Green Markets and Private Provision of Public Goods

by

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Abstract

This paper develops a general model of private provision of a public good that includes the option to consume an impure public good. I use the model to investigate positive and normative consequences of "green markets." Green markets give consumers a new choice: instead of simply consuming a private good and making a donation to an environmental public good, consumers can purchase an impure public good that produces characteristics of both activities jointly. Many governments, nongovernmental organizations, and industries promote green markets as a decentralized mechanism of environmental policy. Nevertheless, I show that under quite reasonable assumptions, green markets can have detrimental effects on both environmental quality and social welfare. I then derive conditions that are sufficient to rule out such unintended consequences. The analysis applies equally to non-environmental choice settings where the joint products of an impure public good are also available separately. Such choice settings are increasingly prevalent in the economy, with impure public goods ranging from socially-responsible investments to commercial activities associated with charitable fund-raising.

JEL Classification Numbers: D6, H4, Q2.

1 Introduction

The economics literature on private provision of public goods has grown extensively over the last 25 years. The general assumption of theoretical research in this area is that individuals choose between consumption of a private good and contributions to a pure public good.[1] Models based on this assumption establish the essential foundation for understanding privately provided public goods. Yet individuals increasingly face a third option: consumption of impure public goods that generate private and public characteristics as a joint product. This paper addresses fundamental questions about how the option to consume impure public goods affects private provision and social welfare.

Markets for "environmentally-friendly" goods and services exemplify the increased availability of impure public goods in the economy. The distinguishing feature of these markets—hereafter referred to as "green markets"—is availability of impure public goods (i.e., green goods) that arise through joint production of a private good and an environmental public good. Consider two particular examples. First is the growing market for "green electricity," which is electricity generated with renewable sources of energy. Typically, consumers voluntarily purchase green electricity with a price premium that applies to all or part of their household's electricity consumption. In return, production of green electricity displaces pollution emissions from electricity generated with fossil fuels. Thus, consumers of green electricity purchase a joint product—electricity consumption and reduced emissions.[2] The second example is the market for price-premium, shade-grown coffee, which is coffee grown under the canopy of tropical forests rather than in open, deforested fields. Shade-grown coffee plantations provide important refuges for tropical biodiversity, including migratory birds. Thus, consumers of shade-grown coffee also purchase a joint product—coffee consumption and biodiversity conservation.[3]

More generally, green markets are expanding in many sectors of the economy in response to

[1] Standard treatments can be found in Bergstrom, Blume, and Varian (1986), Andreoni (1988), and Cornes and Sandler (1996).

[2] More than 80 public utilities in 28 states have developed voluntary green-electricity programs for their customers. Furthermore, green electricity is increasingly an option in states with competitive electricity markets. See Swezey and Bird (2000) for a status report on green electricity in the United States.

[3] Estimates of market revenues for shade-grown coffee are $30 million per year in the United States, and projections of domestic-market potential exceed $100 million (Commission for Environmental Cooperation, 1999). See Perfecto *et al.* (1996) and Tangley (1996) for more on the environmental benefits of shade-grown coffee.

a willingness to pay premiums for goods and services with environmental benefits. According to market research in the United States, green products account for approximately 9 percent of all new-product introductions in the economy (Marketing Intelligence Service, 1999). Furthermore, expansion of green markets worldwide has prompted green certification, or "eco-labeling," programs that cover thousands of products in more than 20 countries (U.S. EPA, 1993; OECD, 1997). Contributing to these trends is the fact that many governments, nongovernmental organizations, and industries promote green markets as a decentralized mechanism to encourage private provision of environmental public goods.

Beyond green markets, it is now common to see joint products with private and public characteristics of various types. In many cases, firms simply donate a percentage of their profits to a charitable cause. This practice ranges from goods such as cosmetics and ice cream to services such as credit cards and long-distance telecommunication. Furthermore, many charitable and nonprofit organizations finance their activities, in part, through the sale of private goods, such as theater tickets or magazine subscriptions.[4] Finally, opportunities for "socially-responsible" investing combine a positive externality with investment return.[5] In each of these examples, the joint product forms an impure public good—with private and public characteristics.

In this paper, I develop a general model of private provision of a public good that includes the option to consume an impure public good. Building on the characteristics approach to consumer behavior (Lancaster, 1971; Gorman, 1980), I assume individuals derive utility from characteristics of goods rather than goods themselves. Individuals have the opportunity to consume a private good and make a contribution to a pure public good, with each activity generating its own characteristic. Additionally, the same private and public characteristics are available jointly through consumption of an impure public good.

The distinguishing feature of the model is the way that characteristics are available through more than one activity. As noted above, the standard pure public good model has only a private good and a pure public good. In the standard impure public good model, Cornes and Sandler

[4] A recent study of the United States nonprofit sector finds that commercial activities account for approximately 54 percent of all fund-raising (Salamon, 1999). Posnett and Sandler (1986) analyze particular aspects of this approach to fund-raising.

[5] Investment portfolios based on some criteria of social responsibility have doubled in value from \$1.185 trillion in 1997 to \$2.16 trillion in 1999 (Social Investment Forum, 1999).

(1984, 1994) assume the private and public characteristics of the impure public good are not available through any other means. Vicary (1997, 2000) extends their basic setup to enable provision of the public characteristic through donations, but again, the private characteristic of the impure public good is otherwise unavailable. In contrast, the model developed here applies when both characteristics of the impure public good are also available separately, through a private good and a pure public good.

This generalization of the choice setting enables broad application of the model. In the context of green markets—the application I focus on throughout this paper—the model captures the fact that individuals typically have three relevant choices: a conventional (pure private) good, a direct donation to an environmental (pure public) good, and a green (impure public) version of the good that jointly provides characteristics of the other two choices. For example, consumers of green electricity have options to purchase conventional electricity and donate directly to reduce emissions. Similarly, consumers of shade-grown coffee have options to purchase regular coffee and make donations to conserve tropical biodiversity.[6]

After establishing the basic model, I focus the analysis on three key questions. Will green markets actually lead to improvements in environmental quality? How will green markets affect social welfare? And how does the potential for induced changes in both environmental quality and social welfare depend on a green market's size? I then consider extensions of the model involving alternative green technologies and the possibility for "warm-glow," or "joy-of-giving," motives for private provision of public goods.

Several results are quite striking. Despite the intent of green markets to improve environmental quality, I show that under reasonable assumptions, introducing a green market may actually discourage private provision of an environmental public good. Furthermore, introducing a green market may diminish social welfare—even though it expands the choice set over market goods and the production possibilities over characteristics. If, however, a green market is sufficiently large, or environmental quality is a gross complement for private consumption, these counterintuitive results are no longer possible. Overall, the analytical results have implications for public policy

[6] Many nongovernmental organizations provide opportunities for donations to specific environmental causes. For example, the Clean Air Conservancy focuses on reducing air pollution emissions, and Rainforest Alliance focuses on conserving tropical biodiversity.

related to the role of green markets as a mechanism to improve environmental quality. The findings also apply generally to questions about how increased availability of impure public goods affects private provision and social welfare.

The remainder of this paper proceeds as follows. Section 2 introduces the basic model and analyzes individual behavior. Section 3 describes properties of the Nash equilibrium. For comparison purposes, Section 4 considers the economy prior to introduction of a green market. Sections 5 and 6 compare the economy with and without the green market to analyze green-market effects on environmental quality and social welfare. Section 7 analyzes the influence of a green market's size, in terms of the number of individuals in the economy. Sections 8 and 9 extend the model to consider alternative green technologies and warm-glow motives for private provision. Section 10 summarizes the main conclusions.

2 The Model

Following the characteristics approach to consumer behavior (Lancaster, 1971; Gorman, 1980), individuals derive utility from characteristics of goods rather than goods themselves. Assume for simplicity there are two characteristics, X and Y. Characteristic X has properties of a pure private good, while characteristic Y satisfies the non-rival and non-excludable properties of a pure public good. We can interpret Y as environmental quality. There are n individuals in the economy, and they all have identical preferences.[7] Preferences are represented by a strictly increasing and strictly quasiconcave utility function

$$U_i = U\left(X_i, Y\right),$$

where X_i is individual i's private consumption of X, and Y is aggregate provision of environmental quality. Specifically, $Y \equiv \sum_{i=1}^{n} Y_i$, where Y_i is individual i's private provision.[8]

[7] Extending the model to incorporate heterogenous preferences is straightforward, but the extension only complicates notation with no change in the main results.

[8] Two things should be noted about the specification of preferences. First, individuals only care about private provision of Y, which is the focus of this paper. Utility functions could, of course, be modified to account for other sources of Y, such as naturally given levels of environmental quality and provision through public policy. Second, individuals care only about aggregate provision, and derive no "warm-glow" benefit from their own level

Each individual is endowed with exogenous wealth w_i, which can be allocated among three market activities: consumption of a conventional good c that generates characteristic X, a direct donation d to improve environmental quality Y, and consumption of a green (or impure public) good g that generates X and Y jointly. To simplify notation, choose units of c, d, and g such that one dollar buys one unit of each. Furthermore, choose units of X and Y such that one unit of c generates one unit of X, and one unit of d generates one unit of Y. Then let $\alpha > 0$ and $\beta > 0$ characterize the green technology such that one unit of g generates α units of X and β units of Y. Finally, assume the relationships between market goods and characteristics are determined exogenously and are known by all individuals.[9]

In order to ensure the most interesting case, whereby c, d, and g are all viable in the market, further assumptions about the green technology are necessary.

Assumption 1. *(i)* $\alpha < 1$, *(ii)* $\beta < 1$, *and* *(iii)* $\alpha + \beta > 1$.

This assumption implies that c is the most efficient way to generate only X (part i), d is the most efficient way to generate only Y (part ii), and g is the most efficient way to generate both X and Y (part iii). Therefore, depending on demand for characteristics, all three goods may be a viable alternative in the market.[10]

Consider the maximization problem for each individual under the assumption of Nash behavior. Individuals choose non-negative quantities of goods to solve

$$\begin{gathered}\max_{c_i, d_i, g_i} \; U(X_i, Y) \\ \text{subject to} \;\; X_i = c_i + \alpha g_i, \;\; Y = d_i + d_{-i} + \beta (g_i + g_{-i}), \\ \text{and} \;\; c_i + d_i + g_i = w_i,\end{gathered} \tag{P1}$$

where i subscripts indicate individual i's consumption, $d_{-i} \equiv \sum_{j \neq i} d_j$, and $g_{-i} \equiv \sum_{j \neq i} g_j$. The first two constraints follow from the choice of units and the green technology. The second con-

of provision. I extend the model in Section 9 to account for this possibility.

[9] This setup is similar to a standard linear-characteristics model (see Deaton and Muellbauer, 1980), except that characteristic Y is a pure public good. Cornes and Sandler (1984, 1994) and Vicary (1997, 2000) use the same approach to model impure public goods. The main difference here is that both characteristics of the impure public good are available separately as well, through a conventional private good and direct donations.

[10] In Section 8, I consider the implications of relaxing each part of Assumption 1.

straint also specifies the interrelationship of each individual's behavior. In particular, the Nash assumption implies that each individual takes d_{-i} and g_{-i} as given. The third constraint is a standard budget constraint.

Let $\hat{c}_i$, $\hat{d}_i$, and $\hat{g}_i$ denote individual i's demand for goods, each of which depends on the exogenous parameters $(w_i, \alpha, \beta, d_{-i}, g_{-i})$. Examination of the Kuhn-Tucker conditions for (P1) reveals the following: no individual will ever demand both $\hat{c}_i > 0$ and $\hat{d}_i > 0$. The intuition for this result is straightforward. Individuals choose market goods to obtain desired levels of X and Y at the lowest cost. By Assumption 1, g generates X and Y jointly at a lower cost than c and d separately. Therefore, an individual would never demand both $\hat{c}_i > 0$ and $\hat{d}_i > 0$, as she could always obtain more X_i and Y by increasing g_i and reducing c_i and d_i.

An alternative way to express the individual's problem is with implicit choices over characteristics. This transformation simplifies the 3-dimensional problem in goods space to a 2-dimensional problem in characteristics space. We have seen that not both $\hat{c}_i > 0$ and $\hat{d}_i > 0$; therefore, it is possible to write the budget constraint in (P1) as satisfying two separate inequality constraints: $c_i + g_i \leq w_i$ and $g_i + d_i \leq w_i$. One or both of these constraints will bind at an optimal solution. The first constraint will bind if $\hat{d}_i = 0$, and the second constraint will bind if $\hat{c}_i = 0$. With these corresponding zero conditions and the identities that $X_i = c_i + \alpha g_i$ and $Y_i = d_i + \beta g_i$, we can substitute c_i, d_i, and g_i out of the two inequality constraints. This yields the two budget constraints for the individual's problem with choices over X_i and private provision Y_i:

$$\begin{gathered}\max_{X_i, Y_i} \; U\left(X_i, Y_i + Y_{-i}\right) \\ \text{subject to } \; X_i + \varphi Y_i \leq w_i \;\text{ and }\; \gamma X_i + Y_i \leq w_i,\end{gathered} \tag{P2}$$

where $Y_{-i} \equiv d_{-i} + \beta g_{-i}$, $\varphi \equiv \frac{1-\alpha}{\beta}$, and $\gamma \equiv \frac{1-\beta}{\alpha}$. In the first constraint, $\varphi < 1$ represents the implicit price of Y in terms of X when the individual makes trade-offs between c and g. In the second constraint, $\gamma < 1$ represents the implicit price of X in terms of Y when the individual makes trade-offs between d and g.

Now, since Y_{-i} is exogenous in (P2), we can add φY_{-i} to both sides of the first constraint and

Y_{-i} to both sides of the second. This yields the individual's "full-income" budget constraints.[11] Then, (P2) is equivalent to the following maximization problem:

$$\max_{X_i, Y} U(X_i, Y)$$
$$\text{subject to } X_i + \varphi Y \leq w_i + \varphi Y_{-i}, \quad \gamma X_i + Y \leq w_i + Y_{-i}, \tag{P3}$$
$$\text{and } Y \geq Y_{-i},$$

where the final constraint requires individuals to choose a total level of environmental quality no less than the level provided by others.

Figure 1 shows the feasible set in characteristics space for problem (P3). The frontier is piecewise linear with a kink at point E, which is the allocation that arises if the individual purchases g only. The segment EM with slope $-\frac{1}{\varphi} < -1$ corresponds to potential allocations when the individual makes trade-offs between c and g (i.e., the first full-income budget constraint). The segment BE with slope $-\gamma > -1$ corresponds to potential allocations when the individual makes trade-offs between d and g (i.e., the second full-income budget constraint).[12]

We can now use (P3) to solve for each individual's demand for total environmental quality and their own level of private provision. Let $f(w_i, Y_{-i})$ denote individual i's demand for Y ignoring the inequality constraint $Y \geq Y_{-i}$. Then, with the inequality constraint, the individual's demand for total environmental quality can be written as

$$\hat{Y} = \max\{Y_{-i}, f(w_i, Y_{-i})\}. \tag{1}$$

Subtracting Y_{-i} from both sides yields the individual's level of private provision:

$$\hat{Y}_i = \max\{0, f(w_i, Y_{-i}) - Y_{-i}\}. \tag{2}$$

This equation states that individuals may free ride with $\hat{Y}_i = 0$, or provide a positive amount of environmental quality with $\hat{Y}_i = f(w_i, Y_{-i}) - Y_{-i}$.

[11] Full income refers to personal income plus the value of public-good "spillins" from provision by others. See Cornes and Sandler (1996) for more on full income, which is equivalent to Becker's (1974) concept of "social income."

[12] The dashed segment BM with slope -1 indicates the budget frontier when g is not available, and the individual makes trade-offs between c and y. This market scenario is discussed in Section 4.

Note that solving for $\hat{Y}_i$ is sufficient to identify demand for X_i and all three market goods. Satisfying both budget constraints implies

$$\hat{X}_i = \begin{cases} w_i - \varphi \hat{Y}_i & \text{if } \hat{Y}_i \leq \beta w_i \\ \frac{1}{\gamma}(w_i - \hat{Y}_i) & \text{if } \hat{Y}_i \geq \beta w_i. \end{cases}$$

It follows that if $\hat{Y}_i \leq \beta w_i$, the individual does not make a direct donation, in which case $\hat{d}_i = 0$, $\hat{g}_i = \frac{1}{\beta}\hat{Y}_i$, and $\hat{c}_i = w_i - \hat{g}_i$. However, if $\hat{Y}_i \geq \beta w_i$, the individual does not consume the conventional good, in which case $\hat{c}_i = 0$, $\hat{g}_i = \frac{1}{\alpha}\hat{X}_i$, and $\hat{d}_i = w_i - \hat{g}_i$.

3 Equilibrium

Each individual's best-response function in equation (2) fully specifies their equilibrium strategy. This strategy involves choosing a level of private provision $\hat{Y}_i$, where $0 \leq \hat{Y}_i \leq w_i$ and Y_{-i} is taken as given. A Nash equilibrium arises with any vector of private provision levels $(Y_1^*, Y_2^*, ..., Y_n^*)$ that satisfies $Y_i^* = \hat{Y}_i$ for all i with $Y_{-i} = \sum_{j \neq i} Y_j^*$. Brouwer's fixed-point theorem guarantees existence of at least one such equilibrium. This section goes on to identify a sufficient condition for uniqueness, and to solve for equilibrium levels of private provision for all individuals.

To begin, it is convenient to define two additional functions. Let $f_c(w_i + \varphi Y_{-i})$ denote individual i's demand for total Y that arises from solving (P3) with only the *first* budget constraint. Also, let $f_d(w_i + Y_{-i})$ denote individual i's demand for total Y that arises from solving (P3) with only the *second* budget constraint.[13] Now assume these functions satisfy the following conditions.

Assumption 2. *(Normality)* $0 < f_c'(\cdot) \leq \eta < \frac{1}{\varphi}$ *and* $0 < f_d'(\cdot) \leq \mu < 1$.

This assumption simply requires that both characteristics X and Y are normal: individuals want more of both when they have more full income. The parameters η and μ imply that the slope of each function is bounded away from $\frac{1}{\varphi}$ and 1, respectively.

Assumption 2 differs in an important way from the normality assumption in the standard model of private provision of a pure public good. The standard model makes no distinction

[13] Note that both functions are Engel curves with respect to full income and the corresponding implicit prices of X and Y.

between characteristics and goods, so the normality assumption applies to the private and public goods directly (see Bergstrom, Blume, and Varian, 1986). In contrast, Assumption 2 applies to characteristics and not goods. As a result, it can be shown that Assumption 2 requires normality of g, while there is no such requirement for c or d. This distinction is important in the context of green markets because it allows the possibility for c to be inferior. It is easy to envision scenarios in which more income induces less demand for the conventional version of a good.[14]

A consequence of Assumption 2 is a guarantee that best-response functions have slopes bounded within the interval $(-1, 0]$. To see this, rewrite equation (1) using our newly defined functions:

$$\hat{Y} = \max\left\{Y_{-i}, \min\left\{f_c\left(\cdot\right), \max\left\{\beta w_i + Y_{-i}, f_d(\cdot)\right\}\right\}\right\}. \tag{3}$$

The different terms in this expression correspond to different allocations on the individual's budget frontier in Figure 1. Demand for total environmental quality must always satisfy $\hat{Y} \geq Y_{-i}$. The quantity $\hat{Y}$ will equal $f_c(\cdot)$ on segment EM if and only if $Y_{-i} \leq f_c(\cdot) \leq \beta w_i + Y_{-i}$. Furthermore, $\hat{Y}$ will equal $f_d(\cdot)$ on segment BE if and only if $f_d(\cdot) \geq \beta w_i + Y_{-i}$, in which case $f_d(\cdot) < f_c(\cdot)$ by normality of Y.[15] Now subtracting Y_{-i} from both sides of (3), we can rewrite best-response functions in equation (2) as

$$\hat{Y}_i = \max\left\{0, \min\left\{f_c\left(\cdot\right) - Y_{-i}, \max\left\{\beta w_i, f_d(\cdot) - Y_{-i}\right\}\right\}\right\}. \tag{4}$$

With Assumption 2, the slope of this expression with respect to changes in Y_{-i} is clearly bounded within the interval $(-1, 0]$.

[14] For example, more income may induce less demand for conventional electricity (or conventional coffee) and more demand for green electricity (or shade-grown coffee).

[15] To see that $f_d(\cdot) \geq \beta w_i + Y_{-i}$ and normality of Y imply $f_d(\cdot) < f_c(\cdot)$, note that individual i has an endowment at $X_i = \alpha w_i$ and $Y = \beta w_i + Y_{-i}$. The value of this endowment, which is equivalent to full income, depends on the implicit prices of characteristics: $m_i(p_X, p_Y) = p_X \alpha w_i + p_Y(\beta w_i + Y_{-i})$. Demand for Y, ignoring the constraint $Y \geq Y_{-i}$, can be expressed as a function $\hat{Y}(p_X, p_Y, m_i(p_X, p_Y))$. Then, $f_d(\cdot) = \hat{Y}(\gamma, 1, m_i(\gamma, 1)) = \hat{Y}(1, \frac{1}{\gamma}, m_i(1, \frac{1}{\gamma}))$, where the second equality follows because demand is homogeneous of degree zero. It is also the case that $f_c(\cdot) = \hat{Y}(1, \varphi, m_i(1, \varphi))$. Writing the demand functions in this way, it is clear that the only difference between $f_d(\cdot)$ and $f_c(\cdot)$ is a decrease in p_Y from $\frac{1}{\gamma} > 1$ to $\varphi < 1$. A standard result of demand theory with endowment income is that if a good is normal and net demand is non-negative, a decrease in the good's own price results in strictly greater demand for the good (see Varian, 1992, p. 145). It follows that normality of Y and $f_d(\cdot) \geq \beta w_i + Y_{-i}$ imply $f_d(\cdot) < f_c(\cdot)$.

These bounds on best-response functions are sufficient for existence of a unique Nash equilibrium. Cornes, Hartley, and Sandler (1999) show this result for the standard pure and impure public good models. Their proof generalizes to the model developed here and is relied upon for the following proposition.

Proposition 1. *There exists a unique Nash equilibrium.*

With this result, let Y^* denote the equilibrium level of environmental quality. We can now solve for each individual's level of private provision Y_i^*.[16]

Proposition 2. *If Y^* is the equilibrium level of environmental quality with the green market, then there exist three critical levels of income $\underline{w} < \tilde{w} < \overline{w}$ such that for all i*

$$Y_i^* = \begin{cases} 0 & \text{if} \quad w_i \leq \underline{w} \\ \frac{1}{\varphi}\left(w_i - \underline{w}\right) & \text{if} \quad w_i \in \left(\underline{w}, \tilde{w}\right) \\ \beta w_i & \text{if} \quad w_i \in \left[\tilde{w}, \overline{w}\right] \\ w_i - \overline{w}\left(1-\beta\right) & \text{if} \quad w_i > \overline{w}, \end{cases}$$

where

$$\underline{w} \equiv f_c^{-1}\left(Y^*\right) - \varphi Y^*, \quad \tilde{w} \equiv \frac{\underline{w}}{\alpha}, \quad \text{and} \quad \overline{w} \equiv \frac{f_d^{-1}(Y^*) - Y^*}{1-\beta}.$$

The different possibilities in Proposition 2 have an intuitive interpretation in terms of demand for market goods. Individuals with sufficiently low income ($w_i \leq \underline{w}$) free ride and purchase only the conventional good c. All individuals with greater income provide positive amounts of environmental quality, and their level of provision increases with income. Among these individuals, those with lower income ($w_i \in (\underline{w}, \tilde{w})$) continue purchasing c and provide environmental quality through purchases of the green good g. They spend all their income above $\underline{w}$ on private provision and face a price of φ for Y, which implies $Y_i^* = \frac{1}{\varphi}\left(w_i - \underline{w}\right)$. As income increases, these individuals substitute away from c and toward more g. Eventually, individuals with higher income ($w_i \in [\tilde{w}, \overline{w}]$) begin to purchase g only, which implies $Y_i^* = \beta w_i$. Finally, individuals with the highest income ($w_i > \overline{w}$) continue purchasing g and provide further environmental quality through direct

[16] The Appendix includes a proof of Proposition 2, along with all other proofs not immediate from the text.

donations d. They spend all their income above $\overline{w}(1-\beta)$ on private provision and face a price of unity for Y, which implies $Y_i^* = w_i - \overline{w}(1-\beta)$.

The following definition establishes four convenient sets based on the different possibilities in Proposition 2, along with the corresponding demands for market goods.

Definition 1. *Individual i is in set*

$$\begin{array}{llll} F \text{ (free riders) if....} & \hat{c}_i > 0, & \hat{g}_i = 0, & \hat{d}_i = 0; \\ C \text{ (contributors) if..} & \hat{c}_i > 0, & \hat{g}_i > 0, & \hat{d}_i = 0; \\ G \text{ (greens) if..........} & \hat{c}_i = 0, & \hat{g}_i > 0, & \hat{d}_i = 0; \\ D \text{ (donors) if.........} & \hat{c}_i = 0, & \hat{g}_i > 0, & \hat{d}_i > 0. \end{array}$$

Using the interpretation of Proposition 2 above, it follows that $i \in F$ if and only if $w_i \leq \underline{w}$; $i \in C$ if and only if $w_i \in (\underline{w}, \tilde{w})$; $i \in G$ if and only if $w_i \in [\tilde{w}, \overline{w}]$, and $i \in D$ if and only if $w_i > \overline{w}$. Finally, note that these sets correspond to different loci on the individual's budget frontier in Figure 1. In particular, sets F, C, G, and D correspond to point M, the interior of segment EM, point E, and the interior of segment BE, respectively.

4 Model Without a Green Market

In order to analyze the effects of introducing a green market, we must compare the model in the previous section to a model of the economy without availability of the green good g. To capture this scenario, we can simply add a constraint to the preceding analysis. Specifically, assume $g_i = 0$ for all i.

Deriving the individual's problem in (P3) with this constraint yields the following:

$$\begin{gathered} \max_{X_i, Y} U(X_i, Y) \\ \text{subject to} \quad X_i + Y = w_i + Y_{-i} \quad \text{and} \quad Y \geq Y_{-i}. \end{gathered} \tag{P4}$$

In contrast to (P3), this problem has a single budget constraint, and implicit prices of X and Y are both unity. Referring back to Figure 1 and holding Y_{-i} constant, the frontier of the individual's budget set is the dashed segment BM, compared to BEM when g is available.

Maximization problem (P4) is equivalent to the standard model for private provision of a pure public good. In this case, each individual's optimal choice of total environmental quality can be written as

$$\check{Y} = \max\left\{Y_{-i}, q\left(w_i + Y_{-i}\right)\right\}, \tag{5}$$

where $q\left(w_i + Y_{-i}\right)$ indicates individual i's demand for Y in (P4) ignoring the constraint $Y \geq Y_{-i}$. Then, without the green market, the individual's private provision is

$$\check{Y}_i = \max\left\{0, q\left(w_i + Y_{-i}\right) - Y_{-i}\right\}. \tag{6}$$

Maintaining normality of X and Y implies $0 < q'(\cdot) \leq \varepsilon < 1$, which continues to guarantee existence of a unique Nash equilibrium through Proposition 1.[17]

We can now solve for each individual's equilibrium level of private provision without the green market. Let Y^+ denote the equilibrium level of environmental quality without availability of g. Invert $q(\cdot)$ in equation (5) and add Y_i^+ to both sides. Solving for private provision yields $Y_i^+ = w_i - q^{-1}\left(Y^+\right) + Y^+$ for an individual with positive provision. Define a critical level of income $w^+ \equiv q^{-1}\left(Y^+\right) - Y^+$. Then for the economy without the green market, the following proposition parallels Proposition 2.

Proposition 3. *If Y^+ is the equilibrium level of environmental quality without a green market, then there exists a critical level of income w^+ such that for all i*

$$Y_i^+ = \begin{cases} 0 & \text{if } \; w_i \leq w^+ \\ w_i - w^+ & \text{if } \; w_i > w^+. \end{cases}$$

This proposition states that if $w_i \leq w^+$, the individual provides no environmental quality and therefore free rides by consuming c only. If $w_i > w^+$, the individual spends all her income above w^+ on private provision, and since the price of Y is unity through donations d, it follows that $Y_i^+ = w_i - w^+$.

[17] See Bergstrom, Blume, and Varian (1986) for an alternative proof that relies on normality to guarantee existence and uniqueness of a Nash equilibrium in the pure public good model.

Together, Propositions 2 and 3 demonstrate the differences between private provision with and without a green market—or more generally, with and without an impure public good that satisfies Assumption 1. With the impure public good, there are three critical levels of income that distinguish between four potential sets of individuals: those who free ride, those who contribute through the impure public good, those who spend all their income on the impure public good, and those who make a donation. Without the impure public good, however, there is only one critical level of income that distinguishes between two potential sets of individuals: those who free ride, and those who make a donation.

5 Environmental Quality

We can now analyze green-market effects on environmental quality. The general perception is that introducing a green market will promote private provision of an environmental public good. This section demonstrates, however, that introducing a green market can actually decrease the privately provided level of environmental quality. Particular outcomes depend on the distribution of income, the green technology, and whether environmental quality is a gross complement (or substitute) for private consumption.

Let us begin with two simple examples that demonstrate the possibility for both an increase and a decrease in environmental quality. Assume the economy consists of two individuals with identical incomes $w_i = w$ and utility functions $U_i = X_i^\rho + Y^\rho$. Let $w = 100$ and $\rho = .3$. Without a green market, it is straightforward to show that the equilibrium is symmetric with $Y_i^+ = \frac{w}{3}$ and $Y^+ = 2Y_i^+ \cong 66.7$. This level of environmental quality serves as a reference point for the following examples that include a green market.

Example 1: The green technology is characterized by $\alpha = \beta = .6$. Solving for a fixed point that satisfies best-response functions in equation (4) implies $Y_i^* = \frac{\varphi^{r-1}w}{2+\varphi^r}$ for $i = 1, 2$, where $r \equiv \frac{\rho}{\rho-1}$. Then substituting in our numerical values, we have $Y^* = 2Y_i^* \cong 111.9$. Figure 2 illustrates this *increase* in environmental quality from Y^+ to Y^*.

Example 2: This example differs only with respect to the green technology, which now favors production of the private characteristic with $\alpha = .9$ and $\beta = .3$. Solving for a fixed point in this case implies $Y_i^* = \frac{w}{1+2\gamma^r}$ for $i = 1, 2$. With our numerical values, we have $Y^* = 2Y_i^* \cong 61$. Figure 3 illustrates this *decrease* in environmental quality from Y^+ to Y^*.

In order to gain an intuition for these examples, it is useful to think of introducing a green market as having two effects on each individual. First is a "*price effect*" from a change in the implicit prices of characteristics X and Y. Second is a "*spillin effect*" from a change in the level of environmental quality provided by others (Y_{-i}). Both effects contribute to changes in each individual's demand for Y, which then influences changes in the equilibrium level of environmental quality.

In Example 1, both the price effect and the spillin effect stimulate demand for Y. Both individuals move to set C and therefore face a lower relative price of Y ($\varphi < 1$). On its own, this price effect stimulates demand for Y, which encourages private provision. Then, increased provision by one individual generates a positive spillin effect for the other individual through an increase in Y_{-i}. This spillin effect further stimulates demand for Y because an increase in Y_{-i} increases full income, and Y is normal. Figure 2 demonstrates both the positive price effect (with the steeper slope of the binding segment of the new budget constraint) and the positive spillin effect (with $Y_{-i}^+ < Y_{-i}^*$). The overall result is an increase in the equilibrium level of environmental quality.

In contrast, Example 2 illustrates a case in which both the price effect and the spillin effect depress demand for Y. Individuals move to set D and therefore face a lower relative price of X ($\gamma < 1$). On its own, this price effect depresses demand for Y, since Y is a gross substitute for X in this example.[18] Then, as individuals begin to reduce their provision, spillins Y_{-i} are reduced as well. This negative spillin effect reduces full income, which further depresses demand for Y. Figure 3 demonstrates both the negative price effect (with the flatter slope of the binding segment of the new budget constraint) and the negative spillin effect (with $Y_{-i}^+ > Y_{-i}^*$). In this case, the overall result is a decrease in the equilibrium level of environmental quality.

These same intuitions apply to the following proposition, which generalizes the results of Examples 1 and 2.

[18] Note that $U_i = X_i^\rho + Y^\rho$ and $\rho \in (0, 1)$ implies X and Y are gross substitutes.

Proposition 4. *After introducing a green market, it will always be the case that*

(a) $Y^+ < Y^*$ *if provision comes from set* C *only;*

(b) $Y^+ > Y^*$ *if provision comes from set* D *only and* Y *is a gross substitute for* X.

This proposition states that with a green market, environmental quality will always increase if no individual makes a donation or purchases the green good only. Furthermore, environmental quality will always decrease if all individuals with positive provision make a donation with the green market, and environmental quality is a gross substitute for private consumption. The second result occurs because the green good induces individuals to reduce their donations and substitute toward more private consumption.

Considering parts (a) and (b) of Proposition 4, it is clear why introducing a green market will, in general, have an ambiguous effect on environmental quality. Availability of the green good changes the relative prices of characteristics. Price effects may then stimulate demand for environmental quality for some individuals, while depressing demand for others. That is, some individuals may move to set C, while others move to set D.[19] In such cases, the net effect on environmental quality, after accounting for spillin effects, is generally ambiguous.

It is important to recognize, however, that a negative price effect on demand for environmental quality is only possible if Y is a gross substitute for X, as in the previous examples. If, on the other hand, Y is a gross complement for X, a more general result is possible.

Proposition 5. *Environmental quality will always increase after introducing a green market (i.e.,* $Y^+ < Y^*$*) if environmental quality is a gross complement for private consumption.*

In this case, introducing a green market unambiguously stimulates demand for Y through the price effect. This induces some individuals to increase their private provision. A consequence of increased provision by some individuals may be crowding out of provision by others. Any crowding out, however, must be less than one-to-one because the increase in spillins further stimulates demand for Y. Therefore, the net effect on equilibrium environmental quality must be positive.

[19] These same possibilities arise for individuals moving to set G, as these allocations are simply corner solutions of sets C and D.

6 Social Welfare

We have seen the different ways a green market can affect environmental quality. But how will green markets affect social welfare? Availability of a green good expands each individual's choice set over market goods. The green technology also expands the production possibilities over characteristics. These facts suggest intuitively that green markets should increase social welfare. This section shows, however, that introducing a green market can either increase or decrease social welfare.[20]

The most straightforward case occurs if the green market increases both environmental quality and social welfare. Figure 2 provides an example. Environmental quality increases from Y^+ to Y^*, and utility increases from U_i^+ to U_i^* for both individuals. Returning to the notions of a price effect and a spillin effect from the previous section, it is clear in Figure 2 that both the lower price of Y and the increased spillins result in positive income effects. This, in turn, causes the increase in utility for both individuals.

Once again, the example in Figure 2 is representative of a more general result. We saw in Proposition 4 that with a green market, environmental quality will always increase if no individual makes a donation or purchases the green good only. The next proposition, which will be especially useful in Section 7, implies that social welfare must increase as well.

Proposition 6. *Introducing a green market will always increase social welfare if provision comes from set C only.*

The intuition for this result follows from the interpretation of Figure 2.

More generally, it is important to recognize that even when a green market increases environmental quality, social welfare need not increase. Introducing a green market may shift the burden of provision from one group of individuals to another, and despite a net increase in environmental quality, those individuals picking up the burden may become worse off. Figure 4 provides an example, with individuals 1 and 2 shown in different panels. Income differs between the two

[20] Note that with or without a green market, the equilibrium level of social welfare will fall short of the Pareto-efficient level. This is because, in both cases, individuals take no account of the external benefits of their own private provision of environmental quality. Therefore, conclusions about changes in social welfare are based on whether one inefficient equilibrium Pareto dominates another.

individuals with $w_1 < w_2$.[21] Without the green market, w_1 is low enough so that individual 1 free rides entirely on individual 2's provision. They enjoy utility levels U_1^+ and U_2^+. With the green market, individual 1 moves to set C and increases provision from zero to Y_1^*. Individual 2 moves to set D and decreases provision from Y_2^+ $(= Y^+)$ to Y_2^*. The net effect is an increase in environmental quality from Y^+ to Y^* and new levels of utility U_1^* and U_2^*. The important thing to note is that $U_1^+ > U_1^*$ and $U_2^+ < U_2^*$. That is, introducing the green market makes individual 1 worse off and individual two better off. Thus, neither equilibrium Pareto dominates, despite the fact that the green market increases environmental quality.[22]

Now consider situations in which the green market decreases the level of environmental quality. It is still possible for social welfare to increase, as Figure 3 demonstrates. Environmental quality decreases from Y^+ to Y^*, as private provision decreases from Y_i^+ to Y_i^* for both individuals. The decrease in spillins generates a negative income effect for both individuals. This, however, is more than offset by the positive income effect from the lower price of X that both individuals face. Thus, utility increases from U_i^+ to U_i^* for both individuals, despite the decrease in environmental quality.

The most counterintuitive possibility arises when introducing a green market actually decreases social welfare. Figure 5 provides an example.[23] Here again, environmental quality decreases, and the reduction in spillins generates a negative income effect for both individuals. In this case, however, the positive income effect from the lower price of X is not large enough to be offsetting. Therefore, utility declines from U_i^+ to U_i^* for both individuals, and the equilibrium without the green market Pareto dominates the equilibrium with it. This occurs despite the facts that with the green market, individuals have a broader choice set over market goods, and the green technology expands the production possibilities over characteristics.

As the contrast between indifference curves in Figures 3 and 5 suggests, the greater the marginal rate of substitution between X and Y the greater the possibility for a decrease in

[21] Parameter values for this simulation are $w_1 = 100$, $w_2 = 250$, $\alpha = .7$, $\beta = .4$, and $\rho = .4$. Environmental quality increases from $Y^+ = 125$ to $Y^* \cong 130.7$.

[22] It can be shown that this scenario is possible regardless of whether Y is a gross substitute or complement for X.

[23] Parameter values for this simulation are $w_i = 100$ for $i = 1, 2$, $\alpha = .95$, $\beta = .15$, and $\rho = .88$. Environmental quality decreases from $Y^+ \cong 66.7$ to $Y^* \cong 36.2$.

social welfare. In such cases, the substitution effect is large relative to the income effect from the change in implicit prices.

Finally, we can show that a decrease in environmental quality is necessary for a decrease in social welfare. A decrease in social welfare implies that every individual's environmental-quality spillin cannot increase. In particular, it must hold that $Y_{-i}^{+} \geq Y_{-i}^{*}$ for all i, with a strict inequality for at least one individual. This implies that $\sum_{i=1}^{n} Y_{-i}^{+} > \sum_{i=1}^{n} Y_{-i}^{*}$, or equivalently $(n-1) Y^{+} > (n-1) Y^{*}$, or $Y^{+} > Y^{*}$. In other words, a decrease in social welfare implies a decrease in environmental quality. Therefore, in cases when environmental quality actually increases, we are assured of the following.

Proposition 7: *All individuals cannot be worse off with a green market if it increases the level of environmental quality.*

7 Green Markets in a Large Economy

Prior research shows that group size influences equilibrium results for private provision of a pure public good (Chamberlin, 1974; McGuire, 1974; Andreoni, 1988; Cornes and Sandler, 1996), an impure public good (Cornes and Sandler, 1984), and direct donations when an impure public good is available (Vicary, 1997, 2000). These findings, along with the trend in efforts to expand green markets, suggest the importance of understanding how group size may influence green-market effects on environmental quality and social welfare. This section considers how green-market effects change as the number of individuals in the economy grows.

To begin, we can use Proposition 2 to identify two conditions that must hold in equilibrium. First, the equilibrium level of environmental quality with a green market must satisfy

$$Y^{*} = \sum_{w_i \in (\underline{w}, \tilde{w})} \tfrac{1}{\varphi} (w_i - \underline{w}) + \sum_{w_i \in [\tilde{w}, \overline{w}]} \beta w_i + \sum_{w_i > \overline{w}} [w_i - \overline{w} (1 - \beta)],$$

where the summands represent provision from individuals in sets C, G, and D, respectively. Second, the critical level of income $\underline{w}$ must satisfy $\underline{w} = \kappa (Y^{*})$, where $\kappa (Y^{*}) \equiv f_c^{-1} (Y^{*}) - \varphi Y^{*}$. Then taking the inverse of this expression yields $Y^{*} = \kappa^{-1} (\underline{w})$. Note that, by Assumption 2, the slope of this inverse function is positive and bounded from above.[24]

Now consider an economy with an arbitrary number of n individuals and a corresponding vector of endowments $(w_1, w_2, ..., w_n)$. Given the equilibrium level of environmental quality, denoted Y_n^*, we can write a function for average, private provision over all i:[25]

$$\begin{aligned} A_n &= \frac{1}{n}\left[\sum_{w_i \in (\underline{w}_n, \tilde{w}_n)} \tfrac{1}{\varphi}\left(w_i - \underline{w}_n\right) + \sum_{w_i \in [\tilde{w}_n, \overline{w}_n]} \beta w_i + \sum_{w_i > \overline{w}_n} \left[w_i - \overline{w}_n\left(1-\beta\right)\right]\right] \\ &= \frac{\kappa^{-1}\left(\underline{w}_n\right)}{n}, \end{aligned}$$

where $\underline{w}_n$, $\tilde{w}_n$, and $\overline{w}_n$ are determined by their definitions in Proposition 2 with Y_n^*. Assume the distribution of endowments is characterized by a continuous probability density function $h(w)$ with support $0 \leq w \leq w_{max}$. We can then increase the number of individuals in the economy by adding to the vector of endowments with random draws from $h(w)$. Then as n grows large and $n \to \infty$, average provision converges to

$$\lim_{n\to\infty} A_n = \int_{\underline{w}_\infty}^{\tilde{w}_\infty} \tfrac{1}{\varphi}\left(w - \underline{w}_\infty\right) h(w)\, dw + \int_{\tilde{w}_\infty}^{\overline{w}_\infty} \beta w h(w)\, dw + \int_{\overline{w}_\infty}^{w_{max}} \left[w - \overline{w}_\infty\left(1-\beta\right)\right] h(w)\, dw \quad (7a)$$

$$= 0, \quad (7b)$$

where $\underline{w}_n \to \underline{w}_\infty$, $\tilde{w}_n \to \tilde{w}_\infty$, and $\overline{w}_n \to \overline{w}_\infty$. The first equality follows by the law of large numbers. The second equality follows because $\underline{w}_n$ is bounded from above by w_{max}, which implies $\kappa^{-1}\left(\underline{w}_\infty\right)$ is finite.[26]

The following lemma identifies a necessary condition for equating (7a) and (7b).

Lemma 1. $\underline{w}_\infty = w_{max}$.

[24] Specifically, $\kappa^{-1}(w)$ satisfies $0 < \partial\kappa^{-1}(w)/\partial w \leq \frac{n}{1-\varphi\eta}$.

[25] This analytical approach is an extension of Andreoni's (1988) technique for the pure public good model.

[26] The easiest way to see that $\underline{w}_n \leq w_{max}$ for any size n is to recognize that normality of Y implies the wealthiest individual will always have positive provision. Then, there must be some w_i such that $\underline{w}_n < w_i \leq w_{max}$ for any size n, which implies $\underline{w}_n < w_{max}$.

This lemma implies that $\underline{w}_n \to w_{max}$ as $n \to \infty$. In words, the critical level of income that distinguishes between individuals who free ride and individuals who have positive provision converges to the maximum level of income in the economy.

The fact that $\underline{w}_n$ converges to w_{max} as the economy grows large has several important implications, which are summarized as follows.

Proposition 8. *If an economy has n individuals, a green market, and incomes distributed according to a continuous probability density function $h(w)$ with $0 \leq w \leq w_{max}$, then the following statements describe the economy as n increases to infinity:*

(a) Only the wealthiest individuals have positive provision;

(b) The proportion of individuals with positive provision decreases to zero;

(c) Total provision increases to a finite level $\kappa^{-1}(w_{max})$;

(d) Average provision decreases to zero;

(e) No individual makes a direct donation d;

(f) Only those who consume the green good g and the conventional good c have positive provision;

(g) Environmental quality is strictly greater than it would be without the green market;

(h) Social welfare is strictly greater than it would be without the green market.

To prove this proposition, we need only review results that have been shown previously. All individuals with $w_i \leq \underline{w}_n$ are free riders (by Proposition 2). Therefore, as $\underline{w}_n \to w_{max}$, only the wealthiest individuals provide environmental quality, and these individuals comprise a diminishing proportion, $1 - H(\underline{w}_n)$, of the population. By construction, $Y_n^* = \kappa^{-1}(\underline{w}_n)$, which is finite as $\underline{w}_n \to w_{max}$. Then by (7b), average provision decreases to zero. Since $\tilde{w}_n = \frac{\underline{w}_n}{\alpha}$ by definition, the fact that $\underline{w}_n \to w_{max}$ implies $\tilde{w}_n \to \frac{w_{max}}{\alpha} > w_{max}$. It follows that sets G and D are empty (by Proposition 2 and Definition 1). That is, no individual makes a donation d or purchases g only. But since provision must be positive for at least the wealthiest individual, provision must come from set C, which includes individuals who consume g and c. Then, since provision comes from set C only, both environmental quality and social welfare must be strictly greater than they would be without the green market (by Propositions 4a and 6).

While parts (a)-(d) of Proposition 8 mirror results of the pure public good model, parts (e)-(h) are novel. A key finding is that availability of a green good in a larger economy will tend to crowd out direct donations to improve environmental quality. This may explain, in part, why many nonprofit organizations are increasingly turning toward commercial activities for fund-raising. In large economies, where the incentive to free rider is greater, individuals with positive provision may tend to purchase impure public goods rather than make direct donations.[27] In such cases, the only consequence of introducing a green market is a decrease in the implicit price of providing the environmental public good. In a sufficiently large economy, therefore, introducing a green market unambiguously increases both environmental quality and social welfare.

8 Alternative Technologies

Thus far we have assumed a green technology that implies g is the most efficient way to generate both X and Y, while c and d remain the most efficient way to generate only X or Y, respectively. This condition, through Assumption 1, is sufficient to ensure viability of all three goods. But how do the effects of introducing a green market differ with alternative assumptions about the green technology? This section examines the effects of relaxing different parts of Assumption 1. We will see that the results are simply special cases of the preceding analysis.

Let us begin by relaxing part (i) of Assumption 1. Assuming $\alpha \geq 1$ implies a green technology such that obtaining X through g is weakly more efficient than through c. Compared to the conventional good, the green good also has the advantage of generating a positive amount of Y. It follows that introducing the green market will crowd out all consumption of the conventional good. With the green market, therefore, all individuals move to either set G or D. We have seen already how this situation—which reduces the price of X—can, in general, either increase or decrease environmental quality and social welfare. In a sufficiently large economy, however, the green-market effects are again unambiguous: both environmental quality and social welfare will increase. To show this, note that no individual is a complete free rider with the green market because there is no consumption of the conventional good. Therefore, Y_n^* does not converge to a finite level as $n \to \infty$. Since this is not the case without availability of g, environmental

[27] Vicary (1997) finds a similar result, but further assumptions are necessary in his model, due to the fact that individuals have no opportunity to obtain the private characteristic of the impure public good through other means.

quality must increase with the green market. Social welfare must then increase as well, because in addition to enjoying more Y, each individual's consumption of X_i cannot fall. This follows because each individual's minimum value of X_i with the green market (αw_i through consumption of g) is weakly greater than their maximum value of X_i without the green market (w_i through consumption of c).

We can now relax only part (ii) of Assumption 1 and use similar reasoning to understand the implications. A green technology with $\beta \geq 1$ implies that providing Y through g is weakly more efficient than through d. Since g also has the benefit of producing a positive amount of X, introducing the green market will crowd out all direct donations. Therefore, provision can come from sets C and G only, and the latter must be corner solutions of the former. In this case, it is straightforward to show that prior results for provision with only set C still apply. That is, introducing a green market will always increase both environmental quality and social welfare, regardless of the economy's size.[28]

Finally, consider the implications of relaxing part (iii) of Assumption 1. If $\alpha + \beta < 1$, individuals will never consume g, as they could always do better obtaining X and Y separately through c and d. In other words, the green technology is simply not viable. If, however, $\alpha + \beta = 1$, individuals will be indifferent between obtaining characteristics jointly through g and separately through c and d. This follows because the green technology is simply a bundling of characteristics that produces no change in the production possibilities. In this case, it can be shown that the mapping between characteristics and goods is no longer unique with the green market. There are an infinite number of Nash equilibria with respect to choices over market goods; however, every equilibrium supports the same levels of environmental quality and social welfare. These levels are also identical with and without the green market. Thus, green technologies that simply bundle characteristics and produce no change in the production possibilities will have no effect on environmental quality or social welfare.

[28] Note that if both $\alpha \geq 1$ and $\beta \geq 1$, the green technology renders both c and d inefficient ways to generate their respective characteristics. In this case, all individuals consume g only, and both environmental quality and social welfare will increase.

9 Warm Glow

This section considers one further extension of the model. The literature on privately provided public goods suggests that private provision may be motivated by more than concern about the aggregate level of the public good. Of particular relevance to the analysis of green markets is the notion of "warm-glow," or "joy-of-giving," motivations (Andreoni, 1989, 1990; Ribar and Wilhelm, 2002). In general, the idea is that individuals may derive a distinct private benefit from their own level of private provision.[29] In the context of the model developed here, the idea is that individuals may simply feel good about the act of improving environmental quality through green-good consumption, direct donations, or both. Drawing on the intuition from previous sections, we can show that incorporating warm-glow motives in the model changes little about the main results.

To capture warm-glow benefits of private provision, individual utility functions are specified as

$$U_i = U\left(X_i, Y, Y_i\right),$$

where U_i remains strictly increasing and strictly quasiconcave. Note that each individual's private provision Y_i enters their own utility function twice: once as part of aggregate provision, and again as a private benefit. In order to focus on the new feature of this setup, assume that $\lim_{Y_i \to 0} \frac{\partial U_i}{\partial Y_i} = \infty$. This Inada condition rules out the original setup as a special case.

Without a green market, the relationship between goods and characteristics implies that utility functions can be rewritten as

$$U_i = U\left(c_i, d_i + d_{-i}, d_i\right).$$

Maximizing this function subject to $c_i + d_i = w_i$ for all i is equivalent to the model analyzed by Andreoni (1990). In this case, continuing to assume X_i and Y are normal with respect to full income guarantees existence of a unique Nash equilibrium. Furthermore, the Inada condition implies that all individuals have an interior solution. That is, all individuals make a donation in order to obtain warm-glow benefits.

[29] Empirical support for this idea is found in research by Kingma (1989), Andreoni (1995), Palfrey and Prisbrey (1997), and Ribar and Wilhelm (2002).

Now consider how warm-glow motives change the basic setup of the model with a green market. Availability of g implies that utility functions can be rewritten as

$$U_i = U\left(c_i + \alpha g_i, d_i + d_{-i} + \beta\left(g_i + g_{-i}\right), d_i + \beta g_i\right).$$

All individuals maximize this function subject to $c_i + g_i + d_i = w_i$. With Assumption 1, it continues to hold that individuals will never set both $\hat{c}_i > 0$ and $\hat{d}_i > 0$. Furthermore, there continues to exist a unique Nash equilibrium.[30] Here again, the important difference with the warm-glow version of the model is that no individuals are complete free riders (i.e., set F is empty). In order to obtain warm-glow benefits, every individual will consume some of the green good and possibly make a donation.

What, then, are the effects of introducing a green market when warm-glow motives contribute to private provision of environmental quality? In general, the effects are identical to those shown previously. Green markets can either increase or decrease environmental quality and social welfare. This follows because individuals continue to face changes in the implicit prices of X_i and Y. The particular prices they face depend on whether they move to set C, G, or D. The only difference is that they all have positive demand for Y_i, which is simply a third characteristic with the same implicit price as Y.

In a large economy where $n \to \infty$, however, the effects of introducing a green market may differ somewhat with warm glow. Without warm glow, we saw that a green market will always increase both environmental quality and social welfare. With warm glow, we can show that a green market can increase or decrease environmental quality, but will always increase social welfare. The change in environmental quality is indeterminate because even as $n \to \infty$, demand for Y_i may be strong enough so that some individuals still move to set D, and thereby face a lower price for X. Then if Y_i is a gross substitute for X, nothing rules out the possibility for a decline in environmental quality. Surprisingly, this implies that stronger warm-glow motives increase the potential for adverse green-market effects on environmental quality. In contrast,

[30] Formally proving existence of a unique Nash equilibrium involves a bit of tedium, although the steps are identical to those in Section 3. Normality of characteristics is used to demonstrate that the continuous best-response functions have slopes bounded within (-1,0]. Then relying on Cornes, Hartley, and Sandler's (1999) result, this condition is sufficient to prove both existence and uniqueness.

warm-glow implies that social welfare will always increase because all individuals have positive provision, which implies $Y_n^* \to \infty$ as $n \to \infty$. Then, assuming that $\lim_{Y \to \infty} \frac{\partial U_i}{\partial Y} = 0$, which is another reasonable Inada condition, the change in utility from a marginal increase or decrease in environmental quality converges to zero for all individuals. Thus, after introducing a green market, the spillin effect on any individual's utility is approximately zero, while the price effect is always positive. The net result is an unambiguous increase in social welfare.

10 Conclusions

This paper analyzes a new choice setting for private provision of a public good. The model captures the reality that impure public goods are increasingly available in the economy. In contrast to existing models, the model developed here applies when the joint products of an impure public good are also available separately—through a private good and a pure public good. Many new results on privately provided public goods emerge from the model, along with its extensions involving various technology assumptions and warm-glow motives for provision.

I apply the model in particular to green markets, which offer impure public goods through joint production of a private characteristic and an environmental public characteristic. Green markets fit the model because in addition to the green good, consumers typically have opportunities to consume a conventional version of the good and to make a direct donation to the associated environmental cause. Increasingly, many governments, nongovernmental organizations, and industries promote green markets as a decentralized mechanism of environmental policy. Despite this trend, questions remain about the positive and normative consequences of introducing green markets. Three of these questions were posed at the outset of this paper. I return to these questions in order to highlight the important conclusions

Will green markets actually lead to improvements in environmental quality? In general, green markets that are based on an efficient technology will change the level of environmental quality. The surprising result is that green markets will not necessarily improve environmental quality. Introducing a green market changes implicit prices of both private consumption and the environmental public good. These price changes may encourage some individuals to provide more of the public good, while encouraging others to provide less. If environmental quality is a gross substitute for private consumption, introducing a green market can either increase or decrease environmental quality. If, however, environmental quality is a gross complement for private consumption, introducing a green market will always increase environmental quality. Therefore, it matters what characteristics are jointly produced in a green good. Finally, environmental quality will always increase if the green technology is such that improving environmental quality is more efficient through the green good than through direct donations.

How will green markets affect social welfare? The potential green-market effects on social welfare are also surprising: green markets can either increase or decrease social welfare. The most intuitive possibility is for a green market to increase both environmental quality and social welfare. This will always occur if the green good is more efficient than donations as a means to improve environmental quality. Even with an increase in environmental quality, however, situations may arise where some individuals become worse off. This follows because introducing a green market may shift the burden of provision from one set of individuals to another. If, on the other hand, the green market decreases environmental quality, the most surprising possibilities emerge. In this case, social welfare may still increase, due to substitution toward private consumption. Alternatively, social welfare may decrease—despite the facts that the green market expands both the choice set over market goods and the production possibilities over characteristics.

How does a green market's size influence its effects on environmental quality and social welfare? Several of these results are related to established theory on private provision of a pure public good. Without warm-glow motives, increasing the number of individuals in the economy implies that the proportion of individuals with positive provision decreases, only the wealthiest individuals provide, average provision decreases, and aggregate provision increases to a finite level. Several other results on the influence of a green market's size are new. When the number of potential participants in a green market increases, direct donations decrease, and the proportion of aggregate provision through the green market increases. Thus, green markets tend to crowd out direct donations to improve environmental quality. A further result is that in sufficiently large economies, the effects on environmental quality and social welfare are no longer ambiguous: introducing a green market increases both environmental quality and social welfare. This result, however, differs somewhat if provision is motivated, in part, with warm glow, in which case the green market's size has less influence on its potential effects.

In conclusion, the increased availability of impure public goods in the economy has both positive and normative consequences. In the context of green markets, this paper demonstrates how these consequences can be counterintuitive. Although green markets are promoted to improve environmental quality and increase social welfare, their actual effects may be detrimental to both. These results, along with the conditions sufficient to rule then out, provide new insight into the potential advantages and disadvantages of promoting green markets as a decentralized mechanism of environmental policy. The results also apply more generally to other situations, such as socially-responsible investing and charitable fund-raising through commercial activities, where the joint products of an impure public good are also available separately.

Appendix

Proof of Proposition 1

See Cornes, Hartley, and Sandler (1999).

Proof of Proposition 2

In equilibrium, equation (3) must hold with $Y^* = \hat{Y}$ for all i. If $Y^* = f_c(w_i + \varphi Y_{-i})$, invert $f_c(\cdot)$, add φY_i^* to both sides, and rearrange to get $Y_i^* = \frac{1}{\varphi}(w_i - \underline{w})$. If $Y^* = f_d(w_i + Y_{-i})$, invert $f_d(\cdot)$, add Y_{-i} to both sides, and rearrange to get $Y_i^* = w_i - \overline{w}(1-\beta)$. Substituting these expressions into equation (4) yields equilibrium private provision for all i:

$$Y_i^* = \max\left\{0, \min\left\{\tfrac{1}{\varphi}(w_i - \underline{w}), \max\{\beta w_i, w_i - \overline{w}(1-\beta)\}\right\}\right\}. \tag{A1}$$

With (A1), we can verify that $\underline{w} < \tilde{w} < \overline{w}$. By definition, $\underline{w} < \tilde{w}$ since $\tilde{w} = \frac{\underline{w}}{\alpha}$ and $\alpha < 1$. To show that $\tilde{w} < \overline{w}$, recall from equations (3) and (4) that if $f_d(w_i + Y_{-i}) - Y_{-i} \geq \beta w_i$ for any level of w_i, then $f_d(w_i + Y_{-i}) - Y_{-i} < f_c(w_i + \varphi Y_{-i}) - Y_{-i}$ by normality of Y. This implies in (A1) that if $w_i - \overline{w}(1-\beta) \geq \beta w_i$ for any level of w_i, then $w_i - \overline{w}(1-\beta) < \frac{1}{\varphi}(w_i - \underline{w})$. Simplifying the first inequality yields $w_i \geq \overline{w}$. Combining the first and second inequality and rearranging terms yields $w_i > \tilde{w}$. Then, to satisfy $w_i \geq \overline{w}$ and $w_i > \tilde{w}$ for any level of w_i, it must be true that $\tilde{w} < \overline{w}$.

With these critical levels of income, the different possibilities in Proposition 2 follow directly from (A1). In particular, $Y_i^* = 0$ if $w_i \leq \underline{w}$, $Y_i^* = \frac{1}{\varphi}(w_i - \underline{w})$ if $w_i \in (\underline{w}, \tilde{w})$, $Y_i^* = \beta w_i$ if $w_i \in [\tilde{w}, \overline{w}]$, and $Y_i^* = w_i - \overline{w}(1-\beta)$ if $w_i > \overline{w}$. Q.E.D.

Proof of Proposition 3

Immediate from the text.

Proof of Proposition 4

The following lemma is stated and proved first.

Lemma A1: *If* $q\left(w_i + Y'_{-i}\right) \geq Y'_{-i}$ *and* $q\left(w_i + Y''_{-i}\right) \geq f_c\left(w_i + \varphi Y''_{-i}\right)$*, then* $Y'_{-i} > Y''_{-i}$*.*

Proof: Starting with endowment income $X_i = w_i$ and $Y = Y'_{-i}$, the condition $q\left(w_i + Y'_{-i}\right) \geq Y'_{-i}$ implies that net demand for Y is non-negative with relative prices $p_X = p_Y = 1$. Then, changing relative prices so that $p_X = 1$ and $p_Y = \varphi$, demand for Y is given by $f_c\left(w_i + \varphi Y'_{-i}\right)$. Normality of Y implies $q\left(w_i + Y'_{-i}\right) < f_c\left(w_i + \varphi Y'_{-i}\right)$.[31] Then if $q\left(w_i + Y'_{-i}\right) \geq f_c\left(w_i + \varphi Y''_{-i}\right)$, it must be true that $Y'_{-i} > Y''_{-i}$. Q.E.D.

Part (a): Assume to the contrary that $Y^+ \geq Y^*$. Then for all i with $w_i > w^+$, which includes at least the wealthiest individual (by normality of Y), the following inequality must hold:

$$Y^+ = q\left(w_i + Y^+_{-i}\right) \geq \max\left\{Y^*_{-i}, f_c\left(w_i + \varphi Y^*_{-i}\right)\right\} = Y^*.$$

Then by Lemma A1, $Y^+_{-i} > Y^*_{-i}$ for all i with $w_i > w^+$.

Now let the notation $\hat{Y}\left(Y_{-i}\right)$ and $\check{Y}\left(Y_{-i}\right)$ serve as a shorthand for best response functions in (4) and (6), respectively. Then, it must hold for all i with $w_i > w^+$ that

$$Y_i^+ = \check{Y}_i\left(Y^+_{-i}\right) \leq \check{Y}_i\left(Y^*_{-i}\right) \leq \hat{Y}_i\left(Y^*_{-i}\right) = Y_i^*.$$

The first inequality follows because best response functions have slopes ≤ 0, and we have shown that $Y^+_{-i} > Y^*_{-i}$. The second inequality follows because a decrease in the price of Y (from 1 to $\varphi < 1$) must weakly increase demand for Y, holding Y_{-i} constant. If, however, $Y_i^+ \leq Y_i^*$ for all i with $w_i > w^+$, then it is not possible for $Y^+_{-i} > Y^*_{-i}$ for all i with $w_i > w^+$, since no individuals reduce their provision with the green market. Therefore, the assumption that $Y^+ \geq Y^*$ leads to a contradiction. It must then be true that $Y^+ < Y^*$, which proves part (a).

Part (b): Assume to the contrary that $Y^+ \leq Y^*$. Consider all i with $w_i > \overline{w}$, which includes at least the wealthiest individual (by normality of Y and the assumption that provision comes from set D only). Then for all such individuals, the following inequality must hold:

$$Y^+ = \max\left\{Y^+_{-i}, q\left(w_i + Y^+_{-i}\right)\right\} \leq f_d\left(w_i + Y^*_{-i}\right) = Y^*.$$

[31] See Varian (1992, p. 145) for further explanation of this point, which is a standard result of demand theory for a price change with endowment income.

This inequality implies that $Y_{-i}^{+} < Y_{-i}^{*}$ for all i with $w_i > \overline{w}$. This follows because the assumption that Y is a gross substitute for X implies $q\left(w_i + Y'_{-i}\right) > f_d\left(w_i + Y''_{-i}\right)$ for any $Y'_{-i} \geq Y''_{-i}$.

It must also hold for all i with $w_i > \overline{w}$ that

$$Y_i^{+} = \check{Y}_i\left(Y_{-i}^{+}\right) \geq \check{Y}_i\left(Y_{-i}^{*}\right) \geq \hat{Y}_i\left(Y_{-i}^{*}\right) = Y_i^{*}.$$

The first inequality follows because best response functions have slopes ≤ 0, and we have shown that $Y_{-i}^{+} < Y_{-i}^{*}$. The second inequality follows because the assumption that Y is a gross substitute for X implies that a decrease in the the price of X (from 1 to $\gamma < 1$) must weakly decrease demand for Y, holding Y_{-i} constant. The condition that $Y_i^{+} \geq Y_i^{*}$ for all i with $w_i > \overline{w}$ implies that all individuals with positive provision after introducing the green market had weakly greater provision before. Hence, it is not possible for $Y_{-i}^{+} < Y_{-i}^{*}$ for all i with $w_i > \overline{w}$, since by assumption, they are the only ones with positive provision with the green market. Therefore, the assumption that $Y^{+} \leq Y^{*}$ leads to a contradiction. It must then be true that $Y^{+} > Y^{*}$, which proves part (b). Q.E.D.

Proof of Proposition 5

This proof extends the proof of part (a) in Proposition 4. Assume to the contrary that $Y^{+} \geq Y^{*}$. Then for all i with $w_i > w^{+}$, which includes at least the wealthiest individual (by normality of Y), the following inequality must hold:

$$Y^{+} = q\left(w_i + Y_{-i}^{+}\right) \geq \max\left\{Y_{-i}^{*}, \min\left\{f_c\left(w_i + \varphi Y_{-i}^{*}\right), \max\left\{\beta w_i + Y_{-i}^{*}, f_d\left(w_i + Y_{-i}^{*}\right)\right\}\right\}\right\} = Y^{*}.$$

Then by Lemma A1, it must be the case that $Y_{-i}^{+} > Y_{-i}^{*}$ for all i with $w_i > w^{+}$.

It must also hold for all i with $w_i > w^{+}$ that

$$Y_i^{+} = \check{Y}_i\left(Y_{-i}^{+}\right) \leq \check{Y}_i\left(Y_{-i}^{*}\right) \leq \hat{Y}_i\left(Y_{-i}^{*}\right) = Y_i^{*}.$$

The first inequality follows because best response functions have slopes ≤ 0, and we have shown that $Y_{-i}^{+} > Y_{-i}^{*}$. The second inequality follows because Y is a gross complement for X, which implies that a decrease in the price of Y from (1 to $\varphi < 1$) or a decrease in the price of X from (1 to γ) must weakly increase demand for Y, holding Y_{-i} constant. The remainder of the proof is identical to part (a) of Proposition 4. Q.E.D.

Proof of Proposition 6

It is sufficient to show that $U\left(X_i^+, Y^+\right) < U\left(X_i^*, Y^*\right)$ for all i. We know from part (a) of Proposition 4 that $Y^+ < Y^*$. Therefore, we need only show that utility increases even if $X_i^+ > X_i^*$. Assume that $X_j^+ > X_j^*$ for some individual j. It must then be true that $w^+ > \underline{w}$ because $X_j^+ = w^+$ and $X_j^* = \underline{w}$. Then since $Y_{-j}^+ = \sum_{w_i > w^+}^{i \neq j} w_i - w^+$ and $Y_{-j}^* = \sum_{w_i > \underline{w}}^{i \neq j} \frac{1}{\varphi}\left(w_i - \underline{w}\right)$, it also follows that $Y_{-j}^+ \leq Y_{-j}^*$. Without the green market, optimization implies $X_j^+ + Y^* - Y_{-j}^* = w_j$. With the green market, optimization implies $X_j^* + \varphi(Y^* - Y_{-j}^*) = w_j$. Then since $Y_{-j}^+ \leq Y_{-j}^*$, we have that $X_j^+ + \varphi(Y^+ - Y_{-j}^*) < w_i$. Therefore, (X_j^*, Y^*) is strictly and directly revealed preferred to (X_j^+, Y^+) for any j with $X_j^+ > X_j^*$. It must then be true that $U\left(X_i^+, Y^+\right) < U\left(X_i^*, Y^*\right)$ for all i. Q.E.D.

Proof of Proposition 7

Immediate from the text.

Proof of Lemma 1

Suppose $\underline{w}_\infty \neq w_{max}$. If $\underline{w}_\infty > w_{max}$, then $\underline{w}_n$ converges to a value greater than the maximum level of income. It follows that $Y^* = 0$ for some n because $Y_i^* = 0$ for all i if $\underline{w}_n > w_{max}$. This, however, contradicts normality of Y, which requires positive provision from at least the wealthiest individual. Now suppose $\underline{w}_\infty < w_{max}$. Then there exists a number θ such that $\underline{w}_\infty < \theta < w_{max}$.

As $n \to \infty$, we will observe $w_i > \theta$ infinitely often. It follows that

$$\begin{aligned}
0 &< \int_{\min\{\theta,\tilde{w}_\infty\}}^{\tilde{w}_\infty} \tfrac{1}{\varphi}\left(w - \underline{w}_\infty\right) h(w)\, dw + \int_{\max\{\tilde{w}_\infty,\min\{\theta,\overline{w}_\infty\}\}}^{\overline{w}_\infty} \beta w h(w)\, dw \\
&\quad + \int_{\max\{\theta,\overline{w}_\infty\}}^{w_{max}} \left[w - \overline{w}_\infty (1-\beta)\right] h(w)\, dw \\
&\leq \int_{\underline{w}_\infty}^{\tilde{w}_\infty} \tfrac{1}{\varphi}\left(w - \underline{w}_\infty\right) h(w)\, dw + \int_{\tilde{w}_\infty}^{\overline{w}_\infty} \beta w h(w)\, dw + \int_{\overline{w}_\infty}^{w_{max}} \left[w - \overline{w}_\infty (1-\beta)\right] h(w)\, dw \\
&= 0.
\end{aligned}$$

The last equality follows by equality of (7a) and (7b) and leads to a contradiction. Therefore, since both $\underline{w}_\infty > w_{max}$ and $\underline{w}_\infty < w_{max}$ lead to contradictions, it must be true that $\underline{w}_\infty = w_{max}$. Q.E.D.

Proof of Proposition 8

Immediate from the text.

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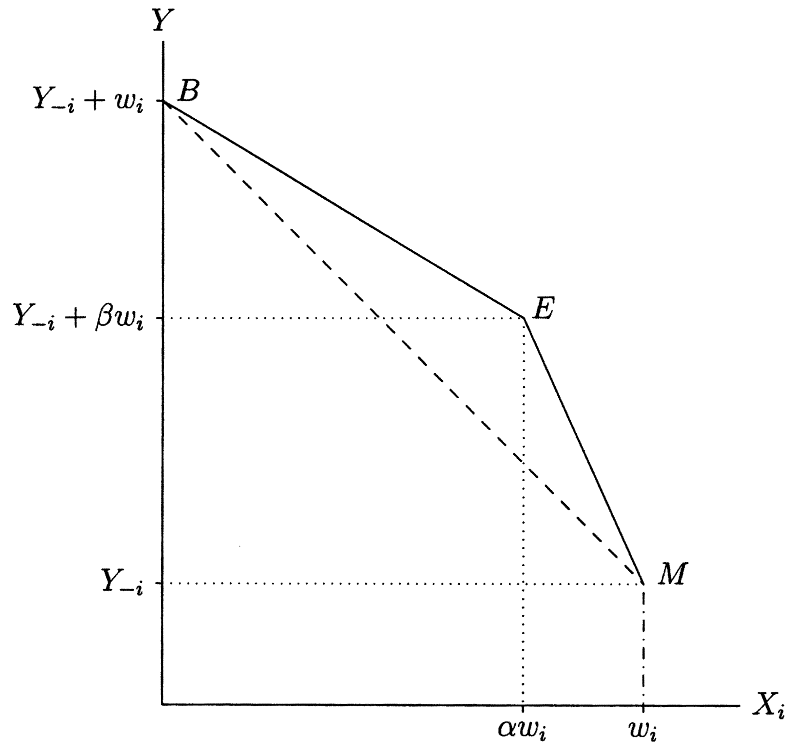

Figure 1: Budget set in characteristics space

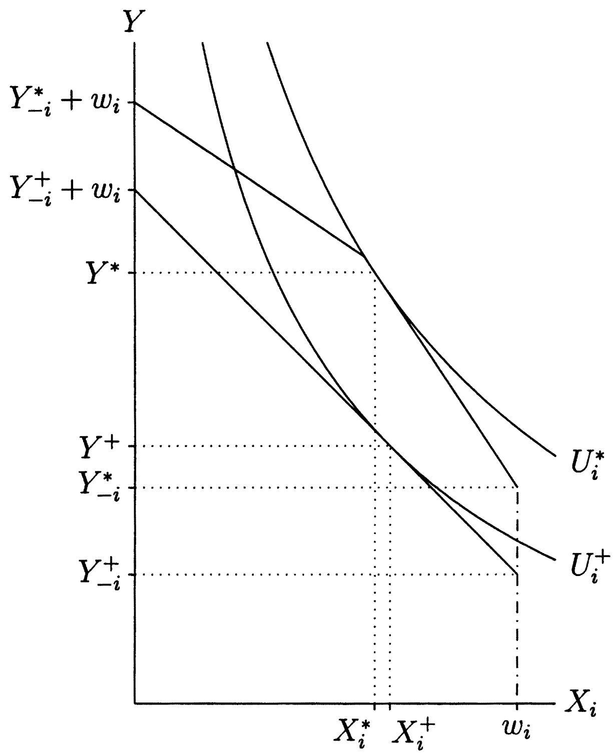

Figure 2: Green market increases both environmental quality and social welfare

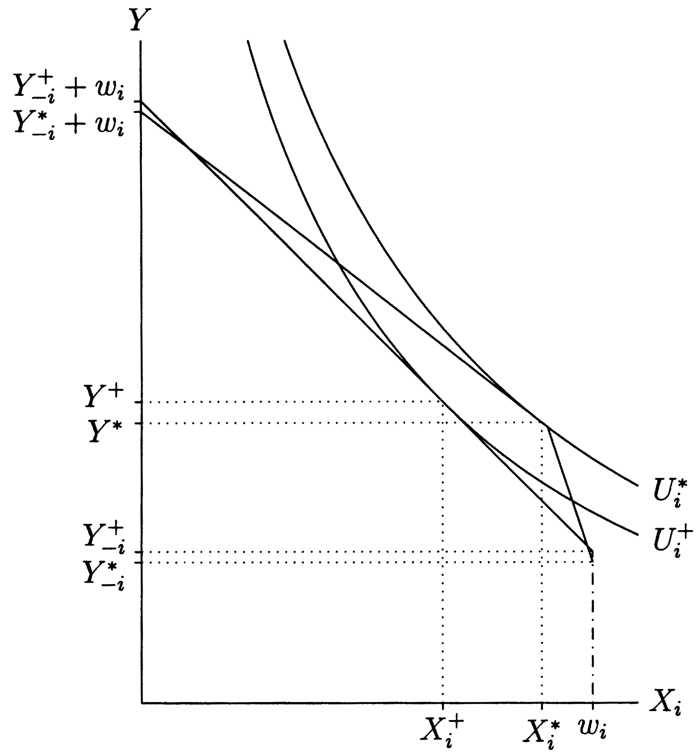

Figure 3: Green market decreases environmental quality and increases social welfare

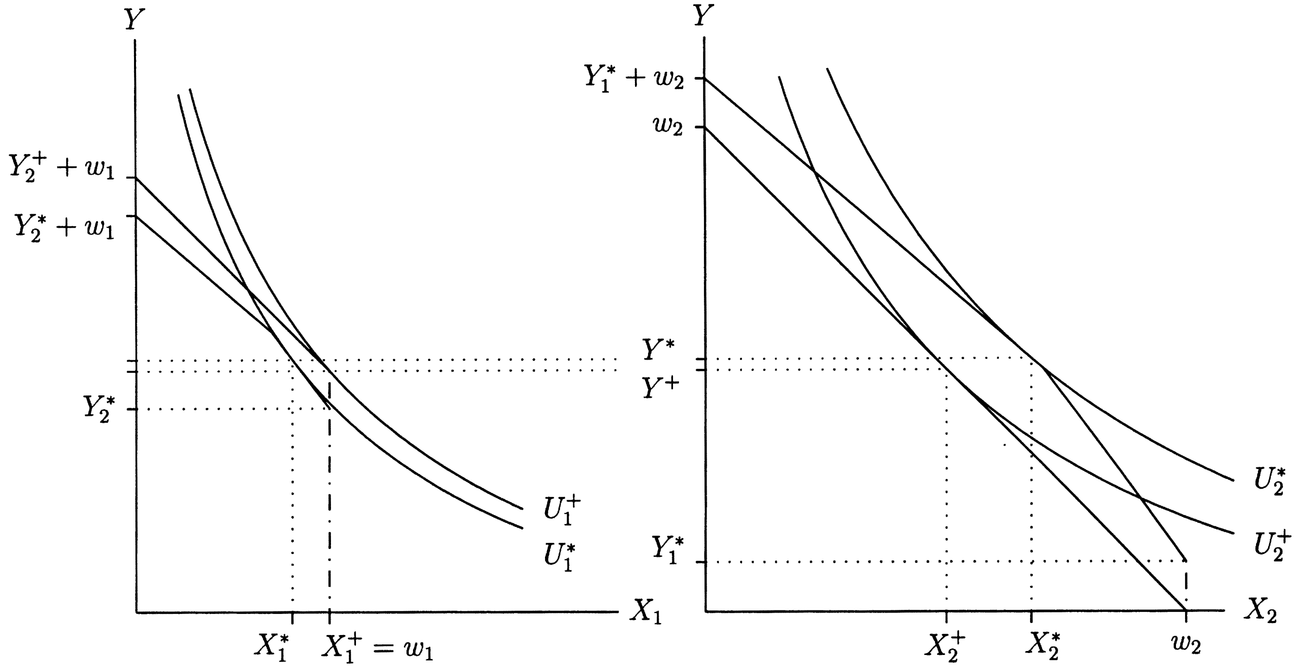

Figure 4: Green market increases environmental quality, decreases utility for individual 1, and increases utility for individual 2

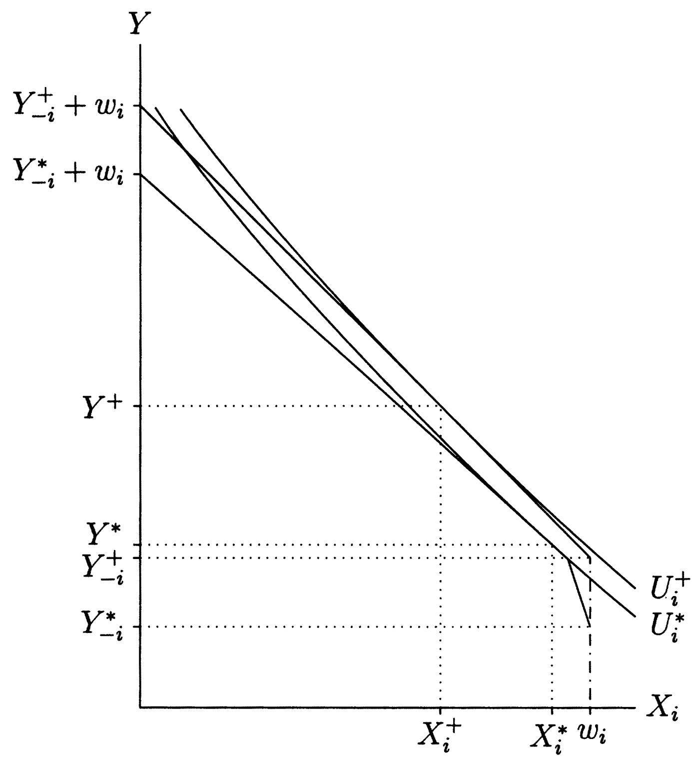

Figure 5: Green market decreases both environmental quality and social welfare