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Abstract

We present a model in which firms voluntarily abate emissions in a market that values environmental quality such that firms can charge a premium for goods that are environmentally friendly. Our results establish conditions under which mandatory abatement crowds out voluntary abatement, or, alternatively, provides an incentive for firms to increase their level of voluntary abatement in order to maintain product differentiation. In addition, we identify cases under which firms that do not abate voluntarily would support mandatory abatement if they are able to collectively pass off (at least part of) the costs of abatement to consumers. Our model predicts that regulatory policies that ignore voluntary abatement are likely to over-regulate non-abating firms compared to the level of regulation that accounts for voluntary abatement if consumer income levels in the green market are relatively high. If consumer income levels in the green market are relatively low, regulation may be ineffective in improving overall environmental quality.

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1 Introduction

Voluntary pollution prevention has been identified as an alternative to traditional regulatory policies for achieving emissions reductions. This has led to both theoretical and empirical analyses regarding the motivation, efficiency, and effectiveness of such voluntary agreements. The theoretical literature has identified several conditions under which firms may voluntarily abate emissions (e.g., Arora and Gangopadhyay (1995), Segerson and Miceli (1998)) and under which voluntary agreements are most likely to be successful and efficient in providing improvements in environmental quality (e.g., Wu and Babcock (1999), Dawson and Segerson (2008)). However, the empirical literature aimed at determining the participation in and success of such programs has been unable to reach a consensus (e.g., Khanna and Damon (1999), Vidovic and Khanna (2007)). Nonetheless, it is generally accepted that a firm will voluntarily abate emissions if the profits obtained under the voluntary abatement agreement are at least as large as the profits obtained in the absence of a voluntary agreement.

Several possible motivations for voluntary abatement have been considered in the literature. One motive is based on the assumption that voluntary abatement is less costly than a mandatory alternative. Therefore, in the presence of a credible regulatory threat, firms may voluntarily abate emissions if they are able to ward off future, costly regulation (Segerson and Miceli (1998)). The assumption that voluntary agreements are less costly is based on the notion that voluntary agreements provide greater flexibility in the methods used to reduce emissions. However, Segerson and Miceli (2008) note that the cost advantage of voluntary agreements occurs primarily because of asymmetric information between the firm(s) and regulator. Improvements in the quality of information available to the regulator erodes the flexibility advantage of voluntary agreements. Dawson and Segerson (2008) use credible regulatory threats in a model with an industry-wide abatement target to analyze the potential for some firms to free-ride on the abatement of others. Their results show that firms always have an incentive to free-ride, however a voluntary agreement can still achieve an optimal level of abatement in the presence of a credible regulatory threat.[1] While all firms prefer not to abate, equilibrium requires that some firms abate in spite of the non-abatement of other firms, in order to avoid the loss in profits that occurs under regulation when the industry does not meet the target. This result relies on the presence and credibility of a regulatory threat.

Another motive for firm participation is the market based motive which does not rely on a credible regulatory threat. Firms that voluntarily abate are able to participate in the green market, and receive a higher price for environmentally friendly products because consumers individually value environmental quality and are willing to pay a higher price, *ceteris paribus*, for environmentally friendly goods. This incentive was studied by Arora and Gangopadhyay (1995), who assumed a duopoly in which firms first choose their level of emissions and then compete over the price charged in the market. While all consumers in their model have identical preferences for environmentally friendly products, differences in income lead to different quantities of abatement demanded. Hence, one firm chooses to abate a relatively large amount of emissions to capture the group of consumers with the highest income. The other firm will choose a relatively low level of abatement and

[1] However, the voluntary agreement does not necessarily provide the optimal level of abatement at least cost.

cater to consumers with relatively low income.[2] An interesting implication is that regulating the low-abatement firm causes the high-abatement firm to increase its abatement in order to further differentiate its product.

Following Arora and Gangopadhyay (1995), we assume consumers are willing to pay for environmental quality. We depart from the notion that firms are coerced into a voluntary agreement in reaction to a regulatory threat and assume that the marginal costs of mandatory and voluntary abatement are the same. In our model, (some) firms voluntarily abate emissions in order to differentiate their products as being environmentally friendly and participate in the green market. Specifically, we assume firms that voluntarily abate receive a higher price than firms that choose not to abate, and thus firms with low marginal costs of abatement find it profitable to reduce emissions. However, we depart from Arora and Gangopadhyay (1995) by abandoning the duopoly model in order to provide a general framework for analyzing market-induced abatement. Using a partial equilibrium analysis to focus on the firms' problem, we model the participation decision of firms, as well as the change in profits following mandatory abatement for firms that voluntarily abate and firms that do not. We compare the mandatory abatement policy in the presence of voluntary abatement to a traditional mandatory policy in which the regulator does not account for green market reactions when choosing the level of mandatory abatement. Differences in consumer income levels in the green market relative to consumer income levels in the brown market identify which conditions most likely result following regulation, and can provide rules of thumb for regulators in choosing the level of regulation in the presence of a green market.

Our model makes four contributions to the existing literature. First, we show that mandatory regulation may crowd out voluntary abatement from green firms. This is contrary to the findings of Arora and Gangopadhyay (1995); our model identifies the result from Arora and Gangopadhyay (1995) as a special case. The intuition for our result stems from the idea that consumers are indifferent between the benefits of environmental quality from mandated abatement and from voluntary abatement. If the regulator imposes a mandatory abatement level on firms that do not voluntarily abate, total environmental quality will increase, *ceteris paribus*, and consumers will be less willing to pay for voluntary abatement from green firms. If the marginal markup that firms command through voluntary abatement declines, firms will reduce their optimal level of voluntary abatement.

Our second contribution is that we identify the case under which firms individually choose not to abate, but support a mandatory abatement policy if it implies a sufficiently large increase in the price received by the firm, resulting in an increase in profits. This result seems counterintuitive. However, if consumers are willing to pay a higher price for green products, mandatory abatement results in an increase in demand in the competitive market at every quantity.[3] This increase in demand guarantees an increase in the competitive market price received by the firm, and makes it possible for firm profits to increase following mandatory abatement.

Third, we show that the relation between the level of mandatory abatement from traditional

[2]The lowest income group chooses not to purchase any level of abatement.

[3]Traditional models do not assume consumers are willing to pay more for abatement; thus the demand curve for the commodity good does not shift following regulation.

regulatory policies that ignore the effects of regulation in the green market and the level of regulation when accounting for changes in the green market depends on the relative magnitudes of the change in environmental quality and firm profitability. We identify conditions under which traditional regulatory policies over-regulate firms that do not voluntarily abate, when mandatory abatement both crowds out and does not crowd out voluntary abatement. Our results are appealing because if the green market reaction to mandatory abatement is large, we expect traditional regulation to over- (or under-) regulate firms that do not voluntarily abate.

Fourth, we show that the relative income disparity between both markets (the market with voluntary abatement and without) can identify which of the cases presented in the paper most likely occur. Policy-makers can use this relative income disparity as a rough guide in determining the likely reaction to mandatory abatement from the green market. Traditional regulatory policies likely over-regulate firms that do not voluntarily abate when the relative income disparity is large. In this case, total environmental quality is likely to be relatively high. Conversely, when the relative income disparity is small, it is not clear as to whether traditional policies over-regulate. It is clear, however, that regulation crowds out voluntary abatement resulting in relatively low environmental quality, possibly even lower than in the absence of regulation. In this case, when the income disparity is relatively low, mandatory abatement may potentially be rendered ineffective at improving environmental quality.

2 Model Structure

2.1 Basic Assumptions

We assume there are two separate markets for a single consumption good, the competitive market and the green market. The consumption good is identical in every respect, except for the level of abatement used during the production of the good. This assumption follows from Arora and Gangopadhyay (1995), and allows for product differentiation based solely on environmental attributes.

The competitive market is characterized by the absence of voluntary abatement, that is, abatement only occurs under mandatory regulation.[4] We label the firms in this market the brown firms. The green market is characterized by the presence of voluntary abatement, i.e., abatement that exceeds minimum regulatory requirements or abatement in the absence of regulation. We refer to the firms in the green market as green firms. We assume all firms are identical to the other firms of the same type (i.e., brown or green), and denote the brown firms with B and green firms with G. We focus on the case in which the level of mandatory abatement is always below the optimal level of voluntary abatement. Hence, green firms are green regardless of the level of mandatory abatement.[5]

The difference between brown and green firms is embodied in the cost structure for each type.

[4] We assume throughout the paper that all firms (at least) comply with minimum legal requirements. See Foster and Gutiérrez (2009) for a model involving firms that (potentially) violate environmental law.

[5] One possible extension of the model is to allow the level of regulation to be binding for both the brown and the originally green firms.

While all firms face increasing marginal costs of abatement, brown firms have higher marginal costs of abatement than green firms. Hence, brown firms require a higher price than green firms in order to voluntarily abate emissions. We assume the cost of abatement borne by each firm is the loss in profits from a reduction in output; abatement requires investment of productive inputs away from production of the commodity good and towards abatement of emissions (Cropper and Oates (1992)).

Following Arora and Gangopadhyay (1995), we assume consumers have a positive but diminishing marginal willingness to pay for environmental quality (positive abatement). This assumption implies that consumers are willing to pay a higher price for a good that is more environmentally friendly, *ceteris paribus*.[6] Thus, green firms are able to charge a markup above the competitive market price, depending on the level of abatement. The green market markup is a reward for any firm that chooses to voluntarily reduce its emissions. We develop the competitive market price and green market markup in the following two sections.

2.2 The Competitive Market Price

Firms that do not voluntarily abate are not able to differentiate their product as being green, and are unable to influence the price they receive in the market. These firms operate in the competitive market and receive the exogenous (to the firm) competitive market price. Our assumption that consumers are willing to pay a higher price for a green product, *ceteris paribus*, allows for an increase in the quantity demanded at every price following regulation. Hence the firm receives a higher price following regulation.[7] The increase in price covers part of the loss in profits from an increase in production costs.

The adjustment in the competitive market price is not the same as the green market markup. Brown firms are still bound by the regulation and are unable to individually influence the price through their abatement. Thus the adjustment in the competitive market price is not a reward for product differentiation. We denote the competitive market price, the total price received by the brown firm, as $P(\bar{z})$, in which $\partial P(\bar{z})/\partial \bar{z} \geq 0$, for some mandatory abatement level, $\bar{z} \geq 0$. For the following analysis, we assume this derivative is strictly positive.

2.3 The Markup

We assume firms operating in the green market are able to exercise some control over the price they receive through their ability to differentiate their product. Our assumption that consumers have

[6] Elfenbein and McManus (2010) provide empirical evidence that consumers are willing to pay a higher price for environmentally friendly goods, among other private goods that provide public benefits.

[7] Traditional models (e.g., Cropper and Oates (1990)) assume the equilibrium market price rises following regulation (e.g., a Pigouvian tax). However, from the perspective of the individual firm, the effect of the tax can be interpreted as an increase in marginal cost, while the equilibrium price received does not change. The magnitude of the increase in marginal cost depends on the share of the tax burden borne by the firm. For any given demand curve, we can identify a shift in the marginal cost such that the equilibrium price received by the firm does not change following regulation. Thus the increase in the competitive market price in our model occurs solely from a shift in the demand curve.

a positive but diminishing marginal willingness to pay for a good that is environmentally friendly, *ceteris paribus*, implies that the markup available to a green firm is increasing at a decreasing rate with the abatement employed by the firm. Hence, the markup is a function of the firm's own level of abatement.

The markup also depends on the aggregate level of environmental quality, which depends on the level of mandatory abatement. Mandatory abatement creates a minimum level of environmental quality; an increase in the level of mandatory abatement implies an increase in environmental quality, *ceteris paribus*. If consumers' marginal willingness to pay for abatement is decreasing as abatement increases, an increase in environmental quality decreases the amount consumers are willing to pay for voluntary abatement. Thus, consumers are willing to pay a higher price for a given level of voluntary abatement in the absence of mandatory abatement than in the presence of mandatory abatement. Mandated abatement increases the aggregate level of environmental quality and reduces the amount consumers are willing to pay for voluntary abatement. Therefore, the markup depends on the level of mandatory abatement; an increase in the level of mandated abatement decreases the markup.

The preceding argument also implies a reduction in the marginal markup following mandatory abatement. Because mandatory abatement increases aggregate environmental quality, *ceteris paribus*, consumers are less willing to pay for marginal abatement. Hence, in addition to decreasing the level of the markup, mandatory abatement decreases the marginal markup. We denote the markup as $\Omega(z_i, \bar{z})$, in which z_i is the abatement undertaken by the i^{th} firm, and $\bar{z}$ is the mandated level of abatement.

Figure 1 shows the markup for a given level of mandatory regulation as a function of the firm's level of abatement. The figure illustrates several features of the model. First, in the absence of regulation, $\bar{z} = 0$, green firms will obtain a markup, $\Omega(z_i, \bar{z})$, for any amount of abatement. This markup corresponds to $\Omega_{\bar{z}_0}$ in Figure 1. Second, as a green firm increases its abatement, the total markup increases, but the marginal markup decreases. Third, given a nonzero level of mandatory abatement[8], $\bar{z} > 0$, the markup only becomes available to firms that voluntarily abate. The markup is zero for firms that abate the mandated level. In addition, the total and marginal markup for any given level of abatement is lower than in the absence of regulation, or for a lower level of mandated abatement.

Consider, for example, an initial level of voluntary abatement $z_i = 2$, shown by the dotted line in Figure 1. In the absence of mandatory abatement, the markup is given by $\Omega_{\bar{z}_0}(z_i = 2)$, shown by point A in the figure. If the regulator imposes a mandatory abatement level $\bar{z} = 1$, the markup is given by $\Omega_{\bar{z}_1}(z_i = 2)$, shown by point B. At this new markup, the total and marginal markup have decreased. The firm's voluntary level of abatement is less differentiated from the competitive market because the firm abates only one unit above the mandatory level instead of two units above the mandatory level as it had prior to regulation. Thus, the total markup decreases. Since demand for abatement is positive but diminishing, consumers are less willing to pay for marginal increases

[8]In Figure 1, the mandatory abatement level is increasing with the subscript on $\bar{z}$, so that $\bar{z}_{i+1} > \bar{z}_i$ for all $i = 0, \ldots, 2$ and $\bar{z}_0 = 0$.

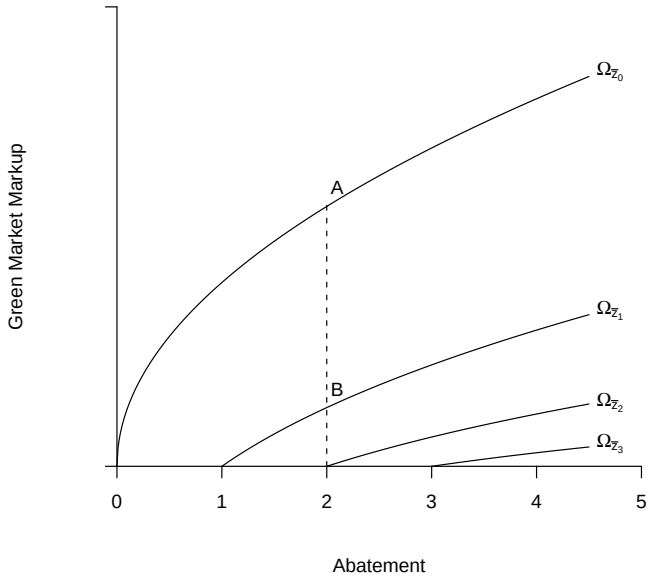

Figure 1: The green market markup, $\Omega(z_i, \bar{z})$.

in abatement following the regulation. Hence the marginal markup falls; the slope of the markup function at B is less than at A.

The above discussion demonstrates that the standard assumption of positive but diminishing marginal willingness to pay (for abatement) has powerful implications regarding the markup obtained by green firms. In the absence of mandatory regulation, small amounts of abatement command a high marginal markup because consumers are unable to otherwise obtain improvements in environmental quality. As environmental quality improves through mandated abatement, consumers are less willing to pay a premium for voluntary abatement. If consumers are indifferent between the benefits from mandated abatement or voluntary abatement, mandatory abatement reduces the reward for firms that voluntarily abate.

We formalize the previous discussion by defining the following derivatives: $\partial\Omega(\cdot)/\partial z_i > 0$ and $\partial^2\Omega(\cdot)/\partial z_i^2 < 0$, while $\partial\Omega(\cdot)/\partial\bar{z} < 0$ and $\partial^2\Omega(\cdot)/\partial\bar{z}\partial z_i < 0$. The first two derivatives refer to the positive and diminishing marginal markup as the firm increases its abatement, *ceteris paribus*. These derivatives capture the extent to which the firm can control the green market price; $\partial\Omega(\cdot)/\partial z_i$ is the marginal markup available to the firm and $\partial^2\Omega(\cdot)/\partial z_i^2$ is the rate at which the marginal markup decreases as abatement increases. The third derivative refers to the decrease in the firm's ability to differentiate its product because of an increase in mandatory abatement. The last derivative refers to the reduction in the marginal markup because of the increase in mandatory abatement. The last two derivatives capture the changes in the markup that the green firm cannot control.

Combining the competitive market price with the markup gives the total price received in the

green market: $[P(\bar{z}) + \Omega(z_i, \bar{z})]$.

3 The Firm's Problem

We assume each firm has a production function, $f_i(z_i)$, in which the only (negative) input is abatement.[9] Since the cost of abatement borne by the firm is a loss in profits from a reduction in output, and the marginal cost of abatement is positive and increasing, increases in abatement lead to marginally greater losses in output. Therefore, $f_i'(z_i) < 0$ and $f_i''(z_i) < 0$. The brown firm, denoted with subscript B, faces higher marginal costs of abatement for any given level of abatement than the green firm, denoted with subscript G, so that $|f_B'(z_B)| > |f_G'(z_G)| > 0$, for all z_B and z_G.

The benefit to the firm from abatement is the increase in price obtained from the markup. The markup is available to all firms, should they choose to voluntarily abate; all firms face the same profit maximizing problem, namely, choosing their optimal level of abatement. We arbitrarily set the initial level of mandatory abatement to zero, $\bar{z} = 0$, but it could also be some positive level without changing the resulting analysis.

The firm's problem is to maximize profits, $\pi_i(z_i)$, by choosing its optimal level of abatement, z_i^*, given the level of mandatory abatement, $\bar{z}$.

$$\max_{z_i} \quad \pi_i(z_i|\bar{z}) = f_i(z_i)[P(\bar{z}) + \Omega(z_i, \bar{z})]. \tag{1}$$

Taking the derivative of equation (1) with respect to z_i yields the first order condition

$$\frac{\partial \pi_i(z_i|\bar{z})}{\partial z_i} = \frac{\partial f_i(z_i)}{\partial z_i}[P(\bar{z}) + \Omega(z_i, \bar{z})] + f_i(z_i)\frac{\partial \Omega(z_i, \bar{z})}{\partial z_i} \leq 0. \tag{2}$$

Equation (2) is made up of two components. The first term is the marginal cost of abatement: the value of the loss in output from a marginal increase in abatement. The second term is the marginal benefit of abatement: the revenue earned from the increase in the markup obtained from a marginal increase in abatement. Rearranging equation (2) yields a trade-off between the marginal cost and marginal benefit of abatement facing each firm:

$$-\frac{\partial f_i(z_i)}{\partial z_i}[P(\bar{z}) + \Omega(z_i, \bar{z})] \geq f_i(z_i)\frac{\partial \Omega(z_i, \bar{z})}{\partial z_i}. \tag{3}$$

The brown firm, by definition, faces a higher marginal cost of abatement, such that the costs outweigh the benefits for each marginal unit of abatement. Hence, brown firms choose the corner solution, $z_B^* = 0$. In this case, the inequality in equation (2) is strictly negative, meaning that any abatement undertaken by a brown firm leads to a loss in profits. Letting $\bar{z} = 0$, brown firm profits are given by $f_B(0)P(0)$.[10]

The green firm, because of a lower marginal cost of abatement, chooses the interior solution,

[9] Dawson and Segerson (2008) make a similar assumption by allowing production to be a function only of emissions.

[10] The markup drops out of the profit equation since $\Omega(z_i, \bar{z}) = 0$ whenever $z_i = 0$.

$z_G^* > 0$, by equating the marginal cost of abatement with the marginal benefit. The benefit from obtaining the markup is enough to offset the cost of the reduction in output for some level of abatement, therefore the firm voluntarily abates. Green profits, assuming initial regulation is zero, is given by $f_G(z_G^*)[P(0) + \Omega(z_G^*, 0)]$.

In general, initial mandatory abatement need not equal zero. Therefore, optimal firm profits can be summarized by the following equation:

$$\pi_i(z_i^*|\bar{z}) = \begin{cases} f_i(z_i^*)P(\bar{z}) & \text{if } z_i^* = \bar{z} \\ f_i(z_i^*)[P(\bar{z}) + \Omega(z_i^*, \bar{z})] & \text{if } z_i^* > \bar{z} \end{cases} \tag{4}$$

4 The Relation Between Mandatory And Voluntary Abatement

By definition, green firms are not subject to the mandatory level of abatement. However, regulation effectively changes the extent to which the green firm can differentiate its product. Because of a reduction in the total and marginal markup, the optimal level of abatement for the green firm changes.

Since the optimal level of abatement, z_G^*, solves equation (2) with strict equality, we must analyze the change in z_G^* from regulation while requiring equation (2) to equal zero. Letting $\pi'_G(z_G|\bar{z})$ denote the marginal profit condition in equation (2), the change in optimal abatement following regulation is

$$\frac{\partial \pi'_G(z_G^*|\bar{z})}{\partial z_G^*} dz_G^* + \frac{\partial \pi'_G(z_G^*|\bar{z})}{\partial \bar{z}} d\bar{z} = 0. \tag{5}$$

Thus, the change in voluntary abatement is

$$\frac{dz_G^*}{d\bar{z}} = -\frac{\partial \pi'_G(z_G^*|\bar{z})/\partial \bar{z}}{\partial \pi'_G(z_G^*|\bar{z})/\partial z_G} \gtreqless 0, \tag{6}$$

which is equivalent to

$$\frac{dz_G^*}{d\bar{z}} = -\frac{\frac{\partial f_G(z_G^*)}{\partial z_G^*}\left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*, \bar{z})}{\partial \bar{z}}\right] + f_G(z_G^*)\frac{\partial^2 \Omega(z_G^*, \bar{z})}{\partial \bar{z} \partial z_G^*}}{\frac{\partial^2 f_G(z_G^*)}{\partial z_G^{*2}}[P(\bar{z}) + \Omega(z_G^*, \bar{z})] + 2\frac{\partial f_G(z_G^*)}{\partial z_G^*}\frac{\partial \Omega(z_G^*, \bar{z})}{\partial z_G^*} + f_G(z_G^*)\frac{\partial^2 \Omega(z_G^*, \bar{z})}{\partial z_G^{*2}}} \gtreqless 0. \tag{7}$$

Since the marginal cost of abatement is increasing at an increasing rate, and the markup is increasing at a decreasing rate with respect to abatement, the denominator is unambiguously negative. The negative denominator and the negative sign in front of equation (7) ensures that the direction of the change in voluntary abatement is the same as the sign of the numerator. The direction of the change in optimal abatement for the green firm depends on the change in marginal profits with respect to the increase in mandatory abatement, *ceteris paribus*.

The numerator of equation (7) can be broken down into two components: the change in the marginal abatement cost, $\frac{\partial f_G(z_G)}{\partial z_G}\left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G, \bar{z})}{\partial \bar{z}}\right]$, and the change in the marginal benefit of abatement, $f_G(z_G)\frac{\partial^2 \Omega(z_G, \bar{z})}{\partial \bar{z} \partial z_G}$. Both changes occur because of regulation. The change in the marginal

cost of abatement depends on the relative magnitudes of the increase in the competitive market price and the decrease in the total markup. The change in the marginal benefit of abatement is always negative. The direction of the change in optimal abatement depends on the relative magnitudes of the changes in the marginal cost and marginal benefit from abatement.

Proposition 1. *The green firm decreases its abatement following regulation if:*

1. *the increase in the competitive market price is greater than the decrease in the green market markup, or*

2. *the increase in the competitive market price is less than the decrease in the markup, and the marginal markup decreases sufficiently.*

Conversely, the green firm increases its abatement following regulation if the increase in the competitive market price is less than the decrease in the markup, and the marginal markup does not decrease sufficiently.

Proof. If the increase in the competitive market price is greater than the decrease in the markup, then $\left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G,\bar{z})}{\partial \bar{z}}\right] > 0$. Thus, the numerator in equation (7) is negative, and the green firm reduces its abatement. This establishes the first part of the proposition.

If the decrease in the markup is greater than the increase in the competitive price, then $\left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G,\bar{z})}{\partial \bar{z}}\right] < 0$. In this case, the sign of the numerator in equation (7) depends on the relative magnitudes of the first and second terms. If the decline in the marginal markup is sufficiently large, such that the second term in the numerator dominates the first, the green firm reduces its abatement. This establishes the second part of the proposition.

The third part of the proposition is similar to the second part because $\left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G,\bar{z})}{\partial \bar{z}}\right] < 0$. Hence, the sign of the numerator in equation (7) depends on the relative magnitudes of the first and second terms. However, if the decline in the marginal markup is small enough, and the first term in the numerator dominates the second, equation (7) will be positive. Thus the green firm increases its abatement. This establishes the third part of the proposition. □

The intuition behind the first part of Proposition 1 is that the marginal cost of a given level of abatement is increasing with the price received by the firm. As the price rises, the value of forgone profits (from the reduction in output) increases. Hence the marginal cost of abatement increases. In this case, the increase in the competitive market price is greater than the decrease in the markup, so the total price received by the firm increases. Since the marginal cost of abatement increases and the marginal benefit of abatement declines, the firm decreases its abatement.

The second part of Proposition 1 begins with a decrease in the price received because the increase in the competitive market price is less than the decrease in the markup. The decrease in price implies that the marginal cost of abatement decreases. When the marginal markup falls sufficiently, so that the decrease in the marginal benefit of abatement outweighs the decrease in the marginal cost, the green firm reduces its abatement. However, the last part of Proposition 1 shows that the green firm increases its abatement if the reduction in the marginal benefit of abatement is

small, relative to the decrease in the marginal cost. If consumers are willing to pay a relatively high marginal markup for voluntary abatement following regulation, i.e. the marginal markup does not decrease sufficiently, the green firm may still find it profitable to further differentiate its product through further abatement.

The cases in which the green firm decreases its abatement following regulation imply that regulation crowds out voluntary abatement. This scenario may arise if consumers' willingness to pay for abatement is relatively low, and is sensitive to the level of mandated abatement. The third case, in which the green firm seeks further product differentiation following mandated abatement, relies critically on a relatively small change in consumers' marginal willingness to pay for abatement. This condition implies a relatively large and inelastic demand for abatement, and is the case studied by Arora and Gangopadhyay (1995).

5 The Change In Optimal Profits Following Mandatory Abatement

We now determine the change in optimal profits for both the brown and green firms following regulation. The brown firm adopts the new level of mandatory abatement, and the green firm shifts from the initially optimal level of abatement to the subsequently optimal level of abatement.

5.1 The Change In Optimal Profits For The Brown Firm

The brown firm does not obtain the markup either before or after regulation, and is subject to the mandated level of abatement, $\bar{z}$. Thus, brown profits are $\pi_B^*(\bar{z}) = f_B(\bar{z})P(\bar{z})$. The change in profits is

$$\frac{\partial \pi_B^*(\bar{z})}{\partial \bar{z}} = \frac{\partial f_B(\bar{z})}{\partial \bar{z}} P(\bar{z}) + f_B(\bar{z}) \frac{\partial P(\bar{z})}{\partial \bar{z}} \gtreqless 0. \tag{8}$$

For any $\bar{z} > 0$, $\partial f_B(\bar{z})/\partial \bar{z} < 0$, since the quantity produced is decreasing in the level of abatement. However, since $\partial P(\bar{z})/\partial \bar{z} > 0$, the change in brown profits following regulation depends on the decrease in output and the increase in the competitive price. The increase in the price increases profits, while the decrease in output decreases profits, *ceteris paribus*.

Proposition 2. *The brown firm's profits increase following regulation if the increase in profits from an increase in the competitive market price is sufficiently large to offset the decline in profits from a reduction in output produced.*

Proof. The first term in equation (8) is negative, and the second term is positive. Hence, the sign of equation (8) depends on the relative magnitudes of the first and second terms. The first term represents the decrease in profits from a reduction in output, valued at pre-regulation prices. The second term is the increase in profits from an increase in the competitive market price following regulation. Thus, when the increase in profits from an increase in the competitive market price is greater than the decrease in profits from a reduction in output, brown profits rise. □

Figure 2 illustrates the intuition for Proposition 2.[11] The firm initially receives a price of $P(0)$ for $f_B(0)$ units produced. Profits are given by the area $P(0) \times f_B(0)$. When $\bar{z}$ is imposed, the firm loses $P(0)$ on each unit it no longer produces, $[f_B(0) - f_B(\bar{z})]$. This area is labeled Loss. Since the competitive price rises, the firm receives the amount of the price increase, $[P(\bar{z}) - P(0)]$, on all remaining units, $f_B(\bar{z})$. This area is labeled Gain. Whether profits rise or fall depends on the relative magnitudes of the gain and loss the firm incurs.

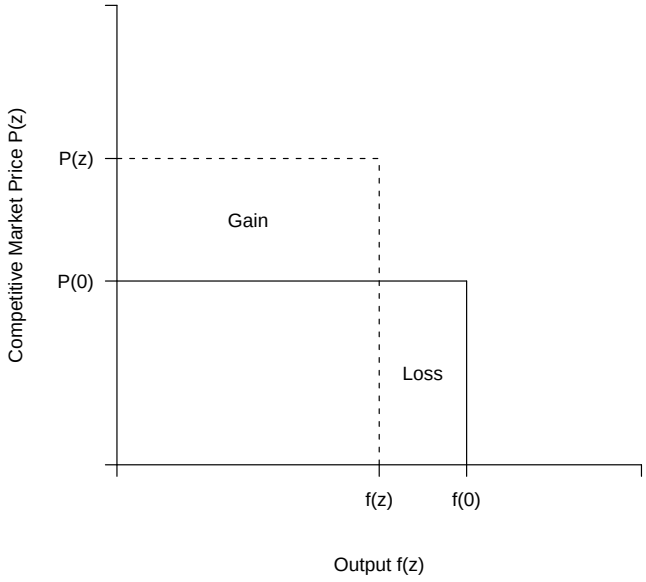

Figure 2: The relative increase and decrease in profits following regulation for the brown firm.

In the absence of regulation, the only benefit from abatement is the markup. By definition, the brown firm does not find it profitable to abate and extract the markup. Therefore, there is no *private* incentive for the brown firm to abate; no individual brown firm is able to influence the price in the competitive market. However, it may be *collectively* better for brown firms to abate if the change in the competitive market price is sufficiently large such that brown firm profits increase. Regulation can have precisely this effect. This case is formalized by the following corollary to Proposition 2.

Corollary 1. *A brown firm is willing to pay the regulator to impose (or not to impose) mandatory abatement if it leads to an increase (decrease) in profits. The maximum amount a firm is willing to pay to impose (or not to impose) the regulation is equal to the positive (or negative) change in profits at that level of mandated abatement.*

Proof. The proof follows from Proposition 2. If the brown firm's profits rise following regulation, the firm is willing to pay any amount up to the rise in profits compared to the pre-regulation

[11] Figure 2 assumes a discrete change in brown profits in order to clearly illustrate the intuition for Proposition 2.

level to impose the regulation. The converse is true if the brown firm's profits decrease following regulation. □

Corollary 1 establishes an interesting result: a firm that would individually choose not to abate may prefer to abate provided that all other competing firms do the same.

5.2 The Change In Optimal Profits For The Green Firm

The change in profits for a green firm is more complicated than for a brown firm, since the green firm chooses z_G^* both in the absence and presence of regulation. However, z_G^* depends on the level of mandatory abatement, $\bar{z}$. Thus, green profits are $\pi_G^*(\bar{z}) = f_G(z_G^*(\bar{z}))[P(\bar{z}) + \Omega(z_G^*(\bar{z}), \bar{z})]$. The change in profits for the green firm is

$$\frac{\partial \pi_G^*(\bar{z})}{\partial \bar{z}} = \frac{\partial f_G(z_G^*(\bar{z}))}{\partial z_G^*(\bar{z})} \frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} [P(\bar{z}) + \Omega(z_G^*(\bar{z}), \bar{z})] + f_G(z_G^*(\bar{z})) \left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}), \bar{z})}{\partial z_G^*(\bar{z})} \frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}), \bar{z})}{\partial \bar{z}} \right] \gtreqless 0. \quad (9)$$

While $\partial \bar{z} > 0$ ensures that $\partial P(\bar{z})/\partial \bar{z} > 0$, it is not clear whether $\partial z_G^*(\bar{z})/\partial \bar{z}$ is greater or less than zero. The sign of $\partial z_G^*(\bar{z})/\partial \bar{z}$ depends on whether the green firm increases or decreases its abatement after the regulation. That is, on whether or not mandatory abatement crowds out voluntary abatement.

Proposition 3. *A green firm's optimal profits increase following regulation if:*

1. *the increase in the competitive market price is greater than the decrease in the markup, regardless of the magnitude of crowding out, or*
2. *the increase in the competitive market price is less than the decrease in the markup and the crowding out of voluntary abatement is sufficiently large.*

Conversely, a green firm's optimal profits decrease following regulation if:

1. *the green firm increases its optimal level of abatement, or*
2. *the increase in the competitive market price is less than the decrease in the markup and the crowding out of voluntary abatement is sufficiently small.*

Proof. The change in optimal profits for a green firm given in equation (9) consists of two terms: the first term is the change in profits because of a change in output, valued at the pre-regulation price received by the firm, and the second term is the change in profits from a change in the price received. The sign of the first term depends on the direction of the change in abatement from the green firm following regulation, and the sign of the second term depends on the relative magnitudes of the increase in the competitive market price and the decrease in the markup.[12]

[12]The markup received by the firm always decreases following regulation because the markup is globally concave, regardless of the change in optimal voluntary abatement. Thus, $\frac{\partial \Omega(z_G^*(\bar{z}), \bar{z})}{\partial z_G^*(\bar{z})} \frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}), \bar{z})}{\partial \bar{z}}$ in equation (9) is always negative.

Condition 1 in the first part of Proposition 3 states that

$$\left[\frac{\partial P(\bar{z})}{\partial \bar{z}}\right] > -\left[\frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial z_G^*(\bar{z})}\frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial \bar{z}}\right].$$

This condition implies that the price received by the firm increases:

$$\left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial z_G^*(\bar{z})}\frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial \bar{z}}\right] > 0.$$

Proposition 1 shows that in this case the green firm decreases its abatement following regulation, $\partial z_G^*(\bar{z})/\partial \bar{z} < 0$. Thus the quantity produced of the commodity good increases: $\partial f_G(z_G^*(\bar{z}))/\partial z_G^*(\bar{z}) > 0$. Therefore, equation (9) is positive, and green profits increase. This establishes Condition 1 in the first part of Proposition 3.

Condition 2 in the first and second parts of Proposition 3 state that

$$\left[\frac{\partial P(\bar{z})}{\partial \bar{z}}\right] < -\left[\frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial z_G^*(\bar{z})}\frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial \bar{z}}\right].$$

Therefore, the price received by the firm decreases

$$\left[\frac{\partial P(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial z_G^*(\bar{z})}\frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial \bar{z}}\right] < 0.$$

In addition, both Conditions 2 state that mandatory abatement crowds out voluntary abatement: optimal abatement decreases, $\partial z_G^*(\bar{z})/\partial \bar{z} < 0$, and output increases $\partial f_G(z_G^*(\bar{z}))/\partial z_G^*(\bar{z}) > 0$. Therefore the first term in equation (9) is positive and the second term is negative. The sign of equation (9) depends on the relative magnitudes of the first and second terms. If the crowding out is sufficiently large, the decrease in voluntary abatement is sufficient so that the first term dominates the second in equation (9). In this case, equation (9) is positive and profits rise. If the crowding out is sufficiently small, the decrease in voluntary abatement is small and the second term in equation (9) dominates the first. In this case, equation (9) is negative, and profits fall. This establishes Condition 2 in the first and second parts of Proposition 3.

Condition 1 in the second part of Proposition 3 states that $\partial z_G^*(\bar{z})/\partial \bar{z} > 0$. Thus the quantity produced decreases: $\partial f_G(z_G^*(\bar{z}))/\partial z_G^*(\bar{z}) < 0$. Proposition 1 shows that in this case the rise in the competitive market price is less than the decrease in the markup:

$$\left[\frac{\partial P(\bar{z})}{\partial \bar{z}}\right] < -\left[\frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial z_G^*(\bar{z})}\frac{\partial z_G^*(\bar{z})}{\partial \bar{z}} + \frac{\partial \Omega(z_G^*(\bar{z}),\bar{z})}{\partial \bar{z}}\right].$$

Therefore, equation (9) is negative, and profits decrease. This establishes Condition 1 in the second part of Proposition 3 and completes the proof. □

The intuition for Condition 1 in the first part of Proposition 3 is straightforward; both the price received and the quantity produced by the firm increase, so profits increase. Condition 1 of the

second part of Proposition 3 deals with the opposite case, in which both the price received and the quantity produced decrease, so profits decrease.

The intuition for Condition 2 in both the first and second parts of Proposition 3 is similar to the intuition for Proposition 2, and is shown Figure 1. The decrease in output decreases firm profits while the increase in the price received increases profits, *ceteris paribus*. The relative magnitudes of these effects determines the change in optimal profits for a green firm.

5.3 Discussion

This section established conditions under which firm profits increase or decrease following regulation. It is not clear *a priori* which case will result following regulation. One lesson that arises through the cases presented so far is that with the exception of the final part of Proposition 1, the green firm reduces its optimal level of abatement following regulation. Typically, mandatory regulation is assumed to increase environmental quality, regardless of the loss in profits realized by the firm. However, this model shows that in the presence of a green market, the incentive for the green firm to reduce its abatement may dampen the effects of the regulation. In the perverse case, in which the reduction in voluntary abatement exceeds the mandated level of abatement, regulation may reduce aggregate environmental quality.

6 The Change In Total Environmental Quality

We now turn to the change in total environmental quality following regulation. Let $z^*_{G_1}$ denote the pre-regulation level of voluntary abatement, and $z^*_{G_2}$ the post-regulation level. In the absence of regulation, environmental quality is determined by $z^*_{G_1}$, since only the green firm undertakes any abatement. Following regulation, total environmental quality is given by $\bar{z}+z^*_{G_2}$: abatement from the brown firm meeting the mandatory level of abatement and the new optimal level of abatement from the green firm.[13] Thus, the net change in environmental quality following regulation is $\bar{z} + \partial z^*_G/\partial \bar{z}$.

Proposition 4. *Total environmental quality increases following regulation if voluntary abatement by the green firm is not crowded out by mandatory abatement by the brown firm.*

Proof. If the green firm increases its abatement following regulation, then $\partial z^*_G/\partial \bar{z} > 0$. Total environmental quality necessarily improves since both the brown and green firm increase their abatement. □

In this case, the green market acts to amplify the effect of regulation. This case may arise in an area in which there is a strong and differentiated green market. Consumers in the green market are not particularly sensitive to mandatory abatement in the competitive market and are still willing to pay a relatively large markup for additional abatement in spite of the increase in environmental quality from regulation.

[13] This representation for total environmental quality assumes only one brown firm and one green firm.

If mandatory abatement crowds out voluntary abatement, but the green firm reduces its abatement by less than the regulated amount, environmental quality will still increase, but the reduction in green market abatement dampens the effect of regulation. In the extreme case, environmental quality declines relative to the pre-regulation level if the green firm decreases its abatement by more than the level of mandated abatement. This case may arise if consumers are sensitive to change in environmental quality, so that given an improvement in environmental quality from regulation the marginal markup for the green firm decreases substantially.

7 Regulation

7.1 Do Not Ignore The Green Market

The reaction of voluntary abatement to mandated abatement makes the resulting level of environmental quality ambiguous. Consider the case in which the regulator's goal is to obtain the level of environmental quality associated with some target level of abatement, $\tilde{z}$. In the absence of a green market, the regulator sets the mandated level of abatement equal to the target level: $\bar{z} = \tilde{z}$. The previous section shows that in the presence of a green market, setting the mandated level of abatement equal to the target level does not achieve the target level of environmental quality. Therefore, the regulator must consider the reaction in the green market when setting the level of mandatory abatement.

When the firm chooses its optimal abatement, it compares its private costs (the loss in output) to its private gain (the increase in price received). The regulator, however, also accounts for the external benefits from abatement, namely, the change in environmental quality. We compare the level of mandated abatement from traditional regulatory policy to the level from regulation in the presence of a green market. Traditionally, there is no green market or increase in the competitive market price. The only benefit of regulation is the improvement in environmental quality. This is the benchmark case because traditionally regulation is assumed to improve environmental quality by forcing brown firms to abate emissions, regardless of the associated loss in profits.

7.2 Traditional Regulation

Traditionally, the regulator only considers the competitive market when setting the level of mandatory abatement, and assumes the competitive market price is constant at $\bar{P} = P(0)$. Thus, he only considers the value of the change in environmental quality, $v(z_B)$, and the loss in competitive market value from a reduction in output as the competitive firm adopts the mandated level of abatement. In this case, the regulator faces the problem:

$$\max_{z_B} \quad v(z_B) + f_B(z_B)\bar{P}. \tag{10}$$

This problem yields the following first order condition:

$$\frac{\partial v(z_B)}{\partial z_B} + \frac{\partial f_B(z_B)}{\partial z_B}\bar{P} = 0, \tag{11}$$

or

$$\frac{\partial v(z_B)}{\partial z_B} = -\frac{\partial f_B(z_B)}{\partial z_B}\bar{P}. \tag{12}$$

Thus, in the traditional case the regulator chooses the level of mandatory abatement, $\bar{z} = z^*_{B_T}$, where the marginal benefits of regulation, namely the value of a marginal improvement in environmental quality, is equal to the marginal cost of regulation, namely the loss in competitive market profits that occurs because of a reduction in output.

7.3 Regulation In The Presence Of A Green Market

7.3.1 The Regulator's Problem

Now consider the case in which some firms operate in the competitive market and others in the green market. As in the traditional case, the regulator directly determines abatement in the competitive market. However, because voluntary abatement is a function of the competitive market level of abatement, the regulator must account for changes in the green market when setting mandatory abatement. The regulator's problem is:

$$\max_{z_B} \quad v(z_B, z_G(z_B)) + f_B(z_B)P(z_B) + f_G(z_G(z_B))[P(z_B) + \Omega(z_G(z_B), z_B)]. \tag{13}$$

The first order condition is

$$\begin{aligned}\frac{\partial v(z_B, z_G(z_B))}{\partial z_B} + \frac{\partial v(z_B, z_G(z_B))}{\partial z_G(z_B)}\frac{\partial z_G(z_B)}{\partial z_B} + \frac{\partial f_B(z_B)}{\partial z_B}P(z_B) + f_B(z_B)\frac{\partial P(z_B)}{\partial z_B} \\ + \frac{\partial f_G(z_G(z_B))}{\partial z_G}\frac{\partial z_G(z_B)}{\partial z_B}[P(z_B) + \Omega(z_G(z_B), z_B)] \\ + f_G(z_G(z_B))\left[\frac{\partial P(z_B)}{\partial z_B} + \frac{\partial \Omega(z_G(z_B), z_B)}{\partial z_G}\frac{\partial z_G(z_B)}{\partial z_B} + \frac{\partial \Omega(z_G(z_B), z_B)}{\partial z_B}\right] = 0.\end{aligned} \tag{14}$$

Equating the marginal social benefits with the marginal social costs,[14] equation (14) becomes

$$\begin{aligned}\frac{\partial v(z_B, z_G(z_B))}{\partial z_B} + \frac{\partial v(z_B, z_G(z_B))}{\partial z_G(z_B)}\frac{\partial z_G(z_B)}{\partial z_B} = \\ - \frac{\partial f_B(z_B)}{\partial z_B}P(z_B) - f_B(z_B)\frac{\partial P(z_B)}{\partial z_B} - \frac{\partial f_G(z_G(z_B))}{\partial z_G}\frac{\partial z_G(z_B)}{\partial z_B}[P(z_B) + \Omega(z_G(z_B), z_B)] \\ - f_G(z_G(z_B))\left[\frac{\partial P(z_B)}{\partial z_B} + \frac{\partial \Omega(z_G(z_B), z_B)}{\partial z_G}\frac{\partial z_G(z_B)}{\partial z_B} + \frac{\partial \Omega(z_G(z_B), z_B)}{\partial z_B}\right].\end{aligned} \tag{15}$$

The marginal social benefit on the left-hand side of equation (15) is the value of the change in

[14] Our use of the term 'social' acknowledges that the regulator considers the changes in environmental quality when setting the level of mandatory abatement which are not considered by firms in the private problem.

environmental quality following regulation. The marginal social cost of regulation, on the right-hand side of equation (15) is made up of two parts: the change in competitive market profits and the change in green market profits. The first two terms on the right-hand side of equation (15) reflect the change in competitive market profits; the last two terms reflect the change in green market profits. The marginal social cost from the change in competitive market profits is smaller in equation (15) than in equation (12) because in equation (15) the regulator takes into account the increase in profits from an increase in the competitive market price following regulation. The solution to equation (15), $\bar{z} = z^*_{B_{GM}}$, depends on the reaction of voluntary abatement to regulation. We consider both cases in which there is no crowding out and crowding out of voluntary abatement following regulation.

7.3.2 Regulation Without Crowding Out

From Propositions 1 and 3, when the green firm increases its abatement following regulation, profits fall. Thus, the net change in profits for the green market in equation (15) is negative. This implies a net increase in the marginal social cost of regulation, compared to the traditional regulation model. The marginal social benefit of regulation in equation (15), compared to equation (12), is larger by the increase in environmental quality from green firms.

Thus, a trade-off between the marginal social benefit and marginal social cost of regulation determines the level of mandatory abatement in the presence of a green market and its relation to mandatory abatement in the traditional case, $z^*_{B_T}$. The marginal social benefit is the improvement in environmental quality from further voluntary abatement from the green firm; the marginal social cost is the net decrease in green profits plus the net change in brown profits. When the value of the increase in the environmental quality is larger than the decrease in green profits plus the net change in brown profits, mandatory abatement in the presence of a green market is larger than traditional mandatory abatement, $z^*_{B_{GM}} > z^*_{B_T}$. Otherwise, mandatory abatement in the presence of a green market is at most as large as traditional mandatory abatement, $z^*_{B_{GM}} \leq z^*_{B_T}$.

7.3.3 Regulation With Crowding Out

Now consider the case in which regulation crowds out voluntary abatement; two different cases arise. In one case, green profits rise; in the other case the change in green profits depends on the relative strengths of two different terms: the loss in profits from a reduction in output, and the gain in profits from a higher price received by the firm.

Consider first the case in which green profits increase and the net change in green profits on the right-hand side of equation (15) is positive. The marginal social cost in equation (15) decreases relative to marginal social cost in equation (12) by the net increase in green profits, for a given change in brown profits. The marginal social benefit in equation (15) decreases by the value of the decrease in environmental quality from green firms. Thus, there is a trade-off between the net increase in profits in the green market, the net change in competitive market profits, and the decrease in voluntary abatement. This trade-off determines the relationship between the level of

mandatory abatement in the presence of a green market and the level of abatement under traditional regulatory policies. If the sum of the net increase in green profits and the increase in competitive market profits exceeds the value of the decrease in environmental quality, $z^*_{B_{GM}} > z^*_{B_T}$, otherwise $z^*_{B_{GM}} < z^*_{B_T}$.

Now consider the case in which the change in green profits is ambiguous. There again exists a trade-off between the net change in green market profits, the decrease in environmental quality from green firms, and the net change in competitive market profits.

Proposition 5. *Traditional regulation over-regulates the competitive market, compared to regulation in the presence of a green market, if*

1. *in the no crowding out case, the loss in green market profits is greater than the sum of the value of the increase in environmental quality in the green market and the increase in profits in the competitive market from an increase in the competitive market price, or*

2. *in the crowding out case, the value of the loss in environmental quality in the green market is greater than the net increase in profits in the green market and the increase in competitive market profits from an increase in the competitive market price.*

Proof. The proof follows directly from the above discussion. □

The intuition for Proposition 5 is straightforward. If the regulator does not consider consumers' green preferences, he fails to take into account the net change in brown firm profits, the net change in green firm profits, and the reaction of voluntary abatement to mandatory abatement. Therefore the marginal social benefit and marginal social cost in the traditional model are not accurate. The relative magnitudes of the changes in brown firm profitability, green market profits, and voluntary abatement determine the relationship between traditional regulation and regulation in the presence of a green market. The level of mandatory abatement in the presence of a green market can be either higher or lower than the traditional regulation level.

8 Consumer Income In The Green Market

Thus far, we have presented a general framework for analyzing the firm's decision to voluntarily abate emissions in the face of a green market markup, as well as firm profitability in the presence of regulation. We have compared the regulatory policy that accounts for green preferences with the traditional policy, and have identified cases under which traditional regulation may over- or under-regulate the competitive market. We now address the conditions under which each of the cases most likely occurs.

8.1 Consumer Income And The Green Market Markup

Arora and Gangopadhyay (1995) state that high income consumers have a higher marginal willingness to pay for abatement than low income consumers, since their opportunity cost of consuming

abatement is lower. Wealthier consumers must forgo less consumption (of the composite commodity, for example) in order to consume abatement. The markup in the green market depends, by definition, on consumers' total and marginal willingness to pay for abatement. Following the intuition in Arora and Gangopadhyay (1995), we make the following claims regarding the markup and the changes in the total and marginal markup following regulation.

First, a green market with relatively high income consumers is likely to have a higher total and marginal markup for any given level of abatement, relative to a green market with relatively low income consumers, *ceteris paribus*.[15] If high income consumers have a relatively high marginal willingness to pay for voluntary abatement, green firms are able to extract a relatively higher markup for a given level of abatement. However, if consumers are less willing to pay for abatement, green firms extract a relatively lower markup. Furthermore, if the marginal willingness to pay for abatement is higher for high income consumers relative to low income consumers, green firms obtain a higher marginal markup in a relatively high income market than in a relatively low income market, *ceteris paribus*.

Figure 3 provides an example of the markup extracted by the green firm for high and low income consumers. The markup with high income consumers is denoted Ω_H, and the markup with low income consumers is Ω_L. At any given level of abatement, the high income markup is both higher and steeper than the low income markup, implying a higher total and marginal markup for the high income market.

Second, the change in the total markup following regulation is larger in the high income green market relative to the low income green market. Consider the example shown in Figure 3; by definition, the markup is available only to firms that voluntarily abate. The markup is unavailable to any firms that choose to abate the mandated level. When mandated abatement increases, e.g., from $\bar{z} = 0$ to $\bar{z} = 1$ in Figure 3, the markup must equal zero at $z_i = \bar{z} = 1$, regardless of the income level of consumers in the green market. Hence, the decrease in the total markup (which is represented by a downward shift of $\Omega(\cdot)$ in the figure) must be large in the high income market, since it must decrease by an amount equal to Ω_A. The markup in the low income market must decrease by an amount equal to Ω_B. Thus the decrease in the markup following regulation must be larger in the high income green market relative to the low income green market, *ceteris paribus*.

Third, the change in the marginal markup, following regulation, is smaller in the high income green market, relative to the low income green market. If high income consumers have a relatively higher marginal willingness to pay for abatement, their demand for abatement is likely to be less sensitive to the level of mandatory abatement. Low income consumers, on the other hand, are sensitive to the level of mandated abatement, since they have a relatively lower marginal willingness to pay for abatement. Low income consumers are more likely to substitute away from abatement following regulation.

We, therefore, summarize the effects of regulation on the markup for low and high income

[15] We assume there exists consumers whose income is sufficiently low such that they participate in the competitive market. Thus, high and low income consumers refer to the relative level of income of the green market consumers.

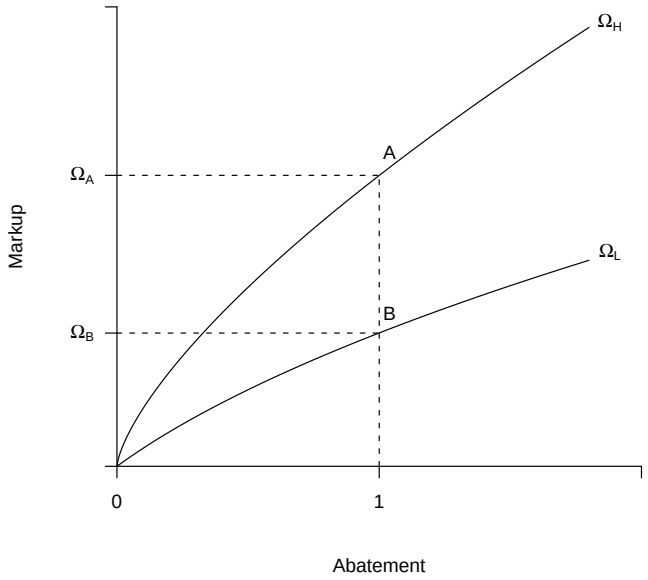

Figure 3: Markup for high income consumers, Ω_H, versus low income consumers, Ω_L.

consumers as:[16]

$$\text{Low Income} = \begin{cases} \dfrac{\partial \Omega(z_i, \bar{z})}{\partial \bar{z}} \approx 0 & \text{Decrease in total markup is relatively small} \\ \dfrac{\partial^2 \Omega(z_i, \bar{z})}{\partial \bar{z} \partial z_i} < 0 & \text{Decrease in marginal markup is relatively large} \end{cases} \tag{16}$$

$$\text{High Income} = \begin{cases} \dfrac{\partial \Omega(z_i, \bar{z})}{\partial \bar{z}} < 0 & \text{Decrease in total markup is relatively large} \\ \dfrac{\partial^2 \Omega(z_i, \bar{z})}{\partial \bar{z} \partial z_i} \approx 0 & \text{Decrease in marginal markup is relatively small} \end{cases} \tag{17}$$

8.2 Using Consumer Income To Identify Changes In Green Market Abatement

The summary in (16) and (17) sheds light on the relative magnitudes of the changes in the total and marginal markup following regulation. For a *given change* in the competitive market price, these changes in the markup determine the change in the optimal levels of abatement and profits for green firms.

Returning to Proposition 1, green firms increase their abatement following regulation if the increase in the competitive market price is less than the decrease in the markup, while the marginal markup does not decrease sufficiently. This is likely to be the case when consumers in the green

[16] We refer to relatively small partial effects in equations (16) and (17) as being approximately zero to distinguish them from partial effects that are relatively large in magnitude.

market are high income consumers, and follows from the changes in the markup for high income consumers summarized in (17). If the decrease in the total markup is relatively large, it is likely that it is larger in magnitude than the increase in the competitive market price. Since the decrease in the marginal markup is relatively small, green firms increase their abatement.

Conversely, crowding out occurs if green market consumers have relatively low income. Proposition 1 states that regulation crowds out voluntary abatement if either the increase in the competitive market price is larger than the decrease in the markup, or the decrease in the markup is larger than the increase in the competitive market price and the decrease in the marginal markup is relatively large. From (16), it is unclear whether or not the change in the competitive market price is larger than the decrease in the total markup, since the change in the total markup is small. However, the change in the marginal markup in equation (16) is relatively large. If the increase in the competitive market price is smaller than the decrease in the markup, green firms reduce their optimal level of abatement because of the relatively large decrease in the marginal markup. Conversely, if the increase in the competitive market price is larger than the decrease in the markup, green firms reduce their abatement regardless of the decrease in the marginal markup. Therefore, the crowding out conditions in Proposition 1 are satisfied.

Our analysis is intuitively appealing since green firms only increase their abatement if further product differentiation is profitable. Green product differentiation is possible if consumers are willing to pay a relatively high markup for voluntary abatement. Following Arora and Gangopadhyay (1995), green market consumers are willing to pay a greater amount for abatement if they have a relatively high income. If consumers in the green market have relatively low incomes, their marginal willingness to pay is more sensitive to mandated abatement, and green firms will be less able to differentiate their products following regulation.

8.3 Using Consumer Income To Identify The Level Of Regulation In The Presence Of A Green Market

We now apply the insights regarding the link between changes in the markup following regulation and consumer income levels in the green market to the issue of regulation in the presence of green preferences. Our goal is to develop a rule-of-thumb for determining whether traditional regulatory strategies are likely to over- or under-regulate the competitive market.

8.3.1 Traditional Regulation vs Regulation In A Green Market With High Income Consumers

If consumers in the green market have relatively high incomes, green firms increase their abatement following regulation. The relevant first order condition for choosing mandatory abatement is given by equation (15).

The first order condition consists of three different terms: the net changes in environmental quality, brown firm profits, and green firm profits. Letting $\partial \pi_B(z_B)/\partial z_B$ denote the change in brown profits and $\partial \pi_G(z_G(z_B))/\partial z_B$ the change in green profits, we rewrite equation (15) as:

$$\frac{\partial v(z_B, z_G(z_B))}{\partial z_B} + \frac{\partial v(z_B, z_G(z_B))}{\partial z_G(z_B)} \frac{\partial z_G(z_B)}{\partial z_B} = -\frac{\partial \pi_B(z_B)}{\partial z_B} - \frac{\partial \pi_G(z_G(z_B))}{\partial z_B}. \tag{18}$$

From Proposition 3, in the no crowding out case, optimal profits for green firms decrease. Therefore the net change in green profits is negative (or $-\partial \pi_G(z_G(z_B))/\partial z_B$ is positive). The net change in brown firm profits is not known. However, for a given change in the competitive market price and for a given production technology, the change in brown profits is constant.[17] We can use the relative income level of consumers in the green market to identify the relative magnitudes of the increase in environmental quality in the green market and the decrease in profits in the green market. By comparing the relative magnitudes of the increase in environmental quality and the decrease in green profits to the first order condition for the traditional regulator, we determine whether or not the traditional regulator sets the level of mandatory abatement too low or too high.

If consumer income in the green market is relatively high, the loss in green profits is likely to be large following regulation. The decrease in the total markup is large when consumer income levels are high, and this decrease becomes larger as relative income levels in the green market increase. Thus, the price received by green firms decreases substantially following regulation. This decrease results in a large decrease in green profits and the decrease in profits increases as relative incomes increase. Thus, relatively high income in the green market results in a large loss in profits following regulation.

Next, consider the magnitude of the increase in environmental quality in the green market. If consumer income levels are relatively high, the total and marginal markup is relatively high at every level of abatement compared to a green market with relatively low income consumers. Thus, the pre-regulation level of voluntary abatement is likely to be relatively large, i.e., $z^*_{G_1}$ is large. The change in the marginal markup following regulation is likely to be small. Therefore, the increase in environmental quality from the increase in voluntary abatement by the green firm is likely to be small.

Combining the large decrease in green firm profits with the small increase in voluntary abatement, we compare the abatement condition in the traditional setting, equation (12) and the abatement condition with a green market, equation (18). We find that traditional regulation likely sets the level of abatement too high in the presence of a green market. For a given change in brown firm profits, the marginal benefit of regulation with a green market is larger than the marginal benefit of traditional regulation by the increase in green market abatement. The marginal cost is larger by the decrease in green firm profits. Since the loss in green market profits is likely to be large, while the increase in green market abatement is likely to be small, compared to the traditional regulation case, the marginal cost of regulation is substantially higher in the presence of a green market, while the marginal benefit is not. The traditional regulator substantially underestimates the costs of regulation, and over-regulates the competitive market relative to the level that accounts for green preferences.

The intuition for this result is straightforward. If green market consumers have relatively high

[17] Both the competitive market price and production technology are exogenous to the firm.

income levels, then green firms have a strong incentive to differentiate their products as being environmentally friendly, since consumers are willing to pay a high price for green products. When the regulator reduces green firms' ability to differentiate their products, it follows that green firms experience a substantial decline in profits. Even though green firms pursue further voluntary abatement following regulation, the increase is environmental quality most likely is small. Therefore, while the increase in environmental quality in the green market amplifies the environmental effect of regulation, the loss in green market profits outweighs the environmental benefits. The resulting level of regulation that accounts for green preferences is therefore lower than in the traditional case.

8.3.2 Traditional Regulation vs Regulation In A Green Market With Low Income Consumers

We now compare traditional regulation to the level of regulation in the presence of a green market for the low income case. When consumer income in the green market is relatively low, the marginal markup decreases substantially following regulation. Thus the green firm decreases its voluntary abatement substantially. This decrease in abatement implies a large increase in output of the commodity good (since production is decreasing in abatement). The decrease in the total markup is likely to be relatively small, and it is unclear as to whether the increase in the competitive market price is greater or less than the decrease in the total markup. For a given increase in the competitive market price, it is likely that the change in the price received by the green firm, $[P(z_B) + \Omega(z_G(z_B), z_B)]$, is small. Since the decrease in voluntary abatement is large, the increase in green profits is likely to be large.[18] Thus, when consumer incomes are relatively low, it is likely that the green firm substantially decreases its voluntary abatement following regulation and obtains a large increase in profits.

Comparing the first order condition in equation (18) to the traditional regulator's first order condition, equation (12), it is unclear as to whether the increase in the marginal benefit of regulation is larger or smaller than the increase in the marginal cost. Therefore, it is not clear as to whether the traditional regulator over- or under-regulates, relative to regulation in the presence of a green market.

Assuming that the purpose of regulation is to improve environmental quality, it is clear that in the low income case, the large reduction in voluntary abatement following regulation drastically dampens and possibly negates the improvements in environmental quality gained from mandatory abatement. From a strictly environmental perspective, the regulator must use caution when setting the level of mandatory abatement if consumer income in the green market is relatively low. Regulation may potentially result in only marginal improvements in environmental quality, if not a reduction in environmental quality.

[18] Profits are determined by the equilibrium price and quantity. If the equilibrium price remains relatively constant, but equilibrium quantity increases substantially, the increase in profits is likely to be large.

8.4 Income Inequality And Mandatory Regulation

We take the income levels of consumers in the competitive market as a fixed, benchmark level, with which to compare the level of incomes in the green market. Thus, variation in green market income levels implies differences in social income inequality: high income consumers in the green market implies greater social income inequality. If consumers in the green market have relatively low incomes, social income inequality is lower.

When social income inequality is large, the traditional regulator likely over-regulates the competitive market, yet total environmental quality is relatively high following regulation. Relatively high environmental quality follows from the increase in voluntary abatement following regulation. It is safe, strictly from an environmental perspective, to regulate the competitive market when income inequality is high.

However, when income inequality is relatively low, it is unclear as to whether or not a traditional regulator over- or under-regulates the competitive market. Regulation is potentially unable to sufficiently influence environmental quality, or in the perverse case lowers environmental quality, since the reduction in voluntary abatement counteracts improvements in environmental quality from regulated brown firms. Therefore, mandatory regulation may be ineffective in the presence of a green market when social income inequality is relatively low. On the other hand, a green market implies that environmental quality is higher in the absence of regulation compared to the analogous setting without a green market.

9 Conclusion

The lessons from the model presented in this paper are the following. First, we reaffirm the results of Arora and Gangopadhyay (1995) that credible regulatory threats are not necessary to induce voluntary abatement from profit maximizing firms. Rather, when there is a green market, firms have the incentive to voluntarily decrease their emissions to differentiate their products from others. However, contrary to Arora and Gangopadhyay (1995), we show that mandatory abatement need not always compel green firms to increase their voluntary abatement to further differentiate their product. Rather, increased voluntary abatement seems to be the special case, occurring when the marginal markup does not diminish substantially following regulation.

Second, we show that when brown firms are able to collectively share the costs of abatement with consumers through an increase in the competitive market price, brown profits may rise and brown firms may support regulation.

Third, the level of regulation depends critically on the reaction of the green market to regulation in the competitive market, regardless of the fact that mandatory abatement is not binding for green firms. Therefore, the regulatory authority must use caution when imposing mandatory abatement in the presence of a green market. In the extreme case, regulation in the competitive market decreases the overall level of abatement if voluntary abatement falls far enough to offset the improvements in environmental quality from regulation.

Relative income levels of consumers in the green market can be helpful in determining whether or not traditional regulatory policies will likely be effective in the presence of a green market. We hypothesize that when social income inequality is high, traditional regulatory policies likely over-regulate the competitive market, but total environmental quality is relatively high. Conversely, when social income inequality is relatively low, abatement from traditional regulatory policies may not be far from the optimal level, however total environmental quality is relatively low.

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