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Voluntary Approaches and the Use of Less Polluting Products

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I. Introduction

There is a growing interest in the use of voluntary approaches (VAs) as an alternative to more traditional approaches to environmental protection, such as regulation or taxation. This interest has spurred a number of theoretical and empirical studies of VAs.[1] This literature addresses a number of different possible impacts of VAs, including impacts on environmental performance, firm profitability, and market structure. Most of this literature has focused on VAs that seek to reduce the pollution generated by firms in their production processes, and the motivation to do so that can stem from, for example, consumer demand (i.e., "green" preferences) or regulatory threats.

In some cases, however, the environmental impact of a firm's activities comes not from its production but rather from the consumption of its products. An example is products whose use entails the consumption of large amounts of energy (e.g., appliances such as washing machines, computers or lighting) or large amounts of water. Such products are particularly important in the context of greenhouse gas emissions and global warming and water scarcity in areas such as the western U.S.

When voluntary impacts stem from a product's consumption rather than its production, a voluntary approach might take the form of some firms within an industry choosing voluntarily to produce a more energy or water efficient product. A subset of firms within the industry may seek to do so in an effort to differentiate their product and

[1] See, for example, Segerson and Li (1999), Khanna (2001), Lyon and Maxwell (2001), and Alberini and Segerson (2002) for recent surveys of the literature on voluntary approaches to environmental protection.

appeal to green consumers. Alternatively, a voluntary approach could take the form of a firm or group of firms (possibly even an entire industry) agreeing to stop producing products that are not efficient, i.e., agreeing to produce only efficient products. In this case, all firms produce an identical product and hence there is no product differentiation. For example, several years ago the principal European producers and importers of clothes washing machines (comprising 95% of the EC market) agreed to stop producing for and importing into the European Union washing machines that have low energy efficiency and hence high associated emissions (Martinez Lopez, 2000). This agreement was aimed at eliminating from the market products that do not meet certain environmental criteria. Similar agreements have also been made for household dishwashers and water heaters (Martinez-Lopez, 2002). In the U.S. a recent negotiated agreement between EPA and manufacturers of washing machines commits the entire industry to energy efficiency standards for all washing machines that exceeds the previous Energy Star voluntary standards (Paton). The near 100% participation in the U.S. EPA's Energy Star Office Products Program for computers has effectively eliminated low efficiency models from the market (Paton).

A key feature of the above agreements is that firms collectively agreed not to produce the low efficiency (polluting) product. In contrast, in the standard literature on voluntary abatement, firms are typically assumed to make individual or unilateral decisions about polluting processes or products.[2] For example, a firm could voluntarily decide to produce a "green" rather than a "brown" product in an effort to differentiate its product and appeal to green consumers **(e.g., Arora and Gangopadhyay, 1995)**. Given this, the question is what, if anything, is to be gained by a collective agreement?

[2] See the references in the surveys cited in footnote 1.

There are a number of different perspectives from which the potential gains from the agreement can be evaluated, all of which contribute to its impact on social welfare. The first is environmental quality. Clearly, if the VA leads to elimination of the polluting product from the market, then relative to the case of no reduction or partial reduction in its production, it will improve environmental quality. In fact, the potential environmental benefits lead the European Commission to grant anti-trust exemptions for the washing machine, dishwasher, and water heater agreements, despite concerns about the implications for competition (Martinez-Lopez, 2000, 2002).

The second perspective for evaluating the collective agreement is that of consumers. Elimination of the low efficiency product clearly eliminated the potential for product differentiation and hence consumer choice. In addition, it can affect the level of competition among producers and thus affect the price of products that remain on the market (i.e., the high efficiency products). The combination of these effects will determine the impact of the agreement on consumers.

Finally, the collective agreement can be evaluated from the perspective of producers. Most analyses of VAs assume that the voluntary actions undertaken by firms are costly and hence reduce producer profits. In the dishwasher and water heater agreements noted above, it was clearly recognized that the agreement would restrict each manufacturer's freedom to produce and market its products (Martinez-Lopez, 2002). For this reason, it is often believed that some external pressure, such as a regulatory threat, is necessary to induce firms to undertake those actions.[3] **(refs)**. In fact, Paton (date?) states that the agreement among U.S. washing machine manufacturers was influenced by the

[3] Examples of theoretical studies that consider the role of external pressures are Segerson and Miceli (1998), Maxwell, Lyon and Hackett (2000), and Lutz, Lyon and Maxwell (2000). Empirical evidence regarding these pressures is presented in Khanna and Anton (2002).

threat of regulation. Despite the restrictions it places on manufacturer choices, the impact of a collective agreement on producer profits is unclear. An interesting question is whether such an agreement might ever actually be beneficial to the firms in the industry. In particular, could the possibility of eliminating one product and thereby focusing demand on another (perhaps more profitable) product ever result in all firms earning higher profits with the agreement than without it?[4] If so, the industry impact would be quite different from what is conventionally assumed. Of course, in this case one might ask why these firms had not previously agreed to remove the product from the market if they could benefit from doing so. Did the agreement play some role in inducing an outcome that was beneficial to all firms but not possible otherwise?

In this paper we develop a simple model of a market in which there are two possible versions (models) of a particular product, a high polluting (low efficiency) model and a low polluting (high efficiency) model. While our model is motivated by the examples of energy-efficient appliances given above (and the discussion in the text reflects this), the analysis is relevant to other context as well (e.g., water use). We use the model to examine the impacts of voluntary initiatives to take the low efficiency model off the market. We consider first the simplest case in which the market is a monopoly and compare the equilibrium where the monopolist is free to produce both models to the equilibrium where it agrees to produce only the high efficiency model. The results here are fairly standard, but they allow us to establish a benchmark regarding the impact of eliminating the competition between the two models. We then examine the more interesting case of a duopoly, in which there is the potential for competition not only

[4] Without any formal analysis, Paton claims that such agreements prevent non-participating firms from undercutting the prices of participating firms.

between the two models as in the monopoly case but also between the two firms. In this context, we compare the equilibria under three scenarios: (A) the pre-agreement scenario, in which both firms produce both models,[5] (B) the scenario under the agreement, in which both firms commit not to produce the low efficiency model, and (C) a hypothetical scenario in which one firm unilaterally commits not to produce the low efficiency model but the other firm does not.

We show that, in the context of a duopoly, even when the firms were both producing both models prior to the agreement, it is possible that a collective agreement will actually increase profits for both firms, suggesting that the agreement is actually beneficial to the industry. Thus, what might at first appear to be a costly move undertaken by the industry to promote environmental protection may, in fact, be a profitable move by the industry. However, even if the collective agreement is profitable for both firms, both firms unilaterally committing to produce only the high efficiency model is not a Nash equilibrium. If one firm unilaterally commits not to produce the low efficiency model, the other firm will choose to produce it. As a result, the firm that voluntarily commits can actually be worse off than without the agreement. Thus, it is the collective nature of the agreement that creates the possibility that voluntarily ceasing production of the polluting model can actually be profitable for all firms in the industry. In terms of its impact on environmental quality, the collective agreement will always reduce pollution relative to the pre-agreement state. In contrast, if one firm commits and the other does not, then the unilateral voluntary action by the one firm can actually result in an *increase* in energy consumption and hence pollution. Thus, the collective

[5] In the examples cited above, the manufacturers generally produce different models rather than specializing in either the low or high efficiency models.

agreement (i.e., commitment by both) is necessary to ensure that the voluntary actions will improve environmental quality.

The paper is organized as follows. Section II presents the basic model structure. Section III summarizes the equilibria when the market is supplied by a monopolist. This provides a baseline for the analysis of the duopoly in Section IV and V. Section VI concludes.

II. The Basic Model Structure

To characterize the demand side of the market, we assume that there are N potential consumers of the product who vary in their intensity of use, denoted θ, which is distributed uniformly on [0,1]. We can think of θ as, for example, the number of hours that the consumer uses the product (or, in the case of washing machines, the number of loads of laundry the consumer does in a given period of time), which we assume is determined by exogenous factors (e.g., family size). Each consumer has the option to buy a single unit of the product, and can choose between the low efficiency model (L) and high efficiency model (H). The utility of a consumer of type θ who purchases a unit of model i (i = L,H) is given by

$$V_i^\theta = U(\theta) - p_E x_i \theta - P_i, \tag{1.1}$$

where $U(\theta)$ is the associated utility from use of the product, p_E is the per unit price of energy, x_i is the energy use per hour by the type-i model, and P_i is the price of the type-i model. The low efficiency model uses more energy per unit of use than the high efficiency model and hence $x_L > x_H$. However, typically low efficiency models are less expensive than high efficiency models, so we would expect $P_H > P_L$, and we will see that in equilibrium this is always true. If the consumer does not buy the product, then we assume that he must purchase the service on a per-unit basis, for a price of *r* per unit. For example, a consumer who does not purchase a washing machine must buy laundry services at a laundromat for a price of *r* per load. The associated utility is given by

(1.2) $$V_0^\theta = U(\theta) - r\theta.$$

The consumer will choose the option (low efficiency, high efficiency, or no purchase) that yields the highest utility. This implies that a consumer will buy the high efficiency model if and only if

(1.3) $$\theta \geq \theta_H \equiv \frac{P_H - P_L}{P_E(x_L - x_H)}.$$

Likewise, provided it is available, he will buy the low efficiency model if and only if[6]

(1.4) $$\frac{P_L}{r - p_E x_L} \equiv \theta_L \leq \theta < \theta_H.$$

Finally, consumers for whom $\theta < \theta_L$ choose not to buy the product at all. Thus, the prices of the two models (along with the other parameters) induce a partitioning of consumers as depicted in the upper part of Figure 1. Given the distribution of θ, the resulting demands when both models are offered on the market are given by

(1.5) $$Q_H = N(1 - \theta_H)$$

and

(1.6) $$Q_L = N(\theta_H - \theta_L),$$

which imply the following inverse demand functions:

(1.7) $$P_L = \delta(1 - Q_H - Q_L)$$

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[6] We assume throughout that $r > p_E x_L$ in order to ensure that there is some consumer demand for the low efficiency model.

and

(1.8) $$P_H = \lambda(1 - Q_H) - \delta Q_L,$$

where $\delta \equiv r - p_E x_L > 0$, $\lambda \equiv r - p_E x_H > \delta$ and we have normalized by setting $N = 1$. Alternatively, when only the high efficiency model is produced, the resulting inverse demand is simply given by

(1.9) $$P_H = \lambda(1 - Q_H).$$

Finally, we assume that production costs are quadratic and that the high efficiency model is more costly to produce than the low efficiency model. This implies

(1.10) $$C_i(q_i) = c_i q_i^2,$$

where q_i is the quantity of model i produced by an individual firm and $c_H > c_L$. For simplicity, we normalize by setting $c_L = 0$.

III. The Monopoly Case

We begin by summarizing the equilibria when the models are produced by a monopolist. This illustrates the nature of demand and the role of product differentiation within the structure of the model.

It is straightforward to show that, given the above structure, the monopolist will choose to produce both models and a commitment to produce only the high efficiency model will reduce profit. In particular, we can show the following, where the *MA*-superscript denotes the monopoly case prior to the voluntary commitment to produce only the high efficiency model and the *MB*-superscript denotes the monopoly case under the voluntary commitment:[7]

[7] Proofs of all propositions are provided in the Appendix.

Proposition 1: *(i)* $P_H^{MB} > P_H^{MA}$, *(ii)* $\theta_L^{MA} < \theta_H^{MB} < \theta_H^{MA}$, *(iii)* $Q_H^{MB} > Q_H^{MA}$, *and (iv)* $\pi^{MB} < \pi^{MA}$.

When the monopolist commits to producing only the high efficiency model, competition between the two models is eliminated, which allows the firm to raise price and increase sales of the high efficiency model simultaneously. It does this by drawing in some (but not all) of the consumers who previously bought the low efficiency model. However, given that the monopolist was producing both models prior to the agreement (when it could have chosen to produce only one), the commitment not to produce the low efficiency model must result in a reduction in profits for the firm. Thus, when the market is supplied by a monopolist, the voluntary agreement will never be profitable, implying that some other inducement (e.g., a regulatory threat) is necessary in order to eliminate the polluting model from the market. We show below that this result does not necessarily hold in the context of a duopoly.

IV. The Duopoly Case

We turn next to the primary case of interest where the market is supplied by two firms. We assume that the two firms have identical costs and are Cournot competitors. Thus, given the inverse market demands in (1.7)-(1.9), each firm seeks to maximize its profits by choosing the quantities of the two models to produce, given the quantities of the other firm and any commitments that have been made.

In scenario A (pre-agreement), there are no commitments, implying that firm j chooses q_L^j and q_H^j so as to

(1.11) $$\max \pi^j = P_H(Q_H, Q_L)q_H^j + P_L(Q_H, Q_L)q_L^j - c_H(q_H^j)^2.$$

The resulting Nash equilibrium is:

(1.12) $$q_L^{1A} = q_L^{2A} = \frac{2c_H}{\beta(2\delta+1)-9\delta}$$

and

(1.13) $$q_H^{1A} = q_H^{2A} = \frac{\lambda(2\delta+1)-3\delta}{\beta(2\delta+1)-9\delta},$$

where $\beta \equiv 3\lambda + 2c_H$.[8] The corresponding equilibrium prices are given by:

(1.14) $$P_L^A = \frac{\delta[(\lambda+2c_H)(2\delta+1)-3\delta-4c_H]}{\beta(2\delta+1)-9\delta}$$

and

(1.15) $$P_H^A = \lambda - 2\frac{\delta(2c_H-3\lambda)+\lambda^2(2\delta+1)}{\beta(2\delta+1)-9\delta}.$$

As expected, it can be shown that in equilibrium $P_H^A > P_L^A$ whenever $Q_H > 0$. Because the low efficiency model uses more energy and hence has higher operating costs, in equilibrium it must have a lower purchase price in order to induce any consumers to buy it.

In scenario B, both firms commit to produce only the high efficiency model, implying $q_L^{1B} = q_L^{2B} = Q_L^B = 0$. The firms each choose their production levels for the high efficiency model to maximize the profit given in (1.11), given this restriction. The resulting Nash equilibrium quantities are given by:[9]

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[8] We assume parameter values that ensure that the quantities produced are non-negative.

[9] Although we assume the firms collectively decide not to produce the low efficiency model, we continue to model their output choices for the high efficiency model as a Nash equilibrium, since any cooperation on the choice of output levels for this model would likely be in violation of anti-trust laws.

(1.16) $$q_H^{1B} = q_H^{2B} = \frac{\lambda}{\beta}.$$

The corresponding equilibrium price is:

(1.17) $$P_H^B = \frac{\lambda(\lambda + 2c_H)}{\beta}.$$

Finally, in scenario C, we assume that firm 1 unilaterally commits to produce only the high efficiency model but firm 2 does not. Thus, $q_L^{1C} = 0$. As before, the firms choose their quantities to maximize the profit in (1.11), given this restriction. The resulting Nash equilibrium quantities are given by:

(1.18) $$q_H^{1C} = 1 - \frac{2\gamma[(\lambda + c_H) - \delta]}{\gamma\beta - \delta\rho},$$

(1.19) $$q_H^{2C} = \frac{\gamma(\lambda - \delta)}{\gamma\beta - \delta\rho},$$

(1.20) $$q_L^{2C} = \frac{c_H \gamma}{\gamma\beta - \delta\rho},$$

where $\gamma \equiv \lambda + 2c_H$ and $\rho \equiv 3\lambda + 5c_H$. The corresponding equilibrium prices are:

(1.21) $$P_H^C = \gamma \cdot \frac{\lambda\delta\gamma - \delta^2(\lambda + c_H)}{\delta\gamma\beta - \delta^2\rho}$$

and

(1.22) $$P_L^C = \gamma \cdot \frac{\delta^2\gamma - \delta^2(\delta + c_H)}{\delta\gamma\beta - \delta^2\rho}.$$

Again, it can be easily verified that $P_H^C > P_L^C$ and $q_H^{1C} > q_H^{2C}$. Thus, the firm that commits to producing only the high efficiency model will supply a greater share of that market.

The results under scenario C imply that the collective agreement not to produce the low efficiency model is not a Nash equilibrium. In other words, $q_L^2 = 0$ is not an optimal response to $q_L^1 = 0$. If firm 1 commits to not producing the low efficiency model, it is not in firm 2's best interest to do the same. Instead, firm 2 will choose a positive level of production for the low efficiency model. This highlights the need for commitment by both firms in order to sustain the collective agreement. The outcome under scenario C implies that, if one firm believes the other will adhere to the agreement, it has an incentive to "cheat" and produce the low efficiency product. Thus, some way to enforce the commitment is necessary. In our context, any cheating on a collective agreement not to produce a given model would be easily detected and most likely punished through negative publicity. Thus, it is likely that a collective agreement that is publicly announced will be implicitly enforced. The outcomes under scenario C underscore the role of the agreement as an enforcement device.

V. Comparisons

Having defined the Nash equilibria under the three scenarios of interest, we now turn to a comparison across scenarios in order to evaluate the collective agreement under scenario B. We first compare scenarios A and B to determine the impact of the collective agreement relative to the pre-agreement state. We then compare scenarios A and C to understand what impact a unilateral commitment would have had. Finally, we compare scenarios B and C to understand the role of the implicit enforcement provided by the public nature of the collective commitment. In all cases, we begin by considering the equilibrium prices under the different scenarios, and the implications for consumer purchasing decisions and hence aggregate demand. We then consider the implications for environmental quality and producer profits.

V.I The Impact of the Collective Agreement

The price and demand effects of the collective agreement relative to the pre-agreement state can be summarized as follows.

Proposition 2: (i) $P_H^B > P_H^A$, *(ii)* $\theta_L^A < \theta_H^B < \theta_H^A$, *and (iii)* $Q_H^B > Q_H^A$.

Proposition 2 implies that, as in the monopoly case, eliminating the low efficiency model from the market and hence reducing the competition between the two models will lead to an increase in the price of the high efficiency model. However, because consumers no longer have the option to buy the low efficiency model, demand for high efficiency models increases despite the price increase. Some of the consumers who used to buy the low efficiency model now buy the high efficiency model instead (those for whom $\theta_H^B \leq \theta < \theta_H^A$), while others now choose not to purchase the product at all. The original partitioning of consumers by purchase decisions prior to any agreement and the partitioning after the collective agreement are depicted in the upper two lines in Figure 1 (labeled A and B).

The impact of the agreement on environmental quality depends not only on the number of high and low efficiency models sold, but also on the intensity of their use. To measure this impact, we first normalize by assuming that one unit of energy consumption generates one unit of emissions or pollution, which implies that total emissions equals total energy use. Second, we assume that, when consumers purchase the service (e.g., go to the laundromat) rather than purchasing the product and using it directly, the supplier of the service employs the high efficiency technology. This is consistent with the result that heavy users (i.e., users with high values of θ) choose to purchase the high efficiency models, since the higher energy savings associated with heavy use justify the higher purchase price. This argument would also apply to suppliers of the service, for whom the higher cost models would be cost-effective. Given these assumptions, total energy use (and hence emissions) when both models are sold is given by

$$E = \int_0^{\theta_L} f(\theta)\theta x_H d\theta + \int_{\theta_L}^{\theta_H} f(\theta)\theta x_L d\theta + \int_{\theta_H}^{1} f(\theta)\theta x_H d\theta , \tag{1.23}$$

where $f(\theta)$ is the distribution of θ. Under a uniform distribution, this become

$$E = \frac{1}{2}\{x_H + (x_L - x_H)(\theta_H^2 - \theta_L^2)\} . \tag{1.24}$$

Alternatively, when only the high efficiency model is sold, energy use is simply $x_H / 2$. It follows directly that the collective agreement improves environmental performance under our assumptions. Note that, while we have assumed in (1.23) that those who do not purchase the product directly purchase the services from a supplier who uses the high efficiency technology, the agreement would still have improved environmental quality even if these suppliers used the low efficiency models (e.g., old technology). This follows from the fact that the agreement increases sales of the high efficiency model, implying that total energy use must decrease, regardless of whether the supplier uses the same technology as previously used by those who no longer purchase low efficiency models or the more efficient, cleaner technology.

A comparison of Propositions 1 and 2 shows that the impact of the agreement on prices and quantities, and hence on environmental quality, is qualitatively similar in the monopoly and duopoly cases. However, this is not true for the impact on producer profits. Our primary result regarding the impact on profits in the duopoly case is the following:

Proposition3: There exist parameter values for r, p_E*,* x_L*,* x_H*, and* c_H *such that* $\pi^{jB} > \pi^{jA}$ *for j=1,2.*

Proposition 3 implies that, depending on the parameter values, the collective agreement can actually be profitable for both firms in the industry, even though in the absence of the agreement both would choose to produce both models and hence the agreement constitutes a restriction on their choices. This is illustrated in Figure 2. As shown, for sufficiently low values of δ, the agreement increases profits for both firms. *Ceteris paribus*, δ will be low when x_L is high (much greater than x_H), which implies that the high efficiency market is relatively more lucrative for producers because of stronger demand. Thus, when δ is sufficiently low, the firms stand to gain more if they can induce some consumers to switch from low to high efficiency models by eliminating the low efficiency option.

Proposition 3 has implications for whether monetary or other inducements should be necessary for collective agreements of this type. If the agreement is actually profitable for the industry, then clearly no inducements should be necessary, although the implicit enforcement provided by the public nature of the commitment is necessary to ensure its success. In addition, the fact that the agreement can be profitable for the industry implies the existence of the agreement not to produce polluting products is not evidence per se of environmental stewardship on the part of the industry. Finally, when coupled with the impact on energy use discussed above, Proposition 3 suggests the possibility of "win-win" outcomes, where the collective agreement both increases producer profits and improves environmental quality. Of course, whether this leads to an increase in social welfare will depend on whether these gains exceed any losses to consumers.

V.2 The Impact of Unilateral Commitment

We turn next to the question of the impact of a unilateral commitment on the part of one firm not to produce the polluting product, to determine whether the effects of a unilateral commitment would be qualitatively similar to those of a collective agreement. For this scenario, we can identify at least two possible cases, depending on the parameter values. Under the first case (C1), $\theta_L^C < \theta_L^A$ and $\theta_H^C > \theta_H^A$. Under the second case (C2), $\theta_L^C > \theta_L^A$ *and* $\theta_H^C < \theta_H^A$. These cases are depicted in Figure 1.

It is clear from Figure 1 that under C2 the unilateral initiative is still effective in reducing the number of low efficiency models sold and increasing the number of high efficiency models sold. Elimination of the competition in the low efficiency market causes the price of the low efficiency model to increase. This reduces the competition between the two models, and triggers an increase in the price of the high efficiency model as well. However, the difference between the two prices is reduced, causing the market for the high efficiency model to expand. This is the case that would have been expected.

In contrast, under C1, despite firm 1's commitment not to produce and sell the low efficiency model, the market for the low efficiency model expands while the market for the high efficiency model is reduced. As shown in Figure 3, this can occur when δ is high. As noted above, *ceteris paribus*, a high value for δ occurs when x_L is low, implying that there is little difference between the two models in terms of energy use and hence that demand for the high efficiency model is relatively weak. As a result, when firm 1 leaves the low efficiency market and concentrates on the high efficiency market, the price in the high efficiency market falls. This triggers a reduction in the price of the low efficiency model as well, which draws into the low efficiency market some consumers who previously did not buy the product. In addition, although the prices of both models decline, the price difference increases, which draws into the low efficiency market some of the consumers who previously bought the high efficiency model. The combined effect is an expansion of the low efficiency market and a decrease in the number of high efficiency models sold.

We summarize this case as follows:

Proposition 4: There exist parameter values for r, p_E, x_L, x_H, *and* c_H *such that (i)* $P_L^C < P_L^A$, *(ii)* $P_H^C < P_H^A$, *(iii)* $P_H^C - P_L^C > P_H^A - P_L^A$, *(iv)* $Q_L^C > Q_L^A$, *and (v)* $Q_H^C < Q_H^A$.

We turn next to the implications of unilateral commitment for energy use and hence environmental quality. Total energy use depends not only on the number of units of each type sold, but also on the use characteristics of the consumers who buy these units (see (1.23)). Nonetheless, when the market either contracts at both ends (Case C2) or expands at both ends (Case C1), the impact on energy use will correspond directly to the impact on market size.[10]

Proposition 5: (i) If $\theta_L^C < \theta_L^A$ and $\theta_H^C > \theta_H^A$ *(Case C1), then* $E^C < E^A$. *(ii) However, if* $\theta_L^C > \theta_L^A$ *and* $\theta_H^C < \theta_H^A$ *(Case C2), then* $E^C > E^A$.

Proposition 5 implies that a unilateral commitment by one firm not to produce and sell the high pollution model could actually lead to a deterioration in environmental quality, i.e., it could be counter-productive. Recall that this was not possible under the collective agreement. Thus, in order to ensure that the commitment is effective in reducing energy use and hence emissions, all firms in the industry must commit.

Despite the possibility that a unilateral commitment could actually cause an expansion in the market for the polluting model and hence be counter-productive, the impacts on producer profits are as expected, i.e., the unilateral commitment is costly to the firm that makes it and works to the advantage of the other firm.

Proposition 6: $\pi_1^C < \pi_1^A = \pi_2^A < \pi_2^C$.

Proposition 6 implies that a win-win outcome is not possible for producers and the environment under a unilateral commitment. In order for this possibility to exist, the commitment must be made by all firms.

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[10] If both θ_H and θ_L were to increase, then total energy use could increase even if the market for the low efficiency model was smaller, since of the switch of some relatively high intensity users from the high efficiency to the low efficiency model.

V.3 The Role of Enforcement

Finally, we compare the outcomes under scenarios B and C to understand the role of enforcement of a collective agreement. As noted above, we can think of scenario C as the scenario under which one firm adheres to a collective agreement and one does not, i.e., it "cheats" on the agreement. The difference in the Nash equilibria under scenarios A and C implies that, absent some enforcement device (e.g., through public pressure to adhere to a publicly announced agreement), a firm would have an incentive to cheat and produce some of the low efficiency model.

The impact of cheating on prices and aggregate demands are as follows.

Proposition 7: (i) $P_H^B > P_H^C$, *(ii)* $\theta_H^C > \theta_H^B$, *(iii)* $\theta_L^C < \theta_H^B$, *(vi)* $q_H^{iC} < q_H^{iB}$ *for i=1,2, and (v)* $Q_H^C < Q_H^B$.

A comparison of sales under the two scenarios can be seen from Figure 1. The market for the high efficiency model is clearly larger under scenario B than C for both C1 and C2, i.e., $\theta_H^C > \theta_H^B$ in both cases. Because the low efficiency model is now on the market and hence competition between the two products exists, the price of the high efficiency model decreases relative to what it would have been if both had adhered to the agreement. Nonetheless, the total quantity of high efficiency units sold in the market declines when the low efficiency model is available, since some consumers who bought the high efficiency model are now drawn into the low efficiency market. Similarly, some consumers who were not buying the high efficiency model are now drawn into the market and purchase the low efficiency model. Note that when both adhere to the agreement the high efficiency market is divided equally between the two firms, while when one firm cheats the firm that adheres to the agreement (firm 1) supplies more than half of the market (see description of equilibria above). Nonetheless, total sales by firm 1 are still lower when firm 2 cheats, i.e., the market share that firm 1 gains when firm 2 cheats does not fully offset the reduction in total demand for the high efficiency model that results from firm 2's cheating.

It is clear that the result of cheating is an increase in energy use.

Proposition 8: $E^C > E^B$.

Finally, cheating has the expected impact on profits, despite the gain in market share in the high efficiency market that firm 1 realizes when firm 2 cheats.

Proposition 9: (i) $\pi_1^C < \pi_1^B$ *and (ii)* $\pi_2^C > \pi_2^B$.

Obviously, part (*ii*) of Proposition 9 creates the incentive for cheating. What presumably prevents this in the context of the collective agreement is the fact that cheating on the agreement would be easily detected and the firm would be expected to suffer damage to its public image by openly cheating on a publicly announced agreement not to produce the low efficiency model.

VI. Conclusion

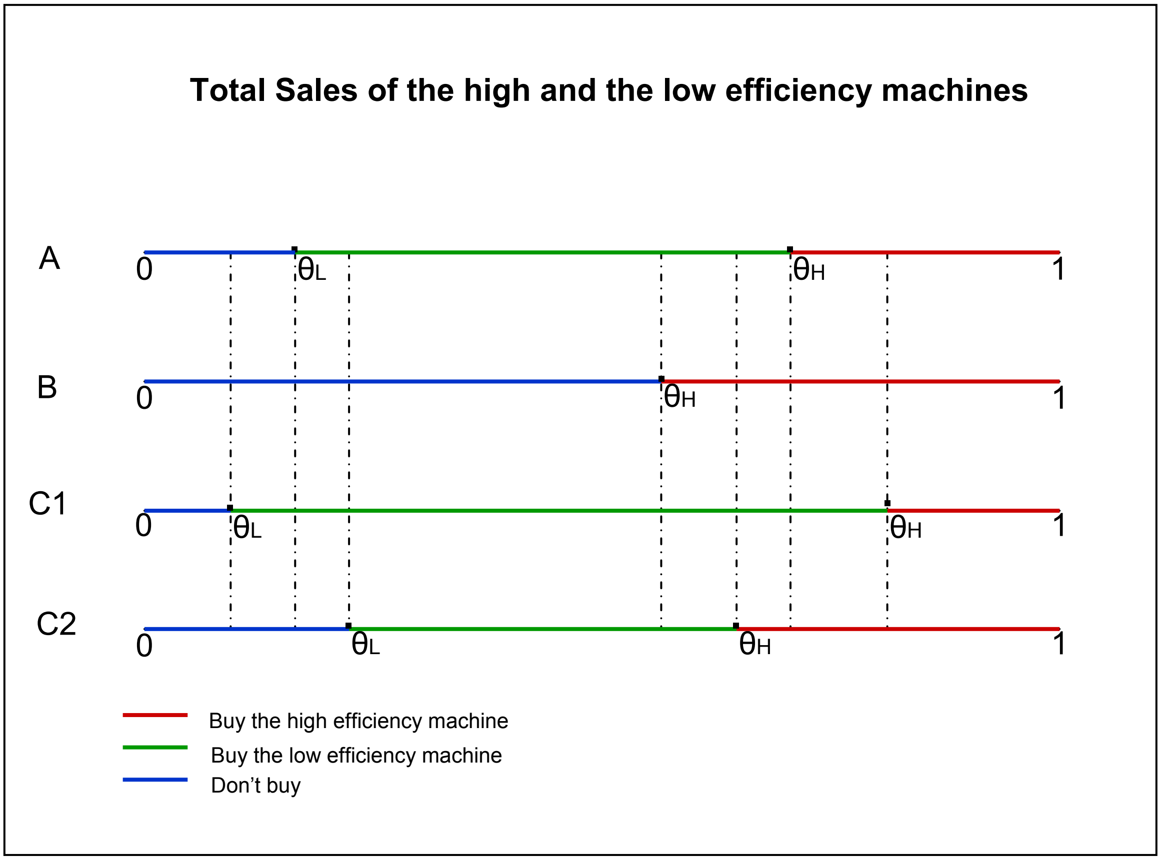
In many contexts pollution stems from consumption or use of a product rather than its production. The most notable example is energy consumption by appliances or other consumer products. In these contexts, environmental quality improvements can be achieved by promoting the use of more energy efficient products. Recently, some industries have collectively agreed not to produce models that do not meet an energy efficiency (and hence an environmental) standard.

In this paper, we have presented a simple model that can be used to examine a voluntary collective agreement to produce only a high efficiency model of a given product (e.g., a high efficiency washing machine). The model incorporates the potential for two forms of competition: (i) between firms, and (ii) between product models (high vs. low efficiency).

Starting from a pre-agreement equilibrium in which each firm supplies both models in response to consumer heterogeneity, we show that, when there is competition between firms, a collective agreement to produce only the high efficiency model can actually increase profits for all firms in the industry, an outcome that is not possible without that competition (i.e., in a monopoly model). This suggests that a collective agreement of this type might actually be beneficial to firms, implying that a win-win outcome for firms and environmental quality is possible. However, the implicit enforcement that comes from the public nature of the commitment is necessary to ensure this outcome. Absent this enforcement, each firm would have an incentive to cheat on the agreement.

Furthermore, we show that, while the collective agreement improves environmental quality, such an outcome is not guaranteed when a single firm commits unilaterally to produce only the high efficiency model. It is possible that a unilateral commitment will actually lead to an expansion of the market for the polluting model and an increase in overall energy consumption and hence pollution. This suggests that unilateral commitments can actually be counter-productive in terms of environmental quality. In addition, one firm gains at the other firm's expense. Thus, a win-win outcome is not possible under a unilateral commitment.

Taken together, our results suggest that in general a collective agreement can be beneficial in terms of both producer profits and environmental quality relative to both the pre-agreement outcome and the outcome if a firm commits unilaterally. This suggests that, by promoting such agreements, policymakers may be able to achieve substantial environmental gains with relatively little inducement. The impact on social welfare will then depend on whether these gains are sufficiently large to offset any consumer losses from reductions in product variety and associated price increases.



Total Sales of the high and the low efficiency machines
A
0
θL
θH
1
B
0
θH
1
C1
0
θL
θH
1
C2
0
θL
θH
1
Buy the high efficiency machine
Buy the low efficiency machine
Don't buy

Figure 1

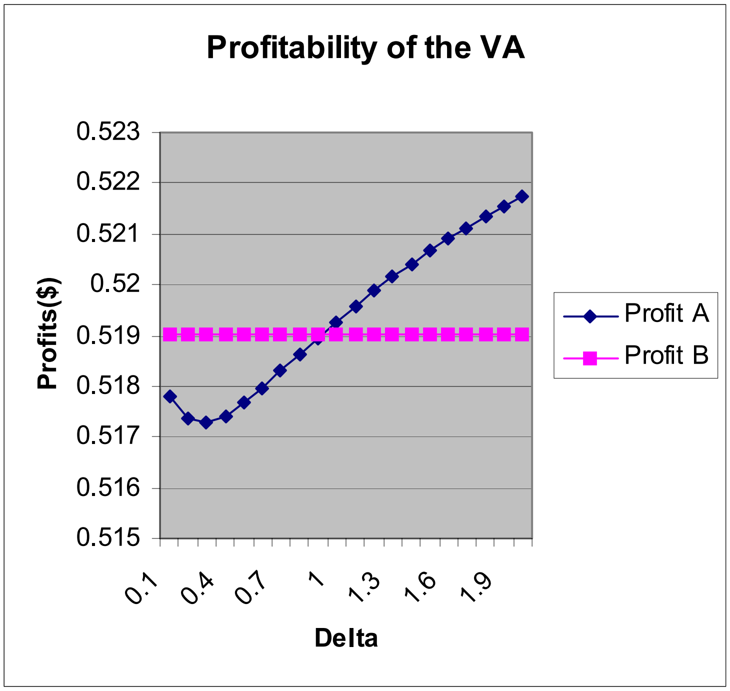

Profitability of the VA
0.523
0.522
0.521
0.52
0.519
0.518
0.517
0.516
0.515
Profits($)
0.1
0.4
0.7
1
1.3
1.6
1.9
Delta
Profit A
Profit B

Figure 2

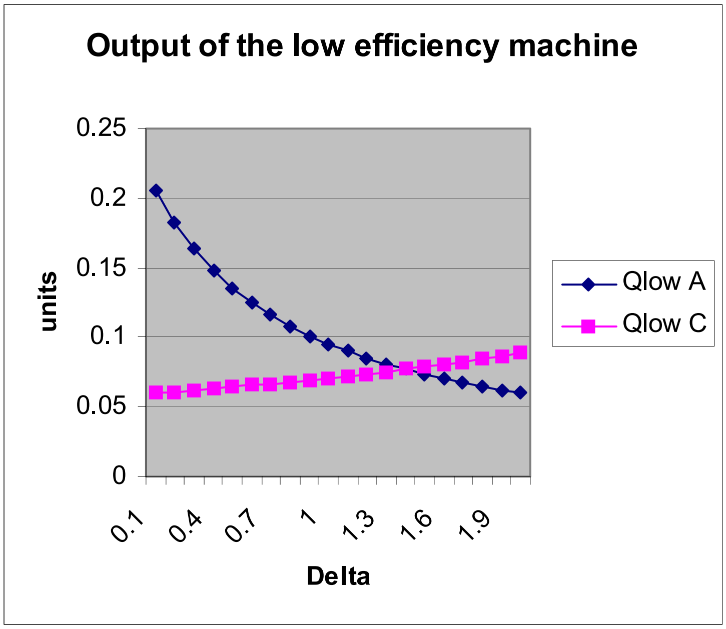

Output of the low efficiency machine
0.25
0.2
0.15
0.1
0.05
0
units
0.1
0.4
0.7
1
1.3
1.6
1.9
Delta
Qlow A
Qlow C

Figure 3

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