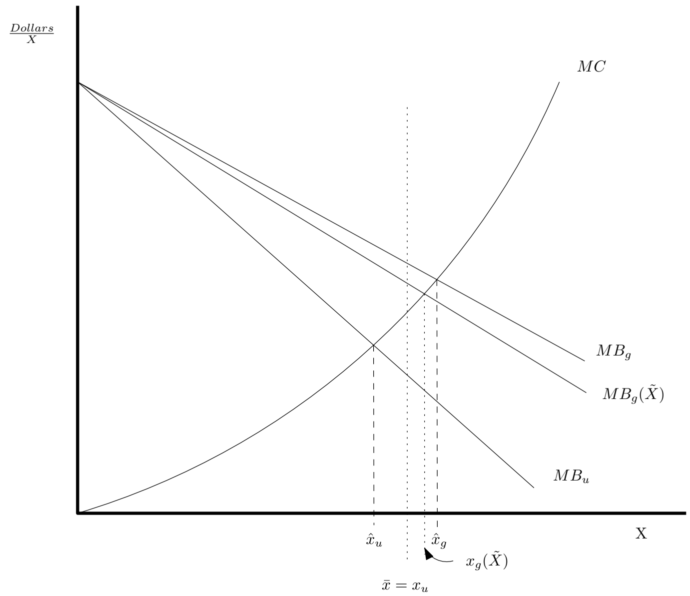

Figure 3: Equilibrium under a standard

agents, and $\tilde{V}$, the strength of their preferences under the price instrument:

Corollary 2: The provision of green agents in the case of price instruments, x_g^t, and the price instrument/subsidy needed to attain a given level of public good provision, τ, are both always decreasing in the percentage of green agents, α.

Corollary 3: The provision of green agents in the case of price instruments, x_g^t, is increasing and the price instrument/subsidy needed to attain a given level of public good provision, τ, is decreasing in the strength of the green preference, $\tilde{V}$.

The intuition behind Corollary 2 is straightforward. If the number of green agents increases then the unregulated level of public good provision increases. As a result, the needed price instrument to attain any particular level of public goods provision falls since less of an incentive is needed. Similarly, as overall provision rises the marginal benefit may fall causing each individual green to produce slightly less. The intuition behind Corollary 3 is almost identical, except that now the increase in unregulated provision comes through increased strength of individual preferences in $\tilde{V}$ rather than an increase in the number of greens overall.

The corollaries lead to two results on the size of the cost advantage offered by a standard:

Proposition 5: For any level of regulated public goods provision, $\tilde{X}$*, such that the standard binds of all agents,* $\frac{\tilde{X}}{N} \geq \hat{x}_g$*, the difference in welfare between the two policies,* Δ_{ts}*, is single peaked in the percentage of green agents,* α*.*

Proposition 5 states that the two policies are identical in the case of homogeneous preferences (reducing to the standard result) but lead to increasingly different levels of welfare as the composition of preferences in the economy becomes more and more different. Intuitively, welfare loss from a price instrument is due to agents providing different levels of the public good at different marginal costs. This cumulative losses, therefore, are most pronounced and most relevant for total provision when the mass of public good provided by each type is large.

Corollary 4: For any level of regulated public goods provision $\tilde{X}$ *such that the standard binds for all agents,* $\frac{\tilde{X}}{N} \geq \hat{x}_g$*, the difference in welfare between the two policies,* Δ_{ts}*, is everywhere increasing in the strength of the green preference,* $\tilde{V}$*.*

As shown above, stronger green preference, $\tilde{V}$, induces more provision from green agents and increases the wedge between green and non-green provision. As a result, the tax leads to progressively greater costs than the standard.

Taken together, the results in this subsection consider the effect on public goods provision when a fraction of people in the economy have pro-social, greener, preferences. We show how these agents provide more of the public good in an unregulated setting, leading to a wedge between their marginal costs and those of the remaining agents in the economy. This wedge is preserved if the government employs a price instrument in order to increase aggregate provision of the public good. Standards, in contrast, act to reduce the cost wedge and therefore attain increases in public goods provision more cheaply. Finally, we find the relative benefit of standards over taxes is increasing in the degree of preference heterogeneity in the economy. In our model, this comes either through stronger preferences among individual greens or an increase in their numbers overall.

2.2 Asymmetric Instruments and Costs

We now relax the assumptions of the model in two key dimensions: first, we consider the possibility of an asymmetric policy instrument where greens can receive a different subsidy than non-greens. Second, we consider asymmetry in the costs of provision, allowing greens to have larger or smaller costs of providing the public good than non-greens.

Proposition 6: There is an asymmetric price instrument which leads to efficient provision of any level of the public good, $\tilde{X}$*, in which the subsidy for non-greens,* τ_u*, is strictly larger than the subsidy for greens,* τ_g*.*

The intuition for Proposition 6 is related to the classic Lindahl price solution in public goods problems. The difference here comes from rising marginal cost, which as above means equal provision of the goods across types will also be required for efficiency. The asymmetric price policy can achieve this: the social planner uses separate subsidies to shift each agent's marginal benefit curve so that it intersects marginal cost at the same point. As a result, each agent provides the same level of the public good at the same cost making the provision efficient. However, this policy would be quite difficult to implement in most practical settings due to difficulty in accurately identifying each type as well as the potential for resale (for example of energy-conserving products).

We can also consider asymmetries across types in the cost of providing the good, quite likely to exist in practice to varying degrees depending on the policy setting. Assume now that green agents, in addition to having the $\tilde{V}$ parameter governing the strength of their green preferences, also have a parameter δ differentiating their marginal costs of abatement. The green agent's maximization problem then becomes:

$$\begin{aligned} U_g(c_g, X|\Theta) &= c_g + \tilde{V} f(X) \\ &\qquad s.t.\ \ y_g = c_g + \delta h(x_g) \\ \Rightarrow U_g(c_g, X|\Theta) &= y_g - \delta h(x_g) + \tilde{V} f(X) \end{aligned} \tag{4}$$

Values of δ greater than 1 scale up the cost of abatement for greens (making cost positively correlated with pro-social preferences), and values less than 1 scale it down (introducing a negative correlation). This extension leads to the following propositions:

Proposition 7: In the case of asymmetric costs, the amount of public good provided by greens is falling in the marginal cost of their abatement relative to non-greens. The (uniform) subsidy needed to reach any level of public goods provision is rising in the marginal cost of their abatement.

Proposition 8: In the case of asymmetric costs, a uniform price instrument is more efficient than in the symmetric costs case as long as green agents' costs of abatement are negatively correlated with the strength of their green preferences, subject to one regularity condition.

Proposition 7 states two very intuitive results: first, as the cost of provision for green agents increases they provide less of the public good. Second, holding non-green cost of provision fixed, as the cost of green provision increases the needed subsidy to provide any given level of the green good increases. This is useful in developing Proposition 8:

Proposition 8 states that the relative benefits of standards over taxes falls if green agents have a lower cost of provision than non-green agents. Conversely, the relative benefits of standards over taxes can rise (in the case where the standard binds only on the non-green agent) if green agents have a higher cost of provision. The intuition for these results is shown in Figure 4 below. The figure provides an example where provision in the unregulated equilibrium is in fact efficient (the green agent's marginal cost of abatement curve is sufficiently less than the non-green agent's costs). In this example, it is easy to see how a uniform subsidy can maintain efficiency (by shifting both types' provision up) while a standard will instead introduce a wedge in marginal costs.

More broadly, the propositions here suggest that cost heterogeneity will tend to decrease the advantage of a standard relative to a subsidy. With enough cost heterogeneity (as for example in Figure 4) the subsidy policy will dominate the standard. We are able to provide more precise intuition on exactly how the effects compete and when each of the two policies is preferred using the algebraic example below.

3 Algebraic Example

The key inequalities can be derived from the general model above, but there is also important intuition in a parsimonious analytical example. With a simple quadratic param-

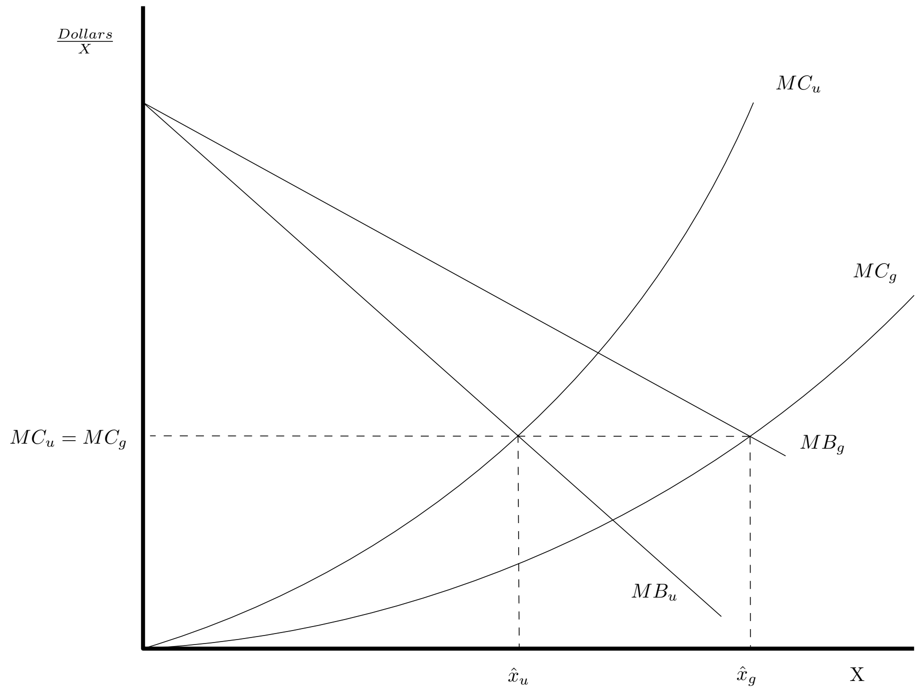

Figure 4: Case of Asymmetric Costs of Abatement

eterization we solve explicitly for the advantage of a standard relative to a price-based instrument. We can then investigate how each factor contributes to the degree of the standard's advantage. The example also allows direct consideration of the competing effects from heterogeneity in cost and heterogeneity in green preferences.

We will assume here that marginal benefits from provision of the public good are constant and that agents' marginal cost of provision rises linearly from the origin. Reductions in carbon emissions in a particular country and year, for example, are likely to fit the constant marginal benefits case closely.[8] Linearly increasing marginal cost – of energy conservation to stay with the climate example – keeps the parameterization simple and also fits a number of technologies quite well (for example automobile fuel economy as shown in Figure 5).

[8] The intuition is that a year's change in one country will affect global climate only slightly, while any nonlinearity in benefits is likely to appear only for much larger temperature movements.

Our example then defines:

$$
\begin{aligned}
f_i'(X) &= m \text{ (constant marginal benefits)} \\
h'(x_i) &= bx_i \text{ (marginal cost rises linearly at rate } b\text{)}
\end{aligned}
$$

The solution to the utility maximization problem given in (1) under a tax τ or standard $\bar{x}$ is now straightforward. We consider policies that achieve a fixed total provision of $\tilde{X}$ and are ambitious enough to bind on all agents ($\bar{x} \geq \hat{x_g}$, as in Proposition 3). Again defining Δ_{ts} as the cost advantage that a standard has over a price-based policy we arrive at the relatively simple expression:

$$\Delta_{ts} = \alpha(1-\alpha)\frac{m^2(\tilde{V}-1)^2}{b} \tag{5}$$

First notice that the advantage of the standard increases with the square of m and $\tilde{V}$: The greater the strength of pro-social preferences among greens ($\tilde{V}$) or the value of benefits from this particular public good (m) the bigger is the initial wedge in conservation choice between greens and non-greens. The standard overcomes this difference, achieving the first best, while the price-based policy does not.

Next we observe that as b declines (marginal costs become flatter) the advantage of the standard increases even further. This is at first counterintuitive, but notice that the levels of $\tilde{V}$ and m alone determine the absolute difference in marginal costs between greens and non-greens. Small values of b (holding the difference in marginal cost fixed) then imply large differences in absolute levels of private provision.[9]

We can also consider α, the share of greens: if everyone is green or everyone is non-green ($\alpha = 1$ or 0) our model reduces to the standard equivalence (in the absence of other sources of heterogeneity) between the two policies. Proposition 5 shows that the advantage of the standard has a single peak in α. In this example the peak occurs at $\alpha = 1/2$. Intuitively this is where the degree of heterogeneity in the population is maximized.

The case where heterogeneity exists both in green preferences *and* in marginal costs of provision can also be presented quite intuitively in this setting. Allowing marginal costs

[9]We cannot examine the case as b goes to 0 in this parameterization since the green's private provision, $\hat{x_g}$, tends to infinity, removing the need for policy.

to differ, $h'(x_g) = b_g x_g$ and $h'(x_u) = b_u x_u$, and solving as before yields:

$$\Delta_{ts} > 0 \Leftrightarrow m(\tilde{V} - 1) > |b_g - b_u|\tilde{X} \tag{6}$$

That is, the standard is preferred as long as the wedge between the green and non-green's benefits is greater than the absolute difference in their marginal costs of provision. When preference heterogeneity is relatively large, the standard dominates. When cost heterogeneity is relatively large, the price-based policy dominates.

4 Policy Discussion

Our model applies in a variety of settings where provision of public goods is accomplished by individuals facing convex costs.[10] We focus here on household energy conservation, with the assumption that each additional step toward zero energy use for the household comes with increasing cost. Further, we choose examples where the cost side heterogeneity may be relatively small; these are cases where the points we make on preference heterogeneity will exert a relatively large influence on policy choice.

4.1 Lighting Technology Choice

Consider the ability of a household to provide a public good (energy conservation) by buying a more efficient lightbulb. Each household works its way out a common marginal cost curve by selecting one of a variety of (ever more expensive) bulbs: standard incandescents, halogen incandescents, compact fluorescents, and LED-based bulbs.[11] Consumers differ widely in their initial desire to conserve, spreading out across the spectrum of bulb choices.

U.S. state and federal governments are currently intervening to increase light bulb efficiency. The policies act on one margin of choice, bulb selection at the store, and the

[10] The individual nature of the costs is a key component of our setting: if the public good is produced centrally (consider highway construction) the cost penalty associated with different contributions by greens and non-greens is removed.

[11] By assuming a common marginal cost curve we assume that consumers place equal value on other differences in the bulbs (for example quality of light or sound emissions) are minimal. Heterogeneity in preferences for these aspects introduces cost-heterogeneity in the language of our model, then competing with the degree of green preference heterogeneity in determining optimal policy.

two types of policies currently in place line up directly with the two alternatives in our model: "price-based" policies here are simply subsidies to more efficient bulbs, dominant historically. The alternative, minimum standard policies, have been introduced more recently: California's AB 1109 places a minimum standard that phases out standard incandescents between 2011 and 2013. Halogen incandescents become the minimum-efficiency bulb permitted by the standard. A federal minimum-standard, roughly one year behind the California law in timing, has similar provisions but has been contentious to the point that congress acted to suspend enforcement in late 2011.[12]

Our model informs this policy choice from an efficiency perspective, arguing that the standards may in fact provide the least-cost option: The existing broad subsidies to efficient bulbs move everyone's choice farther out the technology cost curve, preserving the gap between greens and non-greens. The minimum standards instead push all consumers only as far as the halogen bulbs, taking advantage of a low-cost conservation option available to non-greens without distorting the incentives faced by greens. Note that there will still be heterogeneity (the greens purchasing CFL's or LED bulbs will presumably continue to do so); the advantage of the minimum standard is that it brings us closer to the equimarginal case. This is the case shown in Proposition 4, where the standard binds only on the non-green consumers.

An important caveat here is that our model considers only one margin of choice. We can compare the two competing policy interventions for light bulbs because they act on exactly the same margin of choice, but we cannot draw comparisons with other policies in the portfolio: for example an advertising campaign that promotes turning off lights when leaving a room.

4.2 Automobile Choice

The automobile choice decision again fits within the basic intuition of our model: in order to provide ever more conservation through vehicle choice a household faces a convexly increasing purchase price. To provide a sense for this Figure 5 displays a set of engineering features than can improve fuel economy in a typical compact car. The data points are

[12] See "Let There Be Light Bulbs" in the Wall Street Journal (July 15th, 2011) and the more recent suspension of the law "Congress Kills Light Bulb Ban - Sort Of" in Forbes (December 16, 2011).

from National Research Council (2002) and hold all vehicle characteristics other than fuel economy fixed. Marginal costs increase roughly linearly (lining up well with the assumptions in the algebraic case). Heterogeneity among existing consumers means that some vehicles presently include these low-cost improvements and others don't. Households with even stronger preferences for conservation buy cars that include every one of these improvements and then go well beyond, adding hybrid or even electric drivetrains. At the same time many non-greens fail to provide even a minimal level of conservation when making their car purchase decisions.

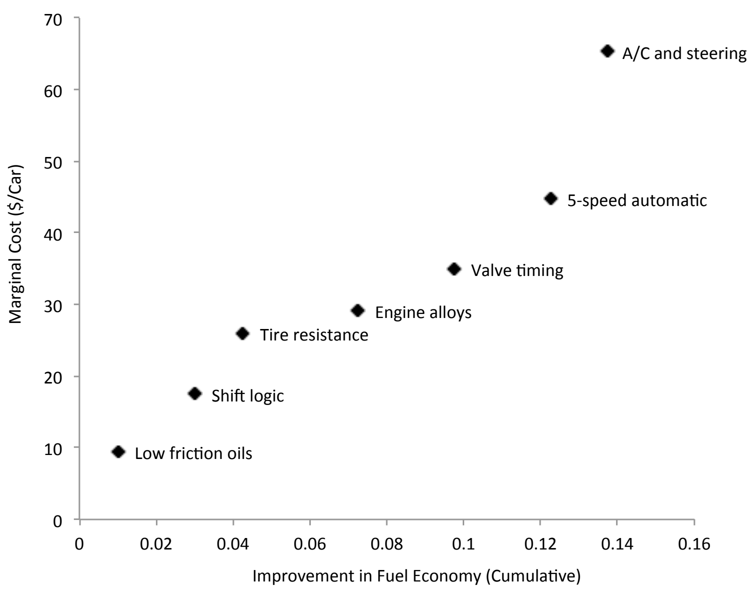

Figure 5: Engineering Cost of Improved Fuel Economy (Typical Compact)

The existing literature on gasoline use tends to focus not on one margin of choice (we will focus on the car purchase decision exclusively) but rather on two: the car purchase decision is interacted with the choice over how many miles to drive. See Parry, Walls, and Harrington (2007) for a discussion of policies and the effects along different margins. While both margins are certainly important (we would be the first to argue that controlling miles driven is important to reduce gasoline use, accidents, and congestion) we restrict ourselves here to policies that act solely on vehicle choice. In terms of policy, this margin

is presently the key focus of gasoline conservation efforts in the U.S.[13]

The U.S. effort to influence automobile choice has been dominated by the Corporate Average Fuel Economy (CAFE) standards, which restrict the average efficiency among the vehicles a manufacturer sells. In the context of our model CAFE is (perhaps counter-intuitively) a *price*-based policy since it places a shadow tax on inefficient vehicles (ones that bring down a manufacturer's average) and a shadow subsidy on the efficient cars. In this sense, CAFE suffers from exactly the problem we identify in our theoretical mode: it pushes both greens and non-greens toward more fuel-efficient vehicles, sending them farther out their individual cost curves for conservation. CAFE fails to take advantage of the fact that the cheapest conservation options on the margin (for example many of the technologies shown in Figure 5) are currently only available to the non-greens: these improvements have already been adopted in most vehicles that greens would consider.

Our model argues instead for a minimum standard on vehicle efficiency (or perhaps efficiency relative to weight, size, or horsepower, akin to the lightbulb standard which is placed on energy use per lumen). In the U.S. the closest existing policy to a minimum standard might actually be the gas guzzler tax. The guzzler tax looks like a minimum standard here since it applies only to a subset of the least efficient vehicles (under 22.5 mpg).[14] It therefore acts to bring up the fuel efficiency choices of the non-greens (to the extent they currently locate under 22.5 mpg) without interfering in the choices made by greens (to the extent they locate above the cutoff). Interestingly, the guzzler tax' lack of influence on choices above 22.5 mpg is sometimes pointed to as a failing, but our model suggests that this aspect is exactly what makes it more efficient. The least green consumers tend to be the ones that still have the cheapest options for conservation remaining, providing an efficiency advantage to policy that influences their decisions.

[13]The Obama administration has announced a near doubling of the present fuel economy standard on new car sales by 2020, see The White House Office of the Press Secretary (2011), while the federal gasoline tax has not been increased since 1993.

[14]Consider the extreme case for clarity: a very high guzzler tax would essentially eliminate vehicles under 22.5 mpg without distorting decisions on vehicles above that cutoff, in essence a minimum standard.

5 Conclusion

We consider the policy implications of heterogeneity in private provision of public goods. We model an economy populated by two types of agents that differ with respect to their preferences for the public good. Whereas some agents care only about their own returns from the public good, others have "green" preferences and care about the benefits received by both themselves and others in the economy. Since both types of agents face identical, but convex, costs of provision, the private equilibrium involves greens working up their marginal cost curve and providing units of the public good that are more costly on the margin than provision by non-greens.

We argue that minimum standards, like those on lightbulb efficiency, can provide an increase in aggregate provision of the public good at lower cost than price-based incentives. Standards tend to reduce the heterogeneity in individual provision and therefore reduce total cost. Price-based policy, on the other hand, places the same incentive on all individuals and so preserves the existing inefficiency stemming from uneven provision of the public good. This result relies importantly on the source of heterogeneity in the model, assuming it enters primarily through green preferences

Cost heterogeneity, however, is also likely to be important in most applied settings and so we extend the model to allow both sources together: when cost heterogeneity is relatively large a price-based policy dominates while the opposite holds when heterogeneity in pro-social preferences is the more important component. We argue that certain policy questions, for example the case of lightbulbs or some low-cost technologies in cars, are likely to present relatively homogeneous costs and therefore fit our main model most closely. Other settings are likely to exhibit substantial differences both in green preferences and also in the costs of provision. Consider for example the conservation of energy through reduced use of air conditioning: some individuals may have very strong green motivation for higher thermostat settings (large preference differences of the type we consider), while at the time considerable variation is also likely in the utility people give up due to warmer indoor temperature (the cost side). Our results here suggest that optimal policy choice depends pivotally on the empirical degree of heterogeneity in these two dimensions.

A number of important caveats remain in our model: we focus on a single margin, for example a policy designed to influence the purchase decision of an energy-using appli-

ance. Other margins (for example utilization of the durable) and therefore more complex variations of policy will be important in specific applications.[15] Further, we employ a model with only two types while a continuum of preferences might better reflect empirical differences in the provision of public goods. This could provide further generalization of our key results.

[15] Hausman (1979) and a rich subsequent literature consider interactions between purchase and utilization of durables, for example.

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Appendix A

Proposition 1: Green agents always provide more of the public good than non-green agents.

PROOF: By definition, $\tilde{V}$ is strictly larger for greens than non-greens. Private equilibrium provision for greens, $\hat{x_g}$, and non-greens, $\hat{x_u}$, are implicitly defined by the following system of equations:

$$h'(\hat{x_g}) = \tilde{V} f'(\alpha N \hat{x_g} + (1-\alpha) N \hat{x_u}) \tag{7}$$

$$h'(\hat{x_u}) = f'(\alpha N \hat{x_g} + (1-\alpha) N \hat{x_u}) \tag{8}$$

Since $\tilde{V} > 1$ it must be that $\hat{x_g} > \hat{x_u}$ giving the desired result.

Proposition 2: For any level of public goods provision $\tilde{X}$, it is cost minimizing to have all agents provide identical quantities.

PROOF: Set up the cost minimization problem directly with a lagrangian such that

$$\min_{\underline{x}} \quad \Sigma_i \; h(x_i) \tag{9}$$

$$s.t. \quad \Sigma_i \; x_i = \tilde{X} \tag{10}$$

$$\rightarrow \quad L = \Sigma_i \; h(x_i) + \lambda \left[\tilde{X} - \Sigma_i \; x_i \right] \tag{11}$$

The first order conditions for this lagrangian are $h'(x_i) = \lambda \; \forall \; i = 1, 2, ..., N$ implying that $h'(x_i) = h'(x_j) \; \forall \; i, j$ which gives the desired result.

Corollary 1: With respect to direct effects, private provision of the public good is socially efficient if all agents have full social efficiency preferences.

PROOF: Economy wide social efficiency preferences are defined by parameters $\alpha = 1$ and $s = 1 \;\rightarrow\; \tilde{V} = N$. In this case, the privately provided equilibrium is defined by the

single equation $h'(\hat{x_g}) = Nf'(N\hat{x_g})$. By definition, the socially optimal level of the public good satisfies the following condition

$$\Sigma_i h'(x_i^*) = Nf'(Nx_i^*) \tag{12}$$

Equation (12) states that the sum of the marginal costs for each agent's provision must equal the sum of the marginal benefits. Summing up the direct effect of all agents' private provision gives: $\Sigma h'(\hat{x_g}) = Nf'(N\hat{x_g})$. By strict concavity of $h(\cdot)$, $x_g = x_i^*$ giving the desired result.

Proposition 3: For any level of regulated public goods provision $\tilde{X}$ such that the standard binds for all agents, $\frac{\tilde{X}}{N} \geq \hat{x_g}$, a standard is always more efficient than a price instrument.

PROOF: Choose a price instrument, τ such that $\Sigma_i x_i = \tilde{X}$. The price instrument, τ, enters the budget constraint as $y = c + h(x_i) - \tau x_i$. Agents still privately optimize such that private equilibrium is jointly determined by

$$h'(\hat{x_g^t}) = \tau + \tilde{V}f'(\tilde{X}) \tag{13}$$

$$h'(\hat{x_u^t}) = \tau + f'(\tilde{X}) \tag{14}$$

By convexity of $h(\cdot)$, $h'(\hat{x_g^t}) \neq h'(\hat{x_u^t})$. Under a standard, all agents provide a minimum level of provision $\frac{\tilde{X}}{N}$ such that $h'(\frac{\tilde{X}}{N}) > \tilde{V}f'(\tilde{X}) > f'(\tilde{X})$. As a result, $\tilde{X}$ is provided such that $h'(x_i) = h'(x_j)\ \forall\ i, j$. By Proposition 2, a standard is a least cost mechanism for providing $\tilde{X}$ whereas by equations (13) and (14) a tax is not, giving the desired result.

Proposition 4: For any level of regulated public goods provision $\tilde{X}$ such that the standard binds for non-greens but not for green agents, $\hat{x_g} \geq \frac{\tilde{X}}{N} \geq \hat{x_u}$, a standard is always more efficient than a price instrument.

PROOF: Equilibrium in the price instrument case is given by the system

$$h'(\hat{x_g^t}) = \tau + \tilde{V} f'(\tilde{X}) \tag{15}$$

$$h'(\hat{x_u^t}) = \tau + f'(\tilde{X}) \tag{16}$$

By convexity of $h(\cdot)$, $h'(\hat{x_g^t}) > h'(\hat{x_u^t})$ and $x_g^t > x_u^t$. In the case of the standard, green agents' provision, x_g^s is defined by their first order condition: $h'(\hat{x_g^s}) = \tilde{V} f'(\tilde{X})$. By convexity of $h(\cdot)$ and $\tau > 0$, it implies $x_g^t > x_g^s$. Further, $\tilde{X} = N(\alpha x_g^s + (1-\alpha)x_u^s)$. As a result, non-green provision of the public good in the case of standards can be expressed as $x_u^s = \frac{(\tilde{X}/N) - \alpha x_g^s}{1-\alpha}$. Since $x_g^t > x_g^s$, it implies $x_u^s > x_u^t$ and subsequently $x_g^t - x_u^t > x_g^s - x_u^s$.

Consider a case in which $x_g^t = x_g^s + \epsilon$ for $\epsilon > 0$ to reach some $\tilde{X}$. Noting that the distribution of provision in the case of a standard would therefore be $\alpha N x_g^s + (1 - \alpha)N(x_u^t + \frac{\alpha}{(1-\alpha}\epsilon$. The average cost of provision for x across agents in the price instrument case is $p^t = \alpha h(x_g^s + \epsilon) + (1-\alpha)h(x_u^t)$ and in the case of subsidies is therefore $p^s = \alpha h(x_g^s) + (1-\alpha)h(x_u^t + \frac{\alpha}{1-\alpha}\epsilon)$. $p^t > p^s$ by concavity of $h(\cdot)$ giving the desired result.

Corollary 2: The provision of green agents in the case of price instruments, x_g^t, and the price instrument/subsidy needed to attain a given level of public good provision, τ, are both always decreasing in the percentage of green agents, α.

Equilibrium in the case of price instruments is given by equations (13) and (14) above in addition to the level constraint: $\tilde{X} = \alpha N x_g^t + (1-\alpha)N x_u^t$. Substituting a transformation of the constraint in for non-green agents provision, $x_u^t = \frac{(\tilde{X}/N) - \alpha x_g^t}{1-\alpha}$, leaves two equations and two unknowns. Cramer's Rule states that

$$\frac{dx_g^t}{d\alpha} = \frac{|\Lambda_{1,\alpha}|}{|H|}, \quad \frac{d\tau}{d\alpha} = \frac{|\Lambda_{2,\tau}|}{|H|} \tag{17}$$

Where H is the hessian of the system and $\Lambda_{n,\phi}$ is the hessian with the n^{th} column replaced with the negatives of the first order condition derivatives with respect to the parameter ϕ.

$$H = \begin{pmatrix} \frac{\partial FOC_g}{\partial x_g^t} & \frac{\partial FOC_g}{\partial \tau} \\ \frac{\partial FOC_u}{\partial x_g^t} & \frac{\partial FOC_u}{\partial \tau} \end{pmatrix} = \begin{pmatrix} -h''(x_g^t) & 1 \\ h''(x_g^t)\frac{\alpha}{1-\alpha} & 1 \end{pmatrix} \tag{18}$$

By inspection, the determinant of the hessian H is negative. Further, $\Lambda_{1,\alpha}$ and $\Lambda_{2,\tau}$ are respectively

$$\Lambda_{1,\alpha} = \begin{pmatrix} 0 & 1 \\ h''(x_g^t)\frac{(\tilde{X}/N)-x_g^t}{(1-\alpha)^2} & 1 \end{pmatrix} \quad \Lambda_{2,\tau} = \begin{pmatrix} -h''(x_g^t) & 0 \\ h''(x_g^t)\frac{\alpha}{1-\alpha} & h''(x_g^t)\frac{(\tilde{X}/N)-x_g^t}{(1-\alpha)^2} \end{pmatrix} \tag{19}$$

Noting that $\tilde{X}/N < x_g^t$ by Proposition 4, by inspection $|\Lambda_{1,\alpha}| > 0$ and $|\Lambda_{2,\tau}| > 0$ implying that $\frac{dx_g^t}{d\alpha} < 0$ and $\frac{d\tau}{d\alpha} < 0$ giving the desired result.

Corollary 3: The provision of green agents in the case of price instruments, x_g^t, is increasing and the price instrument/subsidy needed to attain a given level of public good provision, τ, is decreasing in the strength of the green preference, $\tilde{V}$.

Equilibrium in the case of price instruments is given by equations (13) and (14) above in addition to the level constraint: $\tilde{X} = \alpha N x_g^t + (1-\alpha)N x_u^t$. Substituting a transformation of the constraint in for non-green agents provision, $x_u^t = \frac{(\tilde{X}/N)-\alpha x_g^t}{1-\alpha}$, leaves two equations and two unknowns. Cramer's Rule states that

$$\frac{dx_g^t}{d\tilde{V}} = \frac{|\Lambda_{1,\tilde{V}}|}{|H|}, \quad \frac{d\tau}{d\tilde{V}} = \frac{|\Lambda_{2,\tilde{V}}|}{|H|}, \tag{20}$$

Where H is the hessian of the system and $\Lambda_{n,\phi}$ is the hessian with the n^{th} column replaced with the negatives of the first order condition derivatives with respect to the parameter ϕ. By Corollary 2, $|H| < 0$. Further $|\Lambda_{1,\tilde{V}}|$ and $|\Lambda_{2,\tilde{V}}|$ are defined as

$$\Lambda_{1,\tilde{V}} = \begin{pmatrix} -f'(\tilde{X}) & 1 \\ 0 & 1 \end{pmatrix} \quad \Lambda_{2,\tilde{V}} = \begin{pmatrix} -h''(x_g^t) & -f'(\tilde{X}) \\ h''(x_g^t)\frac{\alpha}{1-\alpha} & 0 \end{pmatrix} \tag{21}$$

By inspection, $|\Lambda_{1,\tilde{V}}| < 0$ and $|\Lambda_{2,\tilde{V}}| > 0$. Therefore $\frac{dx_g^t}{d\tilde{V}} > 0$ and $\frac{d\tau}{d\tilde{V}} < 0$ giving the desired result.

Proposition 5: For any level of regulated public goods provision $\tilde{X}$ such that the standard binds of all agents, $\frac{\tilde{X}}{N} \geq \hat{x}_g$, the difference in welfare between the two policies, Δ_{ts}, is single peaked in the percentage of green agents, α.

This proof proceeds by construction. We first show that the limit of the total derivative of the difference, Δ_{ts}, is positive as $\alpha \to 0^+$ and negative as $\alpha \to 1^-$. We then show that the partial derivative of the difference between the policies, Δ_{ts}, is positive. We can define Δ_{ts} as

$$\Delta_{ts} = \alpha N \int_{\frac{\tilde{X}}{N}}^{x_g^t} h'(x)dx - (1-\alpha)N \int_{x_u^t = \frac{\frac{\tilde{X}}{N} - \alpha N}{1-\alpha}}^{\frac{\tilde{X}}{N}} h'(x)dx \tag{22}$$

The total derivative of equation (22) can be found using Leibniz Rule:

$$\begin{aligned} \frac{d\Delta_{ts}}{d\alpha} = N \int_{\frac{\tilde{X}}{N}}^{x_g^t} h'(x)dx + \alpha N \left(M h'(x_g^t) \right) + N \int_{x_u^t = \frac{\frac{\tilde{X}}{N} - \alpha N}{1-\alpha}}^{\frac{\tilde{X}}{N}} h'(x)dx \\ -(1-\alpha)N \left(-M \frac{(\tilde{X}/N) - x_g^t}{(1-\alpha)^2} h' \left(\frac{(\tilde{X}/N) - \alpha x_g^t}{1-\alpha} \right) \right) \end{aligned} \tag{23}$$

$$M \equiv \frac{(h''(x_u^t)\frac{\tilde{X}}{N} - x_g^t)/((1-\alpha)^2)}{h''(x_g^t) + \frac{\alpha}{1-\alpha} h''(x_u^t)} \tag{24}$$

Note that $M < 0$ for any α and consider $lim_{\alpha \to 0^+}$. The terms with the intergrals converge to zero leaving only the terms multipling M. The first term goes to zero and by Proposition 4, the second term is positive signing $lim_{\alpha \to 0^+} > 0$. Similarly, $lim_{\alpha \to 1^-}$ is sign by the first term multiplying M which is positive signing $lim_{\alpha \to 1^-} < 0$. Finally, the partial derivative of Δ_{ts} is

$$\frac{\partial \Delta_{ts}}{\partial \alpha} = N \int_{\frac{\tilde{X}}{N}}^{x_g^t} h'(x)dx + N \int_{x_u^t = \frac{\frac{\tilde{X}}{N} - \alpha N}{1-\alpha}}^{\frac{\tilde{X}}{N}} h'(x)dx - (1-\alpha)N \left(-M \frac{(\tilde{X}/N) - x_g^t}{(1-\alpha)^2} h' \left(\frac{(\tilde{X}/N) - \alpha x_g^t}{1-\alpha} \right) \right) \tag{25}$$

By inspection, equation (25) is positive completing the proof.

Corollary 4: For any level of regulated public goods provision $\tilde{X}$ such that the standard binds for all agents, $\frac{\tilde{X}}{N} \geq \hat{x_g}$, the difference in welfare between the two policies, Δ_{ts}, is always increasing in the strength of the green preference, $\tilde{V}$.

This proof proceeds by construction. We show that the total derivative of the difference, Δ_{ts}, is everywhere greater than zero. Again using Leibniz rule and simplying we find

$$\frac{d\Delta_{ts}}{d\tilde{V}} = \alpha N \frac{dx_g^t}{d\tilde{V}} \left(h'(x_g^t) - h' \left(\frac{\frac{\tilde{X}}{N} - \alpha N}{1-\alpha} \right) \right) \tag{26}$$

By Proposition 4, Corollary 3, and convexity of $h(\cdot)$, equation (26) is positive, giving the desired result.

Proposition 6: There is an asymmetric price instrument profile which leads to efficient provision of any level of public goods, $\tilde{X}$, in which the subsidy for non-greens, τ_u, is strictly larger than the subsidy for greens, τ_g.

PROOF: There are four conditions which must be jointly satisfied in order to have efficient public good provision with an asymmetric price instrument profile. By Propisition 1 and Proposition 2, these conditions are

$$\begin{aligned}
h'(x_g^t) &= \tau_g + \tilde{V} f'(\tilde{X}) \\
h'(x_u^t) &= \tau_u + f'(\tilde{X}) \\
\tilde{X} &= \alpha N x_g^t + (1-\alpha) N x_u^t \\
h'(x_g^t) &= h'(x_u^t)
\end{aligned}$$

Substituting in, we get the condition $\tilde{V} f'(\tilde{X}) + \tau_g = f'(\tilde{X}) + \tau_u$. Rearranging gives $(V-1) f'(\tilde{X}) = \tau_u - \tau_g$. By assumption, $V > 1$ and $f'(\cdot) > 0$ giving the desired result.

Proposition 7: In the case of asymmetric costs, the amount of public good provided by greens is falling in the marginal cost of their abatement relative to non-greens. The (uniform) subsidy needed to reach any level of public goods provision is rising in the marginal cost of their abatement.

PROOF: This proof proceeds by construction and is similar to Corollary 2. Using the same notation as in Corollary 2:

$$\frac{dx_g^t}{d\delta} = \frac{|\Lambda_{1,\alpha}|}{|H|}, \quad \frac{d\tau}{d\delta} = \frac{|\Lambda_{2,\tau}|}{|H|} \tag{27}$$

These matrices are defined as:

$$H = \begin{pmatrix} \frac{\partial FOC_g}{\partial x_g^t} & \frac{\partial FOC_g}{\partial \tau} \\ \frac{\partial FOC_u}{\partial x_g^t} & \frac{\partial FOC_u}{\partial \tau} \end{pmatrix} = \begin{pmatrix} -h''(x_g^t)\delta & 1 \\ h''(x_g^t)\frac{\alpha}{1-\alpha} & 1 \end{pmatrix} \tag{28}$$

By inspection, the determinant of the hessian H is negative. Further, $\Lambda_{1,\delta}$ and $\Lambda_{2,\delta}$ are respectively

$$\Lambda_{1,\delta} = \begin{pmatrix} -h'(x_g^t) & 1 \\ 0 & 1 \end{pmatrix} \qquad \Lambda_{2,\delta} = \begin{pmatrix} -h''(x_g^t)\delta & -h'(x_g^t) \\ h''(x_g^t)\frac{\alpha}{1-\alpha} & 0 \end{pmatrix} \tag{29}$$

By inspection, the determinants of $\Lambda_{1,\delta}$ and $\Lambda_{2,\delta}$ are positive and negative respectively. As a result, using Cramer's rule, $\frac{dx_g^t}{d\delta} < 0$ and $\frac{d\tau}{d\delta} > 0$ giving the desired result.

Proposition 8: In the case of asymmetric costs, a uniform price instrument is more efficient than in the symmetric costs case as long as green agents' costs of abatement are negatively correlated with the strength of their green preferences, subject to one regularity condition.

PROOF: We can define the equation (22) analog very for this model as

$$\Delta_{ts} = \alpha N(1+\delta)\int_{\frac{\tilde{X}}{N}}^{x_g^t} h'(x)dx - (1-\alpha)N\int_{x_u^t = \frac{\frac{\tilde{X}}{N} - \alpha x_g^t}{1-\alpha}}^{\frac{\tilde{X}}{N}} h'(x)dx \tag{30}$$

By inspection, $\frac{\partial \Delta_{ts}}{\partial \delta} > 0$. However, accounting for indirect effects as in Proposition 5 we take the total derivative use Leibnitz rule:

$$\frac{d\Delta_{ts}}{d\delta} = \alpha N\int_{\frac{\tilde{X}}{N}}^{x_g^t} h'(x)dx + \alpha N\frac{dx_g^t}{d\delta}\left(h'(x_g^t) - h'(x_u^t) + \delta h'(x_g^t)\right) \tag{31}$$

By inspection, the direct effect is still positive but the indirect effect operates in the other direction since $\frac{dx_g^t}{d\delta} < 0$ from Proposition 7. The net effect, though is still positive as long as

$$\frac{h(x_g^t) - h\left(\frac{\tilde{X}}{N}\right)}{-\frac{dx_g^t}{d\delta}h'(x_g^t)} > 1+\delta. \tag{32}$$

This is a regularity condition ensuring that the green agents do not have a marginal cost of abatement curve that is so high they provide less of the public good than non-green

agents. This concludes the proof.

Appendix B

This appendix shows equivalence between the model used in this paper and a model with a linear budget constraint but decreasing marginal utility with respect to the private good.

The utility and budget specification in this paper are represented as

$$\begin{aligned} U_i(c_i, X|\Theta) &= c_i + \tilde{V} f_i(X) \\ & \qquad s.t. \;\; y_i = c_i + h(x_i) \\ \Rightarrow U_i(c_i, X|\Theta) &= y_i - h(x_i) + \tilde{V} f_i(X) \end{aligned}$$

As shown above, the first order condition of the consumer's problem is

$$h'(x_i^*) \geq \tilde{V} f'(X^*) \;\; \forall \, i \tag{33}$$

The function $h'(x_i^*)$ is the first derivative of a convex function.

It is possible to use a linear budget constraint with decreasing marginal utility of the numeraire consumption good. Assume that utility derived from the numeraire consumption good is described by a concave function $\nu(c)$, $\nu'(c) > 0$, and $\nu''(c) < 0$. The consumer's choice problem can then be expressed as

$$\begin{aligned} U_i(c_i, X|\Theta) &= \nu(c_i) + \tilde{V} f_i(X) \\ & \qquad s.t. \;\; y_i = c_i + p_x x_i \\ \Rightarrow U_i(c_i, X|\Theta) &= \nu(y_i - p_x x_i) + \tilde{V} f_i(X) \end{aligned} \tag{34}$$

Now consider the private equilibrium of the consumer given the model in equation (34). The consumer's first order condition is

$$- p_x \nu'(y_i - p_x x_i) \geq \tilde{V} f_i'(X) \tag{35}$$

with equality if $x_i > 0$. The left hand side of the consumer's first order condition in equation (35) is the opportunity cost of spending additional resources on purchase of the public good. Specifically, $-p_x\nu'(y_i - p_x x_i)$ can be evaluated as a function of x_i in equilibrium as opposed to a function of c_i. If $\nu(c_i)$ is concave and increasing in c_i then by definition it is concave and decreasing in x_i. Further, $-p_x\nu'(y_i - p_x x_i)$ is increasing in x_i. Figure 6 shows this relationship visually.

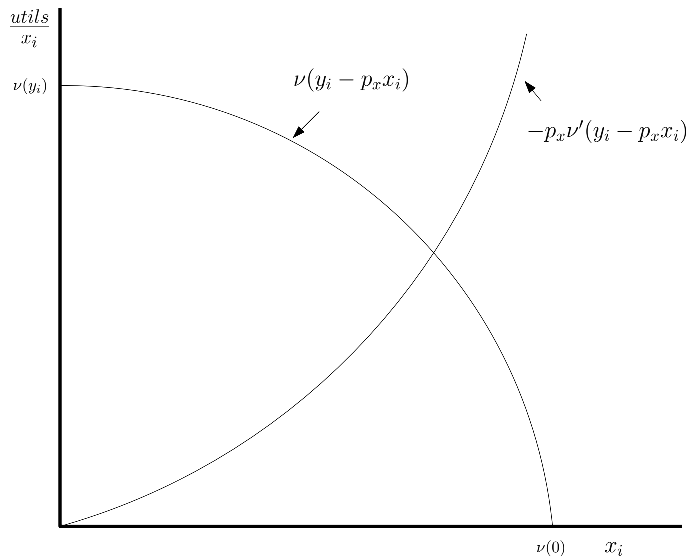

Figure 6: Equivalence of Alternative Utility Specification

Importantly, the left hand side of equations (33) and (35) are both increasing functions of the arguments x_i. As a result, equilibrium in these models will be equivalent. For example, the proof of Proposition 1 under this alternative specification is as follows:

Proposition 1: Green agents always provide more of the public good than non-green agents.

PROOF: By definition, $\tilde{V}$ is strictly larger for greens than non-greens. Private equilibrium provision for greens, $\hat{x_g}$, and non-greens, $\hat{x_u}$, are implicitly defined by the following system of equations:

$$-p_x\nu'(y_i - p_x\hat{x_g}) = \tilde{V}f'(\alpha N\hat{x_g} + (1-\alpha)N\hat{x_u}) \tag{36}$$

$$-p_x\nu'(y_i - p_x\hat{x_u}) = f'(\alpha N\hat{x_g} + (1-\alpha)N\hat{x_u}) \tag{37}$$

Since $\tilde{V} > 1$ it must be that $\hat{x_g} > \hat{x_u}$ since $-p_x\nu'(y_i - p_x\hat{x_g})$ is increasing in x_i giving the desired result.