Voluntary Pollution Abatement and Regulation

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We consider private provision of an environmental public good and the link between voluntary pollution-abatement markets and the optimal level of mandatory environmental regulation. We show that voluntary abatement markets react to the level of mandatory abatement imposed and that an optimal regulatory policy must account for that reaction. We consider several assumptions about consumer behavior and find that the voluntary market's reaction to regulation depends on the motivating behavior of consumers. Whether the optimal level of mandatory abatement is higher than the level provided by traditional settings depends on the direction and magnitude of the voluntary market's reaction to changes in mandatory abatement.

Key Words: consumer demand, environmental regulation, optimal regulation, public goods, voluntary abatement

As the prevalence of environmentally friendly products has increased over time, research has lately emphasized understanding the mechanisms that underlie voluntary provision of environmental public goods (Segerson and Miceli 1998, Maxwell, Lyon, and Hackett 2000, Kotchen 2005, 2006, 2009, Kotchen and Moore 2007, Vicary 2011, Jacobsen, Kotchen, and Vandenbergh 2012). However, to our knowledge, no one has studied the interaction between a voluntary market for environmental quality and mandatory abatement imposed by a regulator. We exploit the fact that abatement and environmental quality are public goods to formalize the link between voluntary markets for abatement and mandatory abatement policies. We then focus on the optimal level of mandated abatement in settings with and without a voluntary market under several consumer behavior models.

Standard economic theory predicts that the nonexcludable and nonrival nature of environmental attributes is sufficient to discourage a rational agent from investing private resources to improve the quality of the environment. Continued expansion of markets for environmentally friendly products has thus led researchers to seek alternative behavioral hypotheses that explain this behavior. Early work focused on strategic interactions between a regulatory authority and a firm (Segerson and Miceli 1998) or an industry (Dawson and

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Segerson 2008) while more recent studies have explored consumer demand as the most compelling force behind the expansion of markets for environmentally friendly products (e.g., Kotchen 2005).[1] The traditional hypotheses include well-known models of altruism by Bergstrom, Blume, and Varian (1986) and impure altruism from Andreoni (1989, 1990), which combines the theories of altruism and warm glow into a unified framework. Recent studies have explored issues associated with signaling of social status (Howarth 1996, Sexton and Sexton 2014, Delgado, Harriger, and Khanna 2015) and with guilt (Kotchen 2009, Jacobsen, Kotchen, and Vandenbergh 2012) as competitive or complementary theories. Thus, the primary motive for consumers' voluntary provision of environmental public goods remains unclear.

An issue that has yet to be addressed is how voluntary markets that privately provide environmental public goods affect standard regulatory policies (e.g., emissions and abatement standards). Studies have typically focused on consumer demand curves derived from a single set of assumptions about consumer behavior and used a static analysis to illustrate the effect of an exogenous improvement in environmental quality on the consumer demand curve. We extend the analysis by (i) analyzing models of voluntary abatement-market equilibrium so we can examine interactions between that market equilibrium and mandatory abatement, (ii) focusing on the optimal level of regulation when abatement provided by a voluntary market changes in response to mandatory abatement, and (iii) considering multiple models of consumer behavior. It is important to recognize that different behavioral hypotheses may influence consumers' demand in response to exogenous improvements in environmental quality and alter conclusions regarding the interaction between the voluntary market equilibrium and the optimal level of mandatory abatement.

Because environmental resources are public goods, an increase in mandatory abatement would lead to an exogenous increase in the environmental quality realized by all consumers of the resource (including voluntary abatement-market participants) and thus would affect the voluntary market's equilibrium and potentially redefine the optimal level of mandatory abatement. This effect does not depend on which behavioral hypothesis drives consumer behavior (though the nature of the interaction between voluntary and mandatory abatement does). As voluntary markets for environmental quality continue to expand in size and scope, understanding the relationship between voluntary and mandatory abatement becomes increasingly important.

We begin our analysis with the simple, classic model of pure altruism to formally establish the interaction between voluntary and mandatory abatement. Our results show that consumer demand, and hence voluntary abatement, decreases in response to an increase in mandatory abatement. What is particularly interesting is the implication of this classic result for environmental regulatory policy. For example, if a regulator sets an abatement standard to achieve a particular level of environmental quality but fails to account for a reduction in voluntary abatement efforts, the results of the regulatory measure may fall short. To understand this relationship, we compare total abatement achieved under a policy that takes the likely reaction by the

[1] See also Arora and Gangopadhyay (1995) for an early theoretical model that focused on consumer demand and voluntary abatement. Their model differs from recent models in that much of the analysis is driven by a duopoly interaction between firms and less by consumer preferences.

voluntary abatement market into account with total abatement achieved under a policy that ignores the voluntary market.

Our review of recent contributions to this line of inquiry (Howarth 1996, Andreoni 1989, 1990, Kotchen 2009, Jacobsen, Kotchen, and Vandenbergh 2012, Sexton and Sexton 2014, Delgado, Harriger, and Khanna 2015) suggests that the simple model of pure altruism is potentially too restrictive and would provide an unrealistic representation of consumer preferences. We thus generalize our consumer framework to include several alternative behavioral hypotheses so the results from the model do not hinge on the assumption of pure altruism. Specifically, we include recently proposed behavioral hypotheses of impure altruism, guilt, and social status as special cases nested within our generalized utility framework. We analyze the effect of each structure on the nature of the voluntary market's reaction to an increase in mandatory abatement to better understand how mandatory abatement changes when the voluntary market is considered.

Our results show that our alternative behavioral hypotheses, which are consistent with observed private provisions of environmental public goods, influence the voluntary market's reaction to changes in mandatory abatement. Furthermore, the optimal level of mandatory abatement when a voluntary market is present depends on several factors. Consider a case of crowding-out—an increase in mandatory abatement crowds out (reduces) voluntary investments in abatement. In that case, when a regulator imposes greater regulation, voluntary abatement will decline as consumers substitute away from voluntary abatement and toward the numeraire. Total environmental quality could fall short of a traditional regulator's expectations because traditional regulation does not account for the voluntary market response. Hence, the level of regulation chosen by the traditional regulator may not be optimal. We identify cases in which the optimal level of regulation is greater when the voluntary market response is taken into account.

Indeed, one implication of our analysis is that differences in optimal regulation between a setting that includes a voluntary market (the "voluntary setting") and one that does not (the "traditional setting") may be market-specific and that the optimal level of regulation is not necessarily greater in a voluntary setting. In particular, we show that a traditional regulator is likely to see a smaller marginal benefit of regulation for consumers who voluntarily abate and a larger marginal benefit of regulation for consumers who do not. An important aspect in determining the relationship between optimal regulation in the presence of a voluntary market and in the traditional setting is the relative size of the voluntary abatement market.

A Simple Model of Altruism

We first consider a version of the standard model of pure altruism (Bergstrom, Blume, and Varian 1986) with two types of consumers. Type I consumers have relatively higher incomes and choose to voluntarily purchase abatement in equilibrium. Type II consumers have relatively lower incomes and do not voluntarily purchase abatement in equilibrium. Both types of consumers have identical preferences. To focus on the interaction between a change in mandatory abatement and the equilibrium in the voluntary abatement market, we assume that all of the consumers *of each type* have identical incomes (income differs only by consumer type) and that all of the equilibrium points are such that Type I consumers always voluntarily purchase abatement in equilibrium and Type II consumers never do.[2] We index Type I consumers with the subscript $i = 1, 2, \ldots, n_1$ and Type II consumers with the subscript $j = 1, 2, \ldots, n_2$.

We follow the standard model of pure altruism and presume that each consumer (i, for example, but the set-up follows by defining the consumer problem in terms of j) derives utility from consumption of a composite private good, x_i, and a purely public good, E, and has a utility function $U(x_i, E)$ that is strictly quasi-concave and twice differentiable in its arguments. We can interpret x as a numeraire good, and in an environmental context, E can be defined as a composite environmental public good. Under the Nash equilibrium assumption that all $-i$ and j contributions to E are exogenous to individual i, the consumer purchases abatement z_i to obtain the level of E that maximizes $U(\cdot)$. Hence, E is determined by $\sum_i z_i + \sum_j z_j$. The consumption decision is bound by a standard budget constraint, $M_i = x_i + Pz_i$, assuming that abatement can be purchased at price P.

This pure altruism framework captures the consumption decision of a consumer who values E instead of z. For example, the consumer might have biocentric preferences or could value health or visibility that accompanies improvements in the public good, E. While abatement, in reality, is typically available as an attribute bundled into an environmentally friendly product such as green electricity or recycled products, for modeling purposes we can ignore nonenvironmental attributes and focus solely on the abatement component and its implicit price (Kotchen 2005).

The demand curve for voluntary abatement under the pure altruism framework is obtained from the following first-order condition:

$$U_E(x_i, E) \;/\; U_{x_i}(x_i, E) = P \qquad (1)$$

in which $U_E(x_i, E)$ denotes the partial derivative of $U(x_i, E)$ with respect to E and likewise for x.[3] It is well known that an exogenous improvement in E, arising from, say, the private contributions of another individual, leads to a reduction in demand for z_i (Bergstrom, Blume, and Varian 1986); that is, $dz_i \,/\, dz_j < 0$.[4] Hence, an exogenous increase in E leads, *ceteris paribus*, to a crowding-out of voluntary abatement. Furthermore, the crowding-out is less than one for one so $|dz_i \,/\, dz_j| < 1$.

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[2] That is, we assume that the incomes of all Type II consumers are sufficiently low that they choose not to purchase abatement in equilibrium. An alternative set-up would be to allow for heterogeneity in income within (and across) consumer type by, for example, assuming a continuum of consumers with incomes uniformly distributed over the total number of consumers. In that set-up, however, some Type I consumers would become Type II consumers following regulation; their incomes would be high enough initially to warrant participation in the voluntary market but low enough to warrant free-riding under the mandatory abatement policy. We avoid such complications with our assumption of identical incomes within each type.

[3] Here, we define the consumer's problem in terms of (x_i, z_i) instead of (x_i, E) and derive the marginal utility with respect to z_i as $\partial U / \partial z_i = \partial U / \partial E \times \partial E / \partial z_i = U_E$ since $\partial E / \partial z_i = 1$.

[4] Recognizing that the constraint $M_i = x_i + Pz_i$ must be satisfied in equation 1, application of the implicit function theorem to equation 1 yields $dz_i / dz_j = (U_E U_{x_i E} - U_{x_i} U_{EE}) / [U_{x_i}(-PU_{Ex_i} + U_{EE}) - U_E(-PU_{x_i x_i} + U_{x_i E})] < 0$. Quasi-concavity of $U(\cdot)$ and the standard assumption of diminishing marginal utility ensure that $dz_i / dz_j < 0$. Furthermore, under the additional assumption that both goods are normal, $|dz_i / dz_j| < 1$ (Bergstrom, Blume, and Varian 1986, Andreoni 1990).

Crowding-out of voluntary abatement is important for mandatory abatement policies. Any standard placed on a jointly bundled product effectively requires consumers who do not voluntarily purchase abatement (i.e., the low-income Type II consumer in our model) to contribute some amount of abatement to E. That is, while a regulator could impose a standard that requires all units of a product to be bundled with some level of an environmentally friendly attribute (abatement), that standard would essentially require noncontributors to purchase some nonzero level of abatement. We denote this mandated level as $\bar{z}$. Voluntary abatement providers respond by reducing their voluntary contributions. This link between the level of mandatory abatement and the voluntary market arises because environmental quality is a public good and Type I consumers can increase their utility by maintaining the same level of E and substituting some $\bar{z}$ for z. Nevertheless, crowding-out of voluntary abatement influences the overall level of E and hence must be accounted for when choosing the optimal level of regulation. If, for example, a regulator seeks a level of environmental quality, $\bar{E}$, by choosing $\bar{z}$, crowding-out of z_i, if not accounted for, will prevent $\bar{z}$ from providing $\bar{E}$.

Formally, under mandatory abatement, $E = n_1 z_i + n_2 \bar{z}$ where $z_i > \bar{z} > 0$ so that only Type II consumers purchase the mandated level of abatement, which acts as an exogenous component of environmental quality for Type I consumers. Hence, the reaction from consumer i to a marginal increase in mandatory abatement is

$$(2) \qquad dz_i / d\bar{z} = \frac{[U_E U_{x_i E} - U_{x_i} U_{EE}][(n_1 - 1) dz_i(\bar{z}) / d\bar{z} + n_2]}{U_{x_i}(-PU_{Ex_i} + U_{EE}) - U_E(-PU_{x_i x_i} + U_{x_i E})}$$

in which $[(n_1 - 1) dz_i(\bar{z}) / d\bar{z} + n_2]$ is the net increase in E from an increase in $\bar{z}$ from the perspective of consumer i. That is, the consumer sees an increase in E from both the marginal increase in $\bar{z}$ from n_2 Type II consumers and the marginal reduction in voluntary abatement from the Type I $(n_1 - 1)$ consumers. Rearranging equation 2 to solve explicitly for the change in z_i following the marginal increase in $\bar{z}$ gives

$$(3) \qquad dz_i / d\bar{z} = \frac{n_2(U_E U_{x_i E} - U_{x_i} U_{EE})}{U_{x_i}(-PU_{Ex_i} + n_1 U_{EE}) - U_E(-PU_{x_i x_i} + n_1 U_{x_i E})}.$$

Since we model relative scale effects of the voluntary market by allowing n_1 and n_2 to be of (appropriately) different magnitudes, a one-unit increase in mandatory abatement for each j Type II consumer does not necessarily lead to a decrease of less than one unit of abatement for each Type I consumer. As n_2 rises relative to n_1, $dz / d\bar{z}$ increases in magnitude: for each one-unit increase in mandated abatement, Type I consumers see larger and larger improvements in environmental quality because n_2 increases and their crowding-out of voluntary abatement increases as a result. In the extreme, it is possible for crowding-out by the ith Type I consumer to be greater than the one-unit increase in abatement mandated for the jth Type II consumer, that is, for $dz_i / d\bar{z} < -1$. Hence, it is possible that crowding-out at a *consumer* level can be greater than 1.

To avoid the situation in which aggregate voluntary-market crowding-out more than offsets the improvement in environmental quality achieved through mandatory abatement and therefore renders the environmental policy counterproductive, we impose the condition that an increase in mandatory abatement is associated with an improvement in environmental quality—that $dE / d\bar{z} = n_1 \times dz_i / d\bar{z} + n_2$ is greater than 0. That is, we assume that the aggregate Type I consumer reaction is smaller than the aggregate Type II contribution. Specifically, we focus on cases in which the relative sizes of n_1 and n_2 are close enough to ensure that (i) a voluntary market exists and voluntary contributions significantly influence environmental quality, and (ii) mandatory abatement is significant enough to influence environmental quality in the presence of voluntary abatement. This condition also eliminates any case in which the number of Type I or Type II consumers is so small (or so large) that abatement from those consumers would have a negligible effect on E (or completely swamp the interaction between voluntary and mandatory abatement). Imposing this condition does not limit the scope or generality of the model because our goal is to develop an economically meaningful interaction between voluntary and mandatory abatement. Any special case of our framework that assumes a particularly weak voluntary market or a particularly small group of noncontributors that is regulated through mandatory abatement is not particularly interesting in the current context since such cases may compromise the existence of the voluntary market equilibrium and/or the practical benefit of mandatory abatement.

Recent empirical research has identified biocentrism as the strongest factor motivating household purchases of green electricity (Clark, Kotchen, and Moore 2003, Kotchen and Moore 2007), providing evidence of a utility structure that depends, at least in part, on E. Since environmental quality is a public good and any mandatory abatement policy changes the level of provision of the public good exogenous to the voluntary market, the voluntary market's equilibrium is endogenous from the perspective of the regulator.

The Supply of Abatement and Voluntary Market Equilibrium

We model the supply of abatement as the marginal cost of producing both voluntary and mandatory abatement—equivalently, in the model, as the marginal cost of producing environmental quality. If there is no qualitative difference between abatement produced by voluntary and mandatory consumption, the total cost of abatement for any firm is simply a function of the sum of the costs of the voluntary and mandatory abatements. Hence, we model the total cost of abatement as $C_m(z_m^s + \bar{z}_m^s)$ for $m = 1, 2, \ldots, M$ perfectly competitive firms and define $C_m(\cdot)$ as any continuous and convex function with z_m^s and $\bar{z}_m^s$ respectively denoting the level of voluntary and mandatory abatement produced by the mth firm. Alternatively, we can assume that both voluntary and mandatory abatement are produced entirely by a single perfectly competitive firm without changing the analysis (Mas-Colell, Whinston, and Green 1995), which allows us to simplify notation and rewrite total cost as $TC(E) = C(z^s + \bar{z}^s)$. Since there is only one firm, z^s and $\bar{z}^s$ respectively denote the total level of voluntary and mandatory abatement produced in the market.

We can derive the marginal cost of voluntary abatement as

$$MC(z^s) = \frac{\partial C(z^s + \bar{z}^s)}{\partial z^s} \qquad (4)$$

and mandatory abatement as

$$MC(\bar{z}^s) = \frac{\partial C(z^s + \bar{z}^s)}{\partial \bar{z}^s}. \tag{5}$$

When determining the supply curve for voluntary abatement (from equation 4), $\bar{z}^s$ is taken as a fixed parameter, and an increase in $\bar{z}^s$ shifts the supply curve for voluntary abatement upward. Likewise, z^s is taken as given in the marginal cost of mandatory abatement, and an increase in z^s decreases the supply of mandatory abatement at any given price.

The equilibrium level of abatement in the voluntary market is the level of abatement that equates the sum of the demand curves for voluntary abatement obtained from equation 1 across all Type I consumers with the demand curve from equation 4, the supply of voluntary abatement. We denote the per capita level of abatement in the voluntary market equilibrium as $z_i^*(\bar{z})$. Since we assume that abatement is produced by a single firm, that firm produces $z^s = n_1 z_i^*(\bar{z})$ total abatement in the voluntary market equilibrium.

Regulation

We now turn to optimal regulation. We assume that the regulator chooses a mandatory level of regulation of $\bar{z} > 0$ and that $z_j = \bar{z}$, $\forall\, j$ so that regulation is binding for all Type II consumers. Regardless of the behavioral assumption chosen for consumer preferences, we model the regulatory decision of choosing the mandatory level of abatement as the level of $\bar{z}$ that equates the marginal benefit of regulation with the marginal cost. We model the marginal benefit of regulation as the benefit to consumers from improvements in environmental quality and let the marginal cost be borne by the firm. From the economywide perspective of the regulator, it does not matter that the entire cost of regulation is borne by the firm; we make this assumption solely for the purpose of deriving the optimal level of regulation in the regulator's problem.

The Marginal Benefit of Regulation

The marginal benefit from mandatory abatement is

$$MB(\bar{z}) = \sum_{i=1}^{n_1} \frac{U_{\bar{z},i}(x_i, E)}{U_{x_i}(x_i, E)} + \sum_{j=1}^{n_2} \frac{U_{\bar{z},j}(x_j, E)}{U_{x_j}(x_j, E)}. \tag{6}$$

That is, the marginal benefit from mandatory abatement is the sum of all consumers' marginal utility from an improvement in E arising from an improvement in $\bar{z}$ relative to the marginal utility of x (the numeraire). Since $z_i = z_i^*(\bar{z})$ in the voluntary market equilibrium and $z_j = \bar{z}$, the regulator recognizes that $U_i = U[M_i - P^*(\bar{z})z_i^*(\bar{z}),\ n_1 z_i^*(\bar{z}) + n_2\bar{z}]$ and $U_j = U[x_j,\ n_1 z_i^*(\bar{z}) + n_2\bar{z}]$. The regulator sees that the choice of consumption of x_i also depends on $\bar{z}$ through the budget constraint: any consumers not already spending their incomes solely on the numeraire (Type I consumers) will purchase less abatement and consume a greater amount of the numeraire following an increase in $\bar{z}$.

Recognizing that $U_i = U(x_i, E) = U(M_i - P^*(\bar{z})z_i^*(\bar{z}),\ n_1 z_i^*(\bar{z}) + n_2\bar{z})$ and that $\partial E / \partial \bar{z} = dE / d\bar{z}$, the marginal utility from $\bar{z}$ for the ith Type I consumer is

$$(7)\quad MU_{\bar{z},i} = U_{\bar{z},i}(x_i, E) = \frac{\partial U(x_i, E)}{dx_i}\ \frac{dx_i}{\partial \bar{z}} + \frac{\partial U(x_i, E)}{\partial E}\ \frac{dE}{d\bar{z}}$$

$$= -U_{x_i}(x_i, E)\left[P^*(\bar{z})\frac{dz_i^*(\bar{z})}{d\bar{z}} + \frac{dP^*(\bar{z})}{d\bar{z}} z_i^*(\bar{z})\right] + U_E(x_i, E)\left[n_1\frac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right].$$

A straightforward revealed-preference argument is sufficient for establishing that the marginal utility from $\bar{z}$ is strictly larger than 0. Following a marginal increase in $\bar{z}$, consumers have the option of maintaining an identical consumption bundle (plus the newly acquired unit of $\bar{z}$) or reallocating their consumption by substituting some income away from z and toward the numeraire. From Andreoni (1990), we know that consumers can make this substitution up to the value of their newly acquired marginal unit of $\bar{z}$ and not be worse off. Any consumer who chooses to make a substitution away from z for x would only do so if they would be better off relative to just accepting the additional unit of $\bar{z}$ and maintaining their original consumption bundle. Therefore, the marginal utility from $\bar{z}$ for Type I consumers cannot be negative.

The marginal utility from x for the ith Type I consumer is $MU_{x_i} = U_{x_i}(x_i, E)$, which is positive by assumption. Hence, the marginal benefit from regulation for each Type I consumer is

$$(8)\quad MB(\bar{z})_i = \frac{-U_{x_i}(x_i, E)\left[P^*(\bar{z})\frac{dz_i^*(\bar{z})}{d\bar{z}} + \frac{dP^*(\bar{z})}{d\bar{z}} z_i^*(\bar{z})\right] + U_E(x_i, E)\left[n_1\frac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]}{U_{x_i}(x_i, E)}.$$

The marginal utility from $\bar{z}$ for the jth Type II consumer is

$$(9)\quad MU_{\bar{z},j} = U_{\bar{z},j}(x_j, E) = U_E\,(x_j, E)\left[n_1\frac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]$$

and the marginal utility from x for this consumer is $MU_{x_j} = U_{x_j}(x_j, E)$. Notice that the crowding-out of voluntary abatement in equation 9 reduces utility for Type II consumers, *ceteris paribus*, because z is a public good. The marginal benefit for each Type II consumer is

$$(10)\quad MB(\bar{z})_j = \frac{U_E(x_j, E)\left[n_1\frac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]}{U_{x_j}(x_j, E)}.$$

Combining equations 6, 8, and 10 yields the social marginal benefit from regulation:

$$(11)\quad MB(\bar{z}) = \sum_{i=1}^{n_1}\frac{-U_{x_i}(x_i, E)\left[P^*(\bar{z})\frac{dz_i^*(\bar{z})}{d\bar{z}} + \frac{dP^*(\bar{z})}{d\bar{z}} z_i^*(\bar{z})\right] + U_E(x_i, E)\left[n_1\frac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]}{U_{x_i}(x_i, E)}$$

$$+\sum_{j=1}^{n_2} \frac{U_E(x_j, E)\left[n_1 \dfrac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]}{U_{x_j}(x_j, E)}.$$

The regulator recognizes that an improvement in $\bar{z}$ is accompanied by a reduction in z_i^* so that the crowding-out of voluntary abatement dampens the increase in E arising from $\bar{z}$. Type I consumers benefit because they enjoy an increase in consumption of both the numeraire and environmental quality. Type II consumers benefit from regulation because of the net increase in environmental quality from regulation. Note, however, that one consequence of crowding-out is that Type II consumers do not realize an increase in environmental quality equal to their total contribution of $\bar{z}$.

The Marginal Cost of Regulation

The total cost of producing abatement is given by $C(n_1 z_i^*(\bar{z}) + n_2\bar{z})$ (as previously shown). That is, the regulator recognizes that the link between voluntary and mandatory abatement influences the cost of producing abatement. The marginal cost of regulation is

$$MC(\bar{z}) = C_E(n_1 z_i^*(\bar{z}) + n_2\bar{z})\left[n_1 \frac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]. \quad (12)$$

Crowding-out in the voluntary market reduces the marginal cost of regulation, *ceteris paribus*, because $n_1 dz_i^*(\bar{z}) / d\bar{z} < 0$. That is, a one-unit increase in mandatory abatement for all n_2 Type II consumers does not lead to an n_2-unit increase in the total supply of abatement because the net increase in environmental quality is less than the marginal unit purchased by Type II consumers under the regulation. In other words, the marginal cost of abatement decreases, *ceteris paribus*, because of the voluntary market response (the marginal cost is lower than it would have been in the absence of the voluntary market response).

Optimal Regulation

The optimal level of regulation is determined by the level of $\bar{z}$ that equates the marginal benefit in equation 11 with the marginal cost given by equation 12. We denote this level of regulation as $\bar{z}^*$. The regulator recognizes that the marginal benefit and the marginal cost of regulation depend on the equilibrium level of voluntary abatement and that the equilibrium level is determined by $\bar{z}$.

Discussion

The model so far remains purposefully simple and omits many of the complexities associated with consumer behavior, voluntary pollution-abatement markets, and regulatory decisions. Yet this simple model illustrates an important general lesson. So long as consumer demand for voluntary pollution abatement depends, at least in part, on the aggregate level of environmental quality provided, voluntary abatement is fundamentally linked to mandatory abatement. The link does not depend on our use of the simple pure-altruism utility framework; rather, it stems from the fact that abatement is a public good and consumer preferences are not purely egoistic.

We acknowledge two limitations of the framework presented so far. First, deriving the condition that describes the optimal level of regulation is not necessarily informative for policymakers wishing to improve existing regulations that do not account for voluntary market reactions. Second, our characterization of consumer demand may ignore crucial complexities that influence the voluntary market's reaction to a change in $\bar{z}$ and, subsequently, the regulatory decision-making process. To address these concerns, we first compare the optimal level of regulation from our simple model to the optimal level for a traditional regulatory policy that does not incorporate the reaction of the voluntary market into the decision-making process to identify fundamental differences between the two regulatory regimes. We then analyze alternative theories of consumer demand for environmental public goods to assess the sensitivity of our initial conclusions to different consumer preference structures.

Optimal Regulation with and without Voluntary Abatement

Traditional Regulation

In the traditional setting for regulators of environmental quality, there is no voluntary market for pollution abatement. The only source of change in environmental quality is change in mandated abatement, $\bar{z}$. In this portion of the analysis, we continue to assume that there are n_1 Type I consumers with high incomes and n_2 Type II consumers with low incomes. To make regulation under this traditional setting comparable to regulation in the presence of a voluntary market, we assume that both types of consumers value environmental quality: $E = n_1 z_i^* + n_2\bar{z}$. In this setting, $n_1 z_i^*$ corresponds to the baseline level of environmental quality seen by the regulator, which does not change in response to a change in the mandated level of abatement. Thus, the two utility functions seen by the traditional regulator are $U_i = U[x_i, n_1 z_i^* + n_2\bar{z}]$ for Type I consumers and $U_j = U[x_j, n_1 z_i^* + n_2\bar{z}]$ for Type II consumers, and z_i^* is no longer a function of $\bar{z}$.

Following our regulation set-up, the traditional marginal benefit of regulation for the *i*th Type I consumer is

$$(13) \qquad MB(\bar{z})_i^T = \frac{n_2 U_E(x_i, E)}{U_{x_i}(x_i, E)}$$

while the traditional marginal benefit of regulation for the *j*th Type II consumer is

$$(14) \qquad MB(\bar{z})_j^T = \frac{n_2 U_E(x_j, E)}{U_{x_j}(x_j, E)}.$$

Therefore, the social marginal benefit seen by the traditional regulator is

$$(15) \qquad MB(\bar{z})^T = \sum_{i=1}^{n_1} \frac{n_2 U_E(x_i, E)}{U_{x_i}(x_i, E)} + \sum_{j=1}^{n_2} \frac{n_2 U_E(x_j, E)}{U_{x_j}(x_j, E)}.$$

Notice the differences between equations 11 and 15. Since the traditional regulator does not need to account for a voluntary market's reaction to a change in $\bar{z}$, the regulator sees neither substitution of x_i for z_i by Type I consumers nor a net reduction in E realized by all consumers from crowding-out of voluntary abatement.

Similarly, the social marginal cost in the traditional regulator's problem is

$$MC(\bar{z})^T = n_2 C_E(n_1 z_i^* + n_2\bar{z}). \tag{16}$$

It is clear from comparing equations 12 and 16 that the result of equation 12 is always less than the result of equation 16 because $0 < [n_1 dz_i^*(\bar{z}) \,/\, d\bar{z} + n_2] < n_2$ in equation 12. That is, the traditional regulator always sees a greater marginal cost of regulation because there is no crowding-out of voluntary abatement in this setting and thus no reduction in the total level of abatement supplied and in the marginal cost of mandatory abatement.

The level of $\bar{z}$ chosen by the traditional regulator is the $\bar{z}$ that equates equations 15 and 16. We denote this level of regulation as $\bar{z}_T^*$.

Optimal Regulation Compared across Settings

Now that we have defined the choice problem facing the traditional regulator, we can explore differences between the traditional regulator and one operating in the presence of a voluntary market. As shown under the general consumer framework, the marginal cost of mandatory abatement is always less in the presence of a voluntary market than in the traditional setting. Unfortunately, comparing equations 11 and 15 is more complex. By revealed preferences, we know that the first term in equation 11 is larger than the first term in equation 15—the total marginal benefit from $\bar{z}$ for Type I consumers is larger in the presence of a voluntary market. Mandatory abatement provides Type I consumers with the option to substitute away from z_i toward x_i without reducing E. The regulator who accounts for the voluntary market recognizes this choice while the traditional regulator does not need to consider substitution by Type I consumers when it is utility-maximizing for them to do so. The inability of Type I consumers to substitute toward x_i following a change in $\bar{z}$ in the absence of a voluntary market means that the traditional regulator sees a smaller increase in the utility that Type I consumers receive when mandated abatement increases marginally.

Conversely, the second term in equation 11 is less than the second term in equation 15, in which Type II consumers derive utility, *ceteris paribus*, from the increase in E from $\bar{z}$ and not from the net increase in E as in equation 11. In the traditional setting, there is no crowding-out of voluntary abatement to dampen the increase in E that Type II consumers receive following regulation.

Since the marginal benefit is larger for Type I consumers but smaller for Type II consumers in the presence of a voluntary market (relative to a traditional setting), the relationships between social marginal benefit and optimal regulation with and without a voluntary market are not clear. There are three possible cases. In the first, the social marginal benefit is larger in the presence of a voluntary market than in the traditional setting (equation 11 is greater than equation 15). In that case, since the marginal cost of abatement is smaller, a regulator in the presence of a voluntary market selects an optimal level of regulation that is larger than the level chosen by a traditional regulator. In the second, the social marginal benefits from the two types of regulatory settings are equal. Because the social marginal cost is smaller, the regulator operating in the presence of a voluntary market selects a larger level of $\bar{z}$ than the traditional regulator. In the third case, the social marginal benefit is smaller in the presence of a voluntary market than in the traditional setting. Since there is also a smaller marginal cost for regulation in the presence of a voluntary market, it is not clear which regulator selects the larger $\bar{z}$.

Discussion

Our models of regulation have shown that the optimal level of regulatory policy in the presence of a voluntary abatement market recognizes the voluntary market's reaction to a change in mandatory abatement. However, we have also shown that the relative magnitudes of the optimal level of mandatory abatement under the traditional and voluntary-market settings are not known *a priori*. That is, it is not simply a matter of choosing an unambiguously higher or lower level of mandated abatement in the presence of a voluntary market. There are several factors that govern the relationship between $\bar{z}^*$ and $\bar{z}_T^*$.

Note that the result of equation 11 is larger than the result of equation 15 when the benefit to Type I consumers from substituting toward x following regulation is larger than the loss in welfare from less environmental quality (*ceteris paribus*, because of crowding-out) for both Type I and Type II consumers. In other words, the marginal benefit is larger for a regulator in the presence of a voluntary market than for a traditional regulator when the magnitude of the traditional marginal benefit to Type II consumers is smaller than the magnitude of the marginal benefit to Type I consumers. Because of the substantial generality of the model considered here, the conditions that would be sufficient to ensure that the marginal benefit in the presence of a voluntary market exceeded the traditional marginal benefit cannot be identified.

One could argue, however, that the relative size of the markets in each case could be an important factor in determining when the marginal benefit is larger. In the model, we have included the parameters n_1 and n_2 to govern the relative size of each market. While we have assumed that n_1 and n_2 are proportional to each other to a degree that allows us to focus on an interior solution of the model, n_1 being greater than n_2 (when both remain within the presumed bounds) would increase the marginal benefit to Type I consumers relative to Type II consumers when holding relative incomes and preferences constant. Hence, when n_1 is sufficiently greater than n_2, the marginal benefit under traditional regulation is smaller than the marginal benefit in the presence of a voluntary market. And under those circumstances, the optimal level of mandated abatement is larger in the presence of a voluntary market than in the traditional setting in which all consumers receive only the mandated level of abatement.

A General Consumer Framework

Our analysis has so far rested on a classic, simple consumer framework of pure altruism to establish the fundamental interaction between voluntary and mandatory abatement and to demonstrate how the interaction is important for designing environmental policy. One potential drawback of this analysis is the simplicity of the utility framework of pure altruism, which ignores several important motives for voluntary participation that have received much attention in recent years (see, for example, Andreoni (1988, 1989, 1990), Howarth (1996), Kotchen (2009), Jacobsen, Kotchen, and Vandenbergh (2012), Sexton and Sexton (2014), and Delgado, Harriger, and Khanna (2015)). We turn now to a generalization of the pure altruism framework to obtain a more thorough understanding of how mandatory abatement policies interact with a voluntary abatement market driven by a variety of other preferences.

Generalized Utility Framework

We begin by generalizing the utility function (we describe consumer i but likewise for consumer j) to include a purely private benefit from purchasing environmental abatement: $U_i = U(x_i, z_i, E)$. We retain the assumption that $U(\cdot)$ is strictly quasi-concave. Utility is still a function of the level of provision of the environmental public good, E, and we expect that the link between voluntary and mandatory abatement will persist. However, consumers also derive purely private satisfaction from voluntarily providing the public good through abatement, z_i, which enters directly into the utility function. Readers familiar with such models may recognize this framework as the model of impure altruism first proposed by Andreoni (1989, 1990); however, while impure altruism remains an important case in our analysis, our set-up is slightly more general. The impure altruism case is the most general case in which $dz_i / d\bar{z} < 0$. However, several recent behavioral hypotheses (Howarth 1996, Kotchen 2009, Jacobsen, Kotchen, and Vandenbergh 2012, Sexton and Sexton 2014, Delgado, Harriger, and Khanna 2015) have suggested that, at least in environmental quality contexts, there are several other more specific behavioral-preference structures that have important implications.

First consider the demand for voluntary abatement that comes from the generalized consumer problem. It is straightforward to show that consumer demand for the ith Type I consumer is given by

$$\text{(17)} \qquad \frac{U_{z_i}(x_i, z_i, E) + U_E(x_i, z_i, E)}{U_{x_i}(x_i, z_i, E)} = P.$$

By imposing $M_i = x_i + Pz_i$ as a constraint on equation 17, we can derive the change in demand for z_i as $\bar{z}$ changes to determine how Type I consumers react to a change in mandatory abatement. Applying the implicit function theorem to equation 17 yields

$$\text{(18)} \qquad dz_i / d\bar{z} = \frac{n_2[(U_{z_i} + U_E)U_{x_iE} - U_{x_i}(U_{z_iE} + U_{EE})]}{\begin{array}{c} U_{x_i}(-PU_{z_ix_i} + U_{z_iz_i} + n_1U_{z_iE} - PU_{Ex_i} + U_{Ez_i} + n_1U_{EE}) \\ -(U_{z_i} + U_E)(-PU_{x_ix_i} + U_{x_iz_i} + n_1U_{x_iE}) \end{array}}.$$

In general, the sign of $dz_i / d\bar{z}$ is unknown. We know that U_{x_i}, U_{z_i}, and U_E are positive; that $U_{x_ix_i}$, $U_{z_iz_i}$, and U_{EE} are less than 0 by diminishing marginal utility; and that $U_{x_iE} = U_{Ex_i} > 0$ and $U_{x_iz_i} = U_{z_ix_i} > 0$ by Young's theorem and the standard assumption of positive cross partials. The complexity of the general utility framework, however, makes it impossible to determine the sign of U_{z_iE} and hence of U_{Ez_i} without further assumptions. This ambiguity arises because of the imperfect substitutability of z_i, $\bar{z}$, and E in the consumer utility function.

In general, the sign of equation 18 is unknown since it depends on U_{z_iE} and its relative magnitude.

Consider first the case in which $U_{z_iE} < 0$. In this case,

$$(U_{z_i} + U_E)U_{x_iE} - U_{x_i}[U_{z_iE} + U_{EE}] > 0$$

since we maintain the assumptions that $U_{x_iE} > 0$ and $U_{EE} < 0$. Since $(1 - n_1) < 0$, the denominator of $dz_i / d\bar{z} < 0$ and, hence, $dz_i / d\bar{z} < 0$. Therefore, we obtain our first result that $U_{z_iE} < 0$ is a sufficient but not necessary condition for crowding-out.

Next consider the case in which $U_{z_iE} > 0$. This case is less straightforward and yields several cases. In the first, let U_{z_iE} be greater than 0 but small enough that $U_{z_iE} < |U_{EE}|$. Then, $(U_{z_iE} + U_{EE}) < 0$ and it immediately follows that $dz_i / d\bar{z} < 0$.

The third case we consider is when U_{z_iE} is greater than 0 and is large enough that $U_{z_iE} > |U_{EE}|$ but small enough that

$$(U_{z_i} + U_E)U_{x_iE} > U_{x_i}(U_{z_iE} + U_{EE}).$$

In this case, it follows that $dz_i / d\bar{z} < 0$. This case again yields crowding-out.

The final two cases we consider arise if

$$U_{z_iE} > 0,\ U_{z_iE} > |U_{EE}| \text{ and } (U_{z_i} + U_E)U_{x_iE} < U_{x_i}(U_{z_iE} + U_{EE}).$$

In this case, it follows that

$$(U_{z_i} + U_E)U_{x_iE} - U_{x_i}[U_{z_iE} + U_{EE}]$$

is negative and, hence, the numerator of $dz_i / d\bar{z}$ is negative. However, since

$$U_{x_i}[-PU_{z_ix_i} + U_{z_iz_i} + U_{z_iE} - PU_{Ex_i} + U_{Ez_i} + U_{EE}] - (U_{z_i} + U_E)(-PU_{x_ix_i} + U_{x_iz_i} + U_{x_iE})$$

is negative under our quasi-concavity assumption and $(1 - n_1)$ is negative, the sign of the denominator of $dz_i / d\bar{z}$ is unknown. If

$$U_{x_i}[-PU_{z_ix_i} + U_{z_iz_i} + U_{z_iE} - PU_{Ex_i} + U_{Ez_i} + U_{EE}] - (U_{z_i} + U_E)(-PU_{x_ix_i} + U_{x_iz_i} + U_{x_iE})$$

is larger in magnitude than

$$(1 - n_1)(U_{z_i} + U_E)U_{x_iE} - U_{x_i}[U_{z_iE} + U_{EE}],$$

the denominator will be negative and $dz_i / d\bar{z} > 0$. Thus, we obtain crowding-in.

Conversely, if

$$U_{x_i}[-PU_{z_ix_i} + U_{z_iz_i} + U_{z_iE} - PU_{Ex_i} + U_{Ez_i} + U_{EE}] - (U_{z_i} + U_E)(-PU_{x_ix_i} + U_{x_iz_i} + U_{x_iE})$$

is smaller in magnitude than

$$(1 - n_1)(U_{z_i} + U_E)U_{x_iE} - U_{x_i}[U_{z_iE} + U_{EE}],$$

the denominator will be positive and $dz_i / d\bar{z} < 0$, providing another case of impure altruism (crowding-out).

To provide further insight, note that the lefthand side of equation 17 is simply the marginal rate of substitution between (z_i, x_i) whereas the righthand side is the relative price of voluntary abatement. Under the quasi-concavity assumption, the equilibrium condition in equation 17 can be represented graphically via the tangency between a convex indifference curve and the linear budget constraint. Figure 1 illustrates the interior equilibrium (z_1, x_1) at the tangency of a standard convex indifference curve, IC_1, and the linear budget constraint, *BL*. A change in $\bar{z}$, *ceteris paribus*, rotates the indifference curve. The top panel of Figure 1 shows that the indifference curve

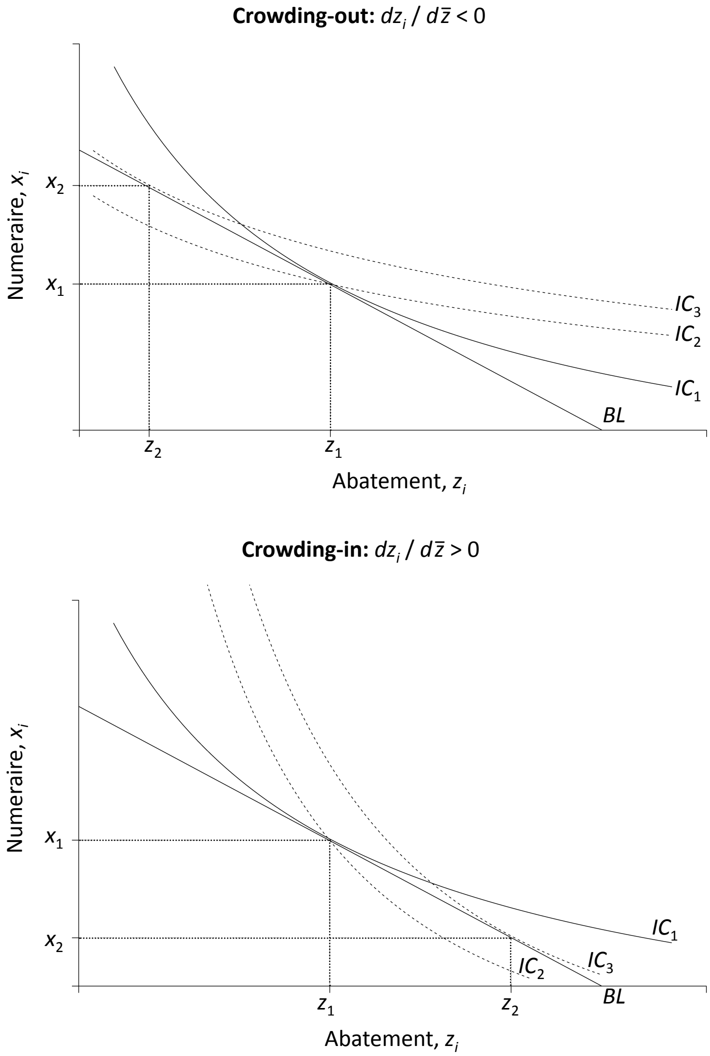

Figure 1. Graphical Illustration of $dz_i / d\bar{z}$ for the Generalized Utility Framework

rotates downward when $\bar{z}$ increases, resulting in the new indifference curve, IC_2, being flatter than the original, while the bottom panel shows a steeper indifference curve (also labeled IC_2). IC_2 in both runs through the initial equilibrium (z_1, x_1). However, note that (z_1, x_1) is no longer the optimal level of mandatory abatement. Hence, consumers move to (z_2, x_2), at which point IC_3 is tangent to *BL*. In the top panel, there is crowding-out of voluntary abatement; in the bottom panel, there is crowding-in. Thus, in contrast to results from the pure altruism framework in which the indifference curve always rotates downward, crowding-out of voluntary abatement is not guaranteed in the generalized model.

Therefore, the key to determining the sign of $dz_i / d\bar{z}$ is the sign and magnitude of U_{z_iE}, which is the change in marginal utility derived from private abatement as the overall level of environmental quality improves. As we have shown, each potential $dz_i / d\bar{z}$ outcome is consistent with one of three explanations for consumers' voluntary provision of environmental public goods. We discuss these models as being consistent with our general consumer framework before returning to our discussion of optimal regulation in the presence of an endogenous voluntary abatement market.

Impure Altruism

The first and most generalized preference structure that is consistent with several cases arising from our generalized model is Andreoni's (1989, 1990) impure altruism model. The primary characteristic of the impure altruism model is that voluntary abatement is crowded out by mandatory abatement; that is, $dz_i / d\bar{z} < 0$. Crowding-out in the general framework occurs either when $U_{z_iE} < 0$ or when $U_{z_iE} > 0$ but is sufficiently small so that $dz_i / d\bar{z} < 0$.

The case in which $U_{z_iE} < 0$ nicely coincides with the recently proposed concept of guilt (Kotchen 2009, Jacobsen, Kotchen, and Vandenbergh 2012) and provides interesting and useful interpretation in the environmental public good context. Hence, we recognize that our notion of consumer "guilt" is consistent with Andreoni's (1989, 1990) impure altruism models. However, in our analysis, we treat it as a separate behavioral structure.

Guilt

The guilt hypothesis maintains that consumer purchases of environmentally friendly products may be motivated by conscience and fueled in part by the desire to avoid alternative actions that are environmentally harmful (Kotchen 2009, Jacobsen, Kotchen, and Vandenbergh 2012). In this framework, the marginal utility from private abatement decreases as the level of environmental quality improves; the consumer is less likely to feel guilty about environmentally harmful activities when the environment is cleaner because the marginal damage from those activities is likely to be lower in a cleaner environment. In a situation in which the overall quality of the environment is low, consumers receive a higher marginal benefit (relief from a relatively strong feeling of guilt) from privately providing abatement.

The implication of this preference structure in the context of the generalized model is that $U_{z_iE} < 0$. The private marginal benefit from purchasing z decreases with improvements in E. By equation 18, $U_{z_iE} < 0$ ensures that $dz_i / d\bar{z} < 0$. Hence, guilt is a sufficient condition for crowding-out of privately provided abatement following regulation.

Status Seeking and Conformism

The third behavioral framework that is consistent with our generalized preference structure is social status seeking and conformism. This hypothesis has been discussed in environmental contexts by, for example, Howarth (1996), Sexton and Sexton (2014), and Delgado, Harriger, and Khanna (2015). While the literature on public economics has identified several behavioral assumptions that can be referred to as "status seeking," we elect to use the more colloquial definition of status that is also referred to as conformism: consumers elect to purchase abatement voluntarily following exogenous improvements in environmental quality to improve or maintain their social positions.

In our generalized framework, social status is characterized by the outcome $dz_i \,/\, d\bar{z} > 0$, which is crowding-in. As we have shown, our definition of social status is consistent with the assumption that U_{z_iE} is greater than 0 in one particular case. It is important to recognize that, in an environmental context, our generalized utility structure is slightly more general than the models considered by Andreoni (1989, 1990) in that, under certain plausible behavioral assumptions, an exogenous improvement in environmental quality coming from an increase in mandatory abatement may induce an increase in voluntary abatement.

Independence of Marginal Utilities

For completeness of our discussion, when our utility function is additively separable in *x*, *z*, and *E*, equation 18 reduces to

$$(19) \qquad dz_i \,/\, d\bar{z} = \frac{-n_2 U_{x_i} U_{EE}}{U_{x_i}(U_{z_iz_i} + n_1 U_{EE}) + PU_{x_ix_i} + (U_{z_i} + U_E)},$$

which is unambiguously negative. Improvements in total environmental quality from $\bar{z}$ do not affect the private marginal utility from *z* and only indirectly affect demand for *z* through its influence on *E*. Under this framework, voluntary abatement is crowded out by mandatory abatement.

Regulation in the General Model

Now that we have developed the generalized consumer framework, have shown that the voluntary market in the general case remains endogenous to mandatory abatement, and have identified multiple potential reactions from the voluntary market to a change in mandatory abatement, we return to our primary question of optimal regulation in the presence of a voluntary market that is endogenous to the level of mandatory abatement.

The Marginal Benefit and Marginal Cost of Regulation

Following our set-up for the regulator's problem for the pure altruism case, the marginal benefit from mandatory abatement in the presence of a voluntary market is given by

$$(20) \quad MB(\bar{z}) =$$

$$\sum_{i=1}^{n_1} \frac{\begin{array}{c}-U_{x_i}(x_i, z_i, E)\left[P^*(\bar{z})\dfrac{dz_i^*(\bar{z})}{d\bar{z}} + \dfrac{dP^*(\bar{z})}{d\bar{z}} z_i^*(\bar{z})\right] + U_{z_i}(x_i, z_i, E)\dfrac{dz_i^*(\bar{z})}{d\bar{z}} \\ + U_E(x_i, z_i, E)\left[n_1\dfrac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]\end{array}}{U_{x_i}(x_i, z_i, E)}$$

$$+ \sum_{j=1}^{n_2} \frac{U_{\bar{z},j}(x_j, z_j, E) + U_E(x_j, z_j, E)\left[n_1\dfrac{dz_i^*(\bar{z})}{d\bar{z}} + n_2\right]}{U_{x_j}(x_j, z_j, E)}$$

where the marginal benefit for the traditional regulator is

$$(21) \qquad MB(\bar{z})^T = \sum_{i=1}^{n_1} \frac{U_E(x_i, z_i, E)n_2}{U_{x_i}(x_i, z_i, E)} + \sum_{j=1}^{n_2} \frac{U_{\bar{z},j}(x_j, z_j, E) + U_E(x_j, z_j, E)n_2}{U_{x_j}(x_j, z_j, E)}.$$

Equations 20 and 21 resemble equations 11 and 15 with the exception of a few additional terms coming from inclusion of the private component, z_i. As before, the first term on the righthand side of equations 20 and 21 represents the marginal benefit from regulation for Type I consumers while the second term represents the marginal benefit for Type II consumers.

The marginal cost of regulation is the same as in the pure altruism model since the marginal cost of mandatory abatement is independent of the structure of the consumer preferences. That is, equations 12 and 16 respectively show the marginal cost of mandatory abatement in the presence of and in the absence of a voluntary market. However, in the general framework, it is not necessarily clear that the marginal cost of mandatory abatement is smaller for the regulator operating with a voluntary market than for the traditional regulator as it is in the pure altruism model. Recall that it is possible in the general model for voluntary abatement to increase following regulation, in which case the marginal cost of mandatory abatement is larger in the presence of a voluntary market than in the traditional setting.

Comparing Regulation: Crowding-out

We first consider the cases under the general utility framework that are characterized by crowding-out of voluntary abatement following regulation ($dz_i \,/\, d\bar{z} < 0$). These cases pertain to the models of guilt, impure altruism, and independence of marginal utilities. Using the revealed preference argument made in the pure altruism model, we know that the marginal benefit for Type I consumers is larger in the presence of a voluntary market than in the traditional setting; in the presence of voluntary abatement markets, the regulator must be able to account for the change in the optimal consumption bundle following regulation. However, the marginal benefit for Type II consumers is smaller in the presence of a voluntary market. Hence, as shown in the pure altruism model, it is not necessarily clear whether the marginal benefit from mandatory abatement is larger in the presence of or in the absence of a voluntary market in cases in which the voluntary market is crowded out by mandatory abatement.

Since the marginal cost of mandatory abatement is smaller in the presence of a voluntary market than in a traditional setting, the intuition developed in the pure altruism framework can be applied here. The marginal benefit for Type I consumers is likely to be larger than the marginal benefit for Type II consumers when the voluntary market is large and smaller when the voluntary market is small relative to the number of Type II consumers. Therefore, when the voluntary market is relatively large and the marginal benefit is thus larger under the nontraditional setting, the regulator will select a higher level of regulation in the presence of a voluntary market than in the traditional setting. Conversely, when the marginal benefit is smaller in the presence of a voluntary market than in the traditional setting, it is not clear if the optimal level of mandatory abatement is higher or lower relative to the traditional setting.

Comparing Regulation: Crowding-in

The last case identified in our general consumer model is social status (conformism) and is characterized by an increase in voluntary abatement in response to regulation. In this case, $dz_i/d\bar{z} > 0$. Notice that the crowding-in of voluntary abatement means that the consumer substitutes away from the numeraire and toward z_i. Applying the revealed preference argument, we know that the regulator sees a higher marginal benefit for Type I consumers, which implies that equation 20 must be larger than equation 21. The regulator also recognizes the greater marginal utility that Type II consumers receive from the increase in voluntary abatement and the larger overall improvement in environmental quality because of crowding-in.

In this case, however, the marginal cost of regulation is larger because of the increase in voluntary abatement following regulation. Given that the marginal cost is greater as well, it is unclear whether the regulator selects a higher level of mandatory abatement in the presence of or in the absence of a voluntary market.

Implications and Conclusions

We build on existing research of multiple behavioral hypotheses regarding private provision of environmental public goods. We use these hypotheses to construct a voluntary abatement market equilibrium and focus on the equilibrium market reactions to a change in mandatory abatement. The primary insight derived from the models is that optimal regulatory policies must account for reactions of voluntary abatement markets. As the relative size and scope of voluntary pollution-abatement markets grow, the insights generated by this study will be increasingly important for environmental policymakers.

Our models are constructed around a basic principle: as long as consumer demand for environmental public goods is driven, at least in part, by the total net level of environmental quality that results, voluntary abatement markets will react to a change in the level of mandatory abatement regulation imposed. To add to the generality of the model, we consider several competing hypotheses of consumer behavior and analyze the voluntary market's reaction to a change in mandatory abatement under each preference structure. In each case, we consider the level of regulatory policy that is optimal when accommodating the voluntary market's reactions.

To make the model more accessible from a practical regulatory perspective, we compare optimal regulation with and without the presence of a voluntary market. Our results show that the optimal level of regulation varies depending on the preference structure involved. The results suggest that the optimal level of regulation in the presence of a voluntary abatement market is likely to be relatively high when the voluntary market is relatively large.

As voluntary abatement and overcompliance continue to gain popularity, it will be increasingly important to (i) continue to study drivers of voluntary investments in environmental quality (Clark, Kotchen, and Moore 2003, Kotchen 2009) and (ii) determine the relative size of the voluntary abatement market. Together, these two factors determine how voluntary markets react to changes in mandatory abatement. For example, it is reasonable to expect that markets for carbon offsets are driven by guilt while markets for more visible abatement efforts, such as hybrid cars and solar panels, are driven by status seeking. Markets for less visible items and goods for personal use, such as recycled products, may be driven primarily by warm glow or biocentric altruism. If voluntary abatement markets turn out to be characterized by consumer preference structures, then, depending on the relative size of the voluntary market, the level of regulation imposed may need to be tailored to the particular market in which it will be imposed.

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