Eliminating Polluting Products: Voluntary vs. Regulatory Approaches?

by

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I. Introduction:

In many of the contexts where pollution stems from the use of the final product, voluntary agreements (VAs) have emerged. These agreements are designed to encourage substitution towards the more environmentally friendly (“greener”) versions of the product. For many products, environmental friendliness is directly linked to energy efficiency, since reductions in energy use generally imply reductions in emissions stemming from combustion of fossil fuels. For this reason, product-based VAs often focus on reducing or eliminating use of products with low energy efficiency (e.g., low efficiency appliances, lighting, computers, automobiles).

Several VAs designed to improve the energy efficiency of products (particularly appliances) have emerged, most notably in Europe, covering a number of household appliances. In April 1996, the European Committee of Domestic Equipment Manufacturers (CECED) comprised of the principal European producers and importers of clothes washing machines, presented their first commitment targeting domestic washing machines. The Voluntary Agreement on Washing Machines presented by the CECED (representing 95% of the EC market) was a commitment to stop producing for and importing into the European Union washing machines that have low energy efficiency and hence high associated emissions, and to reduce the average energy consumption of washing machines by 20% (CECED, 1997; CECED, 2000). This agreement was aimed at eliminating from the market products that do not meet certain environmental criteria. By the end of the initial washing machines agreement, the percentage of high efficiency machines (class A and B) had increased from 51% in 1997 to around 83% in 2002 (CECED, 2002). The successful fulfillment of the first commitment motivated the
industry to present a second commitment for the period 2002-2008 (CECED, 2003; CECED, 2004). Several successful VAs were also implemented covering refrigerators, freezers, water heaters, and dishwashers. While these agreements successfully eliminated from the market the least energy efficient versions of a given product, the CECED Steering Committee decided on 21 March 2007 that they will not update their voluntary agreements for any of their products and therefore will not voluntarily achieve any further improvements in energy efficiency (CECED, 2007).

However, in other markets the success of VAs has been more limited. An example is the European Voluntary Agreement for Automobiles. In 1989-1999 the European Commission signed VAs with three automobile industry groups to reduce carbon dioxide emissions. The target of 140 g/km across the fleet of new cars was to be reached by 2008-2009. However, despite some initial improvements in new fleet efficiency, recent reviews of the progress of the automotive industry indicate that it cannot be guaranteed that the target will be met before the due date. An official monitoring report in August 2006 indicates that if car makers do not meet the target, they will face legislative measures (European Federation of Transport and Environment, 2006). The European Declaration on Paper Recovery presented in November 2000 is another example of an agreement with limited success. The agreement aims to ensure that by the year 2005 recycled paper would constitute 56% of the paper products consumed in Europe (Confederation of European Paper Industries, 2000). This agreement was not recognized by the European Commission since the target they set to achieve was not perceived to be ambitious (Schnabl, 2005).

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1 In the U.S., improvements in average fuel efficiency of automobiles have resulted from regulation (i.e., CAFE standards) rather than voluntary efforts on the part of the automobile industry.
Thus, VAs appear to be successful mechanisms for improving energy efficiency (and hence reducing pollution) in some contexts but not in others. This observation has led to a growing literature analyzing the different factors behind the successful implementation of VAs. This literature focuses on pollution stemming from polluting production processes and assumes that voluntary actions undertaken by firms are costly and hence reduce producer profits. Much of the previous literature has explained the incentives behind firms joining VAs in terms of avoiding future regulation or negative publicity (e.g. Maxwell (1998); Lyon and Maxwell (2001) and Alberini (2002)). Thus, the institutional environment plays an important role in the successful implementation of VAs. In the contexts where political power is fragmented, as in the US, it becomes harder for the regulator to credibly commit to a certain plan of action once firms fail to meet certain environmental goals, and thus VAs are less likely to be successful (e.g. Delmas and Terlaak (2001, 2002) and Delmas and Heiman (2001)). Also when legal constraints are too binding, VAs that require concerted industry effort rather than unilateral action are less likely to be successful since coordinated industry action runs the risk of violating antitrust laws (Kappas, 1997).

In contrast to the previous literature where voluntary actions on the part of firms are perceived to be costly, Ahmed and Segerson (2007a) have shown that an industry wide VA can serve as a device to raise firm profits. In the contexts where pollution stems from product use, it is possible that a VA where all firms in an industry commit to reduce production of the polluting product can be profitable even though it would restrict each manufacturer’s freedom to produce and market its products. In particular, eliminating some products and thereby focusing demand on fewer (perhaps more profitable) products
can result in higher industry profits with the agreement than without it. This suggests that
VAs are more likely to be successful mechanisms for reducing use of polluting products
when they can also serve as a device to raise firm profit.

In this paper we identify two factors that affect the impact of a product-related
VA on industry profit, namely, the nature of the product and the nature of the VA. More
specifically, regarding the nature of the product, we distinguish between products for
which there is a tradeoff between energy efficiency and other quality attributes and
products for which there is no tradeoff. A tradeoff exists for products such as
automobiles where improvements in fuel efficiency typically require a sacrifice of
desirable product characteristics such as performance or safety.2 Similarly recycled
paper is not well suited for making certain grades of paper, e.g. graphical paper
(European recovered Paper Council, 2002). Thus, the higher the percentage of recycled
paper, the fewer are its uses. In contrast, for products such as washing machines, more
energy efficient versions (e.g., front-loading machines) offer equal or better performance

2 The quality efficiency tradeoff can be interpreted as the short run situation where firms only
have access to technologies that allow production of green products by sacrificing other product qualities.
In the long run technological innovation in product design may enable firms to modify their product lines
so as to produce green products without deterioration in other product quality attributes (e.g., through the
introduction of a new technology such as hybrid vehicles). The fact that technological innovation makes
the VA more profitable may provide impetus for technological change. This will depend on the cost of
development as well as the costs of production of the models. One problem with the VA under the quality
efficiency tradeoff is that average product quality declines: Automakers claim that proposed legislation to
increase the CAFE standard would force them to build lighter potentially less safe vehicles (Shepardson,
2006). This has spurred opposition from many officials and senators who believe that tightening CAFE
standards will sacrifice reliability, performance and safety through focusing purely on fuel economy
(Committee on Commerce, Science and Transportation, 2001). Policy makers claim that automakers need
to change their product lines (Shepardson, 2006), in effect eliminating the quality-efficiency tradeoff.
President Bush proposed to impose a CAFE standard based on vehicle dimension rather than a uniform
standard for the entire car fleet. This standard in effect prevents manufacturers from reducing the weight of
heavy vehicles to comply with the standard (White House, 2006). Under the new proposal manufacturers
would be forced to comply by redesigning their product lines to produce more fuel efficient cars without
sacrificing other quality related attributes, such as safety.
along other quality dimensions as well.\textsuperscript{3} We show that the existence of a quality-efficiency tradeoff is an important factor that determines the impact of the VA on firm profit.

The second factor that we consider relates to the nature of the VA. We distinguish between two types of VAs: (1) a VA that sets a minimum average fuel or energy efficiency across all models of a product produced by a firm, and (2) a VA limiting or eliminating the output of the polluting model. The European automobile VA is an example of the former type of VA, while the washing machine agreement is an example of the latter type. We show that the latter is more powerful in suppressing competition between firms. In particular, we show that a quota or a quantity-based VA can increase firm profit over a certain range regardless of whether a quality-efficiency tradeoff exists. In contrast, whether the former type of VA can raise firm profit will depend on the relationship between product quality and fuel or energy efficiency.

Taken together, our results suggest a possible explanation for why appliance-related VAs such as the European washing machine agreement have been successful, while success in using VAs for automobiles or paper recycling has been more limited. In particular, they suggest that the limited success of the European VA for automobiles may be attributable, at least in part, to the combination of the quality-efficiency tradeoff and the use of a VA based on an average fuel efficiency standard. The combination of these two factors makes the VA costly to firms, regardless of the stringency of the target set. In contrast, if the VA had instead been based on a quota or quantity approach that directly

\textsuperscript{3} According to Consumer Reports (2006), front loading washing machines rank higher than top loading machines in terms of energy and water efficiency. In addition, they rank higher in terms of overall performance, which includes not only energy and water efficiency but other characteristics as well, such as washing performance, gentleness, noise and cycle time.
limits sales of low efficiency models, it would have been less costly to firms (and might even have been profitable, depending on its stringency), despite the quality-efficiency tradeoff. In contrast, for appliances that do not involve a tradeoff, our results suggest that VAs might be expected to emerge regardless of the type of constraint they impose. However, even with these products, a quota-based VA is more profitable or less costly to firms than a VA based on average energy efficiency. Hence, use of a quota-based constraint might increase the likelihood that firms would voluntarily enter into (and meet the terms of) a VA. Our results also indicate that a very stringent quota will reduce firm profits relative to the pre agreement situation which provides an explanation for why the CECED will not update their original VAs to achieve further improvements in energy efficiency.

The organization of the paper is as follows. Section II presents the basic model structure and the initial equilibrium. Section III presents the equilibrium analysis under the average efficiency VA. Section IV presents the equilibrium under the quota based VA for products that do not involve a quality-efficiency tradeoff and for products where there is a tradeoff. Section V presents a brief comparison of both types of VAs. Section VI concludes.

II. The Model

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 $\theta$, which is uniformly distributed on $[0, 1]$. We can think of $\theta$ as representing, for example, the number of hours that the consumer uses the product (or, in the case of cars, the number of
miles driven in a given period of time), which we assume is determined by exogenous factors. Each consumer has the option to buy a single unit of the product or to hold onto an old model. We assume that two new product models are available, a low quality model (L) and a high quality model (H). Consumers who do not buy a new model will hold onto the old model (O). We let $x_i$ denote the energy consumption per unit of use (e.g., per hour or per mile) by the type-$i$ model. The new models are more efficient than the old model so $x_O > x_L$ and $x_O > x_H$. We consider first the case where $x_L > x_H$, and so the low quality product is the low efficiency or the high polluting product (the “brown” product), while the high quality product is the high efficiency or the low polluting product (the “green” product). Clearly, in this case there is no tradeoff between product quality and energy efficiency. An example is washing machines where the higher efficiency models are of at least the same quality as the low efficiency models. We later turn to the case where $x_L < x_H$, which implies a quality-efficiency tradeoff. Note that neither the demand and cost functions nor the initial equilibrium presented in this section depends on whether a tradeoff exists.

The utility of a consumer of type $\theta$ who purchases one unit of the new model is given by

$$V_s^\theta = \omega_s u(\theta) - p_e x_s \theta - P_s,$$

where $s=L$ or $H$, $u(\theta)$ is the associated utility from use of the product, $p_e$ is the per unit price of energy, $\omega_s$ is the quality of type-$s$ model (excluding energy efficiency) where $\omega_H \geq \omega_L$, and $P_s$ is the price of the type-$s$ model. For simplicity we assume that $u(\theta) = \theta$. Thus, the utility of a consumer of type $\theta$ who buys model $s$ is $V_s^\theta = \alpha_s \theta - P_s$. 

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where $\alpha_s = \omega_s - p_c x_s$ and $\alpha_L < \alpha_H$. \(^4\) The utility of a consumer who does not buy a new model and hold onto the old model is $V^\theta_0 = \alpha_0 \theta$, where $\alpha_0 = \omega_0 - p_c x_0$ and $\omega_0 < \omega_L < \omega_H$. The parameter $\alpha_s$ reflects the net marginal utility of use of model $s$, which depends on the energy price and the energy efficiency of model $s$, as well as its other quality characteristics. Note that this specification does not embody “green” preferences; energy efficiency affects utility only through its impact on the variable cost of using the product. We normalize by setting $\alpha_0 = 0$ and thus $V^\theta_0 = 0$.

We will show that in equilibrium $P_H > P_L$. This has to be true to induce any consumers to buy the low quality product. Thus, when both models are produced and hence available, 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 and 2. Under this partitioning, a consumer of type $\theta$ will buy the high quality model if and only if
\[
\theta \geq \theta_H \equiv \frac{P_H - P_L}{\alpha_H - \alpha_L},
\]
while he will buy the low quality model if and only if
\[
\frac{P_L}{\alpha_L} \equiv \theta_L \leq \theta < \theta_H.
\]
Consumers for whom $\theta < \theta_L$ choose not to buy the product at all.

Given the distribution of $\theta$, the resulting demands when both models are offered on the market are given by
\[
Q_H = N(1 - \theta_H)
\]
and
\[
Q_L = N \theta_L.
\]

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\(^4\) We restrict our analysis to positive values of $\alpha_H$ and $\alpha_L$. 
where $Q_s$ is the quantity demanded of model $s$. This implies the following inverse demand functions:

\[
P_H = \alpha_H (1 - Q_H) - \alpha_L Q_L,
\]

and

\[
P_L = \alpha_L (1 - Q_H - Q_L)
\]

where we have normalized by setting $N=1$. Finally, we assume that production costs are quadratic. This implies

\[
C_s(q_s) = c_s (q_s)^2,
\]

where $q_s$ is the quantity of model $s$ produced by an individual firm.

We assume that the market is supplied by two firms that have identical costs and are Cournot competitors. Thus, given the inverse market demands in (6) and (7), each firm seeks to maximize its profits by choosing the quantities of the two models to produce, given the quantities of the other firm. Thus, absent any commitments to reduce production of the polluting product, firm $i$ simply chooses $q_H^i$ and $q_L^i$ so as to maximize

\[
\Pi^i = P_H q_H^i + P_L q_L^i - c_H (q_H^i)^2 - c_L (q_L^i)^2
\]

where $i=1,2$. It is straightforward to show that the resulting Nash equilibrium has the following properties (where the superscript “$0$” denotes the initial equilibrium prior to any commitments):

**Proposition 1:** (i) $P_H^0 > P_L^0$, (ii) $q_L^0 = q_L^{00}$ and $q_H^0 = q_H^{00}$, and (iii) $q_L^0 = 0$ if and only if $c_H = 0$. 

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As expected, in equilibrium the price of the high quality model is higher than that of the low quality model. Because the net benefit per use of the low quality model is lower than that of the high quality model, i.e., \( \alpha_H > \alpha_L \), in equilibrium it must have a lower purchase price in order to induce any consumers to buy it. In addition, the firms produce the same amount of each of the models, i.e. there is no quality specialization, and both firms will choose to produce both models unless the high quality model is costless to produce. This is consistent with the observation that firms often produce very similar product lines that include both environmentally friendly and less friendly models, rather than specializing in the production of one or the other as predicted by much of the quality choice literature (see Chen, 2001).

We consider the impact of a VA on two different types of markets: the no tradeoff and the tradeoff market. Under the no tradeoff market it is possible to produce high quality products that are energy efficient, i.e. \( x_H < x_L \) and at the same time \( \alpha_H^N > \alpha_L^N \), where the superscript \( N \) denotes values for the no tradeoff market. The tradeoff market represents the case where improvements in energy efficiency can only be achieved by sacrificing other quality attributes (e.g., performance or safety). Thus \( \alpha_H^T > \alpha_L^T \), where the superscript \( T \) denotes values for the tradeoff market, while \( x_H > x_L \). To simplify the analysis and comparison of the effect of an agreement on firm profit with and without the tradeoff, we assume that \( \alpha_H^N = \alpha_H^T = \alpha_H \), \( \alpha_L^N = \alpha_L^T = \alpha_L \), \( c_H^N = c_L^N = c_L \) and \( c_H^T = c_L^T = c_H \).

This ensures that the initial (pre-agreement) equilibrium quantities, prices, and profit will be identical for both types of markets, which simplifies the analysis. Thus, the only
difference between the two cases is that $x_H < x_L$ when there is no tradeoff and $x_H > x_L$ when a tradeoff exists.

Given a characterization of the initial equilibrium, we then turn to the equilibrium under each type of VA. Although we assume the firms collectively commit to the agreement, we continue to model their output choices as a Nash equilibrium, since any cooperation on the choice of output levels would likely be in violation of anti-trust laws. Thus, each firm chooses its production levels for both models to maximize its profit, given the restriction imposed. We start by analyzing the impact of a VA based on an average efficiency standard and then turn to the impact of a quota-based VA. We consider the impact of each VA on the market equilibrium for both the tradeoff market and the no tradeoff market. We show that the nature of the agreement plays a key role in determining whether the VA can be profitable for firms. More specifically, we show that, when a quality-efficiency tradeoff exists, a VA that imposes an average efficiency standard will always reduce firm profit while a VA that imposes a quota on sales of the polluting product can be profitable for firms.

III. The Average Efficiency Standard VA:

We first consider a VA based on an average efficiency standard. A VA of this type imposes an upper limit on the average energy consumption across the models produced by each firm. In terms of our model, this constraint on average efficiency is given by

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5 We consider only collective VAs. In particular, we do not consider the possibility that a firm would unilaterally agree to a VA. For a discussion of a firm’s incentive to restrict its output of the polluting product unilaterally, see Ahmed and Segerson (2007a).
where $\eta < \eta^0$ and $\eta^0$ is the free market level of weighted average energy consumption across models.\textsuperscript{6} Note that tightening $\eta$ does not directly restrict production of any model. Firms can freely set the amounts as long as the above constraint is satisfied.\textsuperscript{7}

The average efficiency constraint simplifies to a limit on the ratio of the high to the low quality models that a firm produces. In the no tradeoff market the average efficiency constraint simplifies to

\begin{equation}
\frac{q_H^j}{q_L^j} \geq \frac{\eta - x_i}{x_H - \eta}
\end{equation}

On the other hand, for the trade off market the average efficiency constraint simplifies to

\begin{equation}
\frac{q_H^j}{q_L^j} \leq \frac{\eta - x_i}{x_H - \eta}
\end{equation}

In this case setting $\eta = x_L$ represents the agreement to eliminate the brown product. In both cases raising the value of $\eta$, would proportionately increase production of the green product.

We model the firms entering the VA as a reduction of $\eta$ below the free market level. We let $Z = \frac{\eta - x_L}{x_H - \eta}$ and we can show that tightening $\eta$ represents an increase in $Z$ under the no tradeoff case and a decrease in $Z$ under the tradeoff case.\textsuperscript{8}

\begin{equation}
\frac{x_Hq_H^j + x_Lq_L^j}{q_H^j + q_L^j} \leq \eta
\end{equation}

\textsuperscript{6}The binding range of $\eta$ is $[0, \eta^0)$ where $\eta^0 = \frac{2(\alpha_H c_L x_H + \alpha_L c_H x_l) + 3\alpha_L x_H (\alpha_H - \alpha_L)}{2(\alpha_H c_L + \alpha_L c_H) + 3\lambda_L (\alpha_H - \alpha_L)}$.

\textsuperscript{7}Equation (10) represents, for example, the CAFE standard. Although CAFE is the harmonic average of the miles per gallon across a firm’s fleet (Kleit, 1990), we simplify the analysis by using a simple average instead since both impose a maximum on the ratio of the luxury to the economy model.

\textsuperscript{8}
Based on that, we model the average efficiency VA for both markets together by allowing each firm to maximize profit in (9) subject to the constraint that $\frac{q_H}{q_L} = Z$. Values of $Z$ belonging to the range $[0, Z^0]$ will be the relevant range of $Z$ for the tradeoff market and values of $Z$ belonging to the range $[Z^0, \infty)$ will be the relevant range for $Z$ for the no tradeoff market. Based on that, we can compare the impact of tightening the average efficiency standard, $\eta$, on market outcomes under the tradeoff and the no tradeoff market. We use superscript $Z$ to denote equilibrium values under the average efficiency standard. Since all equilibria considered are symmetric, the superscript $i$ will be dropped when defining the equilibrium under each agreement. We first examine the impact of changing $Z$ on market quantities and summarize the result in Proposition 2.

**Proposition 2:**

(i) The output of the low quality model is decreasing in $Z$,

(ii) the output of the high quality model is increasing in $Z$ when the cost of the high quality model is low enough, otherwise it reaches a maximum in $Z$ at $Z > Z^0$,

(iii) total market output reaches a maximum in $Z$ at $Z < Z^0$.

(iv) the price of the high quality model reaches a minimum in $Z$ at $Z = Z^0$, and

(v) the price of the low quality model reaches a minimum in $Z$ at $Z < Z^0$.

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\[ \frac{\partial Z}{\partial \eta} = \frac{x_H - x_L}{(x_H - \eta)^2}, \text{ which is positive if } x_L < x_H. \]
The average efficiency constraint allows firms more flexibility in their output choice. The standard allows firms to choose any output level as long as the ratio of the high to the low quality model equals $Z$. Starting from the equilibrium point where $Z=0$, i.e. where $q_{H}^{Z} = 0$, increasing $Z$ causes a substitution towards the high quality model as shown in Figure 3. Note that this substitution is not at a constant rate since total output is non-monotonic in $Z$. Total output reaches a maximum in $Z$ at a value below $Z^0$ beyond which total output declines. Both prices, $P_{H}^{Z}$ and $P_{L}^{Z}$, are non-monotonic in $Z$ as shown in Figure 4. The difference between prices declines with an increase in $Z$ making the high quality model relatively less expensive which induces the substitution away from the low quality model.\footnote{The above changes will always hold for low enough values of $c_{H}$. If $2c_{H} > 3c_{H}$, i.e. the cost of producing the high quality model is high enough, and if $Z > Z^0$, then further increases in $Z$ result in reducing production of the high quality model. This is because the cost of producing the high quality model significantly increases as more units are produced. At that point, further increases in $Z$ reduce production of both models.}

Given the above analysis we can now analyze the impact of the average efficiency VA on each market type. Starting from the equilibrium point where $Z = Z^0$ we can show the impact of the average efficiency VA on each market. Tightening the standard initially results in a substitution towards the green model. The impact on the price of the green product will be determined by whether it is the high or the low quality product. As shown in Figure 2, in the tradeoff market, i.e. where the green model is the low quality product, it is possible to expand the green product market by: (1) attracting the consumers who used to buy the brown model, and (or) by (2) attracting the consumers who did not buy at all. (1) can be achieved as the brown model becomes relatively more expensive
and (2) takes place as the price of the green model declines. In fact both changes take place with the initial tightening of the standard.

On the other hand, tightening the standard always increases the price of the green product in the no tradeoff market, i.e. when the green model is the high quality product. As shown in Figure 1, the green market can expand only by attracting the buyers of the brown model, which does not necessarily require a decline in the price of the green model. Tightening the standard raises both prices and causes the brown model to become relatively more expensive to induce consumers to substitute away from it.

We next turn to the impact of tightening the standard on firm profit. The impact of this tightening on firm profit is given by the following proposition and corollary.

**Proposition 3:** $\pi^Z$ reaches a maximum at a value of $Z$ given by $Z^*$, where $Z^* > Z^0$.

Firm profit is non-monotonic in $Z$. The value of $Z$ that sustains a higher profit equilibrium is always greater than $Z^0$, as shown in Figure 5. If both firms had the opportunity to collude and act as a single firm, they would restrict output of both models as well as produce more of the high relative to the low quality model, i.e. set a higher value of $Z$ than the one that prevails under the free market equilibrium. By enforcing a high value of $Z$ close to the collusion equilibrium, the agreement allows firms to move closer to the collusion outcome and therefore can raise firm profit. This will be achieved by tightening the average efficiency standard under the no tradeoff market. Thus,
tightening the value of $\eta$ can potentially raise firm profit under the no tradeoff market, an outcome that is not possible under the tradeoff market.\footnote{We can show that $\frac{\partial \pi}{\partial \eta} = \frac{2c_H(x_H - x_L)(2c_H x_H + 3x_L(x_H - x_L))^2}{9x_H x_L (x_H - x_L)(2c_H + 3(\alpha_H - \alpha_L)) (2c_H \alpha_L + 3\alpha_H (\alpha_H - \alpha_L))}$ which is negative if $x_L > x_H$. Thus tightening $\eta$ at $\eta = \eta^0$ raises firm profit only for the no tradeoff market.}

More formally we can decompose the effect of changing $Z$ on firm profit. Firm $i$’s profit under the average efficiency standard is given by the Lagrangian function

$$\Phi^{iz} = P_H q_{H}^{iz} + P_L q_{L}^{iz} - c_H (q_{H}^{iz})^2 - c_L (q_{L}^{iz})^2 + \rho(Z - \frac{q_{H}^{iz}}{q_{L}^{iz}})$$

where $\rho$ is the Lagrangian multiplier. The impact of a reduction in $Z$ on firm profit is given by

$$\frac{\partial \pi^{iz}}{\partial Z} = \frac{d\Phi^{iz}}{dZ} = (\rho + \frac{dP_H^{iz}}{dZ} q_{H}^{iz} + \frac{dP_L^{iz}}{dZ} q_{L}^{iz})$$

where $\frac{dP_s}{dZ} = \frac{\partial P_s}{\partial q_s^{iz}} \frac{dq_s^{iz}}{dZ} + \frac{\partial P_s}{\partial Q_s} \frac{dQ_s}{dZ}$ for $s=H,L$.

This decomposition shows that the agreement has two effects on firm profit: a restriction effect and a strategic effect.\footnote{This is an application of the general principle that, in the presence of strategic behavior, the shadow price of a constraint is not the Lagrange multiplier (see Caputo 2006).} The restriction effect, given by $\rho$, represents the gain in profit to firm $i$ from a marginal increase in $Z$ that results from changing the restriction on its own quantity choices. The restriction effect is given by

$$\rho = \frac{(\alpha_L + Z\alpha_H)(2c_H Z\alpha_L - 3\alpha_L (\alpha_H - \alpha_L) - 2c_L \alpha_H)}{(2c_L + 2c_H Z^2 + 3\alpha_L (1+2Z) + 3Z^2 \alpha_H)^2}$$
As shown in Figure 6, the restriction effect is always positive for values of \(Z\) below \(Z^0\) and negative otherwise. This indicates that setting \(Z\) at a value other than \(Z^0\), all else equal, is always detrimental to profit. Thus, the restriction effect indicates that absent any strategic behavior, the agreement always reduces firm profit as in the monopoly case.

The strategic effect, on the other hand, represents the marginal gain in profit to firm \(i\) from raising \(Z\) that results from constraining the quantity choices of its competitor, firm \(j\). The strategic effect captures the change in firm \(i\)’s profit as market prices change in response to constraining firm \(j\)’s choices. Thus, the strategic effect captures the impact of the constraint on competition between firms. The sign of the strategic effect is generally ambiguous. The constraint can increase or decrease competition depending on the specific demand functions as well as the type of restriction imposed on firms. The strategic effect, denoted by \(SE\) is given by

\[
(16)
\]

\[
\delta = -\frac{(\delta + Z\lambda)(2\epsilon \lambda^2 + 2Z^2\lambda^2 + \delta\lambda(1+4Z)) + \delta(3(\lambda - \delta)(\delta + 2Z\delta + Z^2\lambda) - 2c_jZ(\delta(2+3Z) + Z\lambda(1+2Z)))}{(2\epsilon \lambda^2 + 2c_jZ^2 + 3(\delta + 2Z\delta + Z^2\lambda))}
\]

As shown in Figure 6, the strategic effect is negative for low enough values of \(Z\) suggesting that there are losses to firm profit as a result of a marginal increase in \(Z\). This is because increasing \(Z\) increases competition between firms. As \(Z\) increases further the strategic effect becomes positive indicating that there are gains to profit from increasing \(Z\) that result from reduced competition between firms. Thus the relationship between \(Z\) and competition between firms is non-monotonic as shown in Figure 7.
The value of $Z$ that maximizes firm profit will depend on the combination of both the restriction and the strategic effect. This will always be true at values of $Z$ greater than $Z^0$. Figure 8 shows the locus of equilibrium points in $(q_H, q_L)$-space for different values of $Z$ and the iso-profit line through the free market equilibrium. The part of the iso-profit line that is above point O, the free market equilibrium point, corresponds to the tradeoff market while the part below point O corresponds to the no tradeoff market. Points above the iso-coverage line indicate equilibrium points under the VA where total output expands. Point C represents the output choice if firms were to collude. It is clear that the equilibrium path crosses the iso-profit line at values of $Z$ higher than $Z^0$ indicating that a higher level of firm profit can be achieved through a marginal increase in $Z$, which brings firms closer to the collusion point. The part of the equilibrium path corresponding to the tradeoff market is outside the iso-profit line and thus corresponds to lower profit equilibrium points.\textsuperscript{12}

Corollary 1 follows immediately:

**Corollary 1:** A profitable VA imposing an average efficiency standard only exists for products that do not have a quality-efficiency tradeoff.

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IV. **A Quota-based VA:**

The No tradeoff Market: As noted above, we consider first products for which there is no tradeoff between energy efficiency and other product qualities. A quota based

\textsuperscript{12} This result is consistent with empirical evidence cited earlier showing that the European car agreement could not meet the goals that were set, while the second washing machine agreement is successful in meeting its goals. Both agreements adopt an average efficiency standard however there is a quality efficiency tradeoff only in the cars market.
VA is hence an agreement designed to limit production/sales of the brown (low quality) model. We capture the effect of a VA by imposing a constraint on each firm’s production decision as follows

\[(17) \quad q^i_L = K\]

where values of \(K\) below \(q^0_L\) represents VAs to limit production of the polluting model.\(^{13}\) Note that a value of \(K\) equal to zero represents the agreement to completely eliminate the polluting model from the market.

Under the VA imposing a quota on the output of the brown model, each firm maximizes profit in (9) subject to the constraint in (17) where \(q^i_H\) is the only choice variable.\(^{14}\) We model the VA by a reduction in \(K\). The effect of this reduction is summarized in Proposition 4.

**Proposition 4:** In the absence of a quality-efficiency tradeoff, the VA imposing a quota results in:

(i) an increase in production of the green model by each firm and hence in total, and

(ii) an increase in the prices of both models (i.e., \(\frac{\partial P^N_s}{\partial K} < 0\) where \(s=H\) or \(L\)).

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\(^{13}\) This is the type of constraint used in the European washing machine agreement. The agreement also had a target for average energy efficiency, but given the commitment to eliminate production and sales of low efficiency machines, the average efficiency target was not binding.

\(^{14}\) The maximization problem under the average efficiency standard can also be written such that \(q^i_H\) is the only choice variable since \(q^i_L = \frac{q^i_H}{Z}\). However, the fact that \(q^i_L\) is a function of \(q^i_H\) under the average efficiency standard, which is not true under the quota, makes the two problems totally different since the choice of \(q^i_H\) affects not only the prices of both models but also the output of the other model.
As expected, the quota results in a substitution towards the green model. Limiting the output of the polluting model below the market equilibrium reduces competition between firms in that market and raises the price of the brown model. This causes some of the consumers who used to buy the brown model to switch to the green version and some to stop buying at all. Due to the increased demand for the green model, both its output and its price increase while total sales decline as shown in Figure 9. The agreement thus raises the prices of all products in the market as shown in Figure 10. As $K$ is reduced the price differential decreases encouraging consumers to substitute to the high quality model. The impact of the agreement on the segmentation of consumers by purchase decision is shown in Figure 1.

We consider the impact of the quota-based agreement on firm profit by examining $\pi^{NK}$, the individual firm’s maximum profit as a function of $K$. The relationship is summarized in Proposition 5.

**Proposition 5:** $\pi^{NK}$ is non-monotonic and reaches a maximum at a value of $K$ given by $K^*$, where $K^* < q_L^0$.

Proposition 5 implies that, up to a given level, limiting production of the polluting model can actually increase firm profit relative to the pre-agreement scenario, although further restriction of the quota beyond a certain point would result in a decline in profits as shown in Figure 11. In particular, a quota with a value of $K$ that is binding but greater than $K$, where $K$ is the quota that gives a profit level equal to that in the pre-agreement
equilibrium, will be profitable relative to the pre-agreement equilibrium. Further reductions in output of the polluting model beyond \( K \) will cause profits to decline.

We can decompose the effect of changing \( K \) on firm profit as we did under the average efficiency standard. Firm \( i \)'s profit is given by the Lagrangian function

\[
\Phi^{iNK} = P_H q_H^{iNK} + P_L q_L^{iNK} - c_H (q_H^{iNK})^2 - c_L (q_L^{iNK})^2 + \varepsilon (K - q_L^{iNK})
\]

where \( \varepsilon \) is the Lagrangian multiplier. The impact of a reduction in \( K \) on firm profit is given by

\[
\frac{\partial \pi^{iNK}}{\partial K} = \frac{d \Phi^{iNK}}{dK} = \varepsilon \left( \frac{d P_H^{iNK}}{dK} q_H^{iNK} + \frac{d P_L^{iNK}}{dK} q_L^{iNK} \right) + \frac{d P_H^{iNK}}{dK} q_H^{iNK} + \frac{d P_L^{iNK}}{dK} q_L^{iNK}
\]

where

\[
\frac{d P_s^{iNK}}{dK} \bigg|_{q_H^{iNK}, q_L^{iNK}} = \frac{\partial P_s}{\partial Q_s} \frac{dq_L^{iNK}}{dK} + \frac{\partial P_s}{\partial Q_s} \frac{dq_L^{iNK}}{dK} \quad \text{for } s = H, L.
\]

As mentioned before the restriction effects is always positive indicating that limiting firm \( i \)'s choices all else equal is always detrimental to its profit. The restriction effect, \( \varepsilon \), is given by

\[
\varepsilon = \frac{2 \alpha_L c_H - 3 \alpha_L K (3 \alpha_H - \alpha_L) + 2c_H}{3 \alpha_H + 2c_H},
\]

which is positive for values of \( K < q_L^0 \), while the strategic effect, denoted by \( SE \) is given by

\[
SE = \frac{-\alpha_L}{3 \alpha_H + 2c_H} \left[ 2c_H \frac{\alpha_H - 3 \alpha_L K}{3 \alpha_H + 2c_H} + K (3 \alpha_H - \alpha_L) + 2c_H \right].
\]

Under the quota, the strategic effect is always negative, suggesting that limiting the quantity of the low efficiency model produced by firm \( j \) has a positive impact on firm
i’s profit as it reduces competition between firms. The net effect on firm i’s profit will depend on the value of $K$ as shown in Figure 11 that depicts both the strategic effect and the restriction effect as a function of $K$. At $K = q_{L}^{0}$ the strategic effect is negative and while the restriction effect is zero indicating that a marginal decrease in $K$ raises firm $i$’s profit (this corresponds to the region where $\pi^{NK}$ decreases in $K$ in Figure 12). Further reductions of $K$ beyond $K_{c}$ reduce firm profit below the pre-agreement level.$^{15}$

The impact of the quota based VA can also be shown in Figure 13, which shows the equilibrium locus under the quota.$^{16}$ Part of the equilibrium locus lies inside the iso-profit line that goes through the pre-agreement equilibrium, point O. This implies that, although not all agreements are profitable, it is always possible to find output restrictions that would be profitable for both firms. Note that even though a profitable agreement exists, it is not a Nash equilibrium, i.e. in the absence of the agreement both firms would choose not to limit production of the low efficiency model on their own and hence the agreement constitutes a binding restriction on their choices (Ahmed and Segerson, 2007a).

**The Quality-Efficiency Tradeoff:** As under the no tradeoff case, we model a quota as a reduction in $K$, but in this case the restriction is placed on the high quality product since this is now the brown product. The effect of this reduction in $K$ on output,

\footnote{This can explain why the European Committee of Domestic Equipment Manufacturers have decided in April 2007 not to update their VAs on product energy efficiency (CECED press release, 2007). While enforcement problems could be a possible reason behind not updating the VAs as the CECED claims, it is also possible that further reduction in the production of the inefficient models would reduce industry profit as explained in Figure 12.}

\footnote{The dashed line represents equilibrium points under the quota where $K > q_{L}^{0}$, which is not the point of interest in this analysis.}
prices and equilibrium profit is qualitatively the same as for the no-tradeoff product. Thus, the results in Propositions 4 and 5 also hold for a product that involves a quality-efficiency tradeoff. The quota agreement results in a substitution away from the brown model towards the green model, and there is always a profitable binding level of $K$. The impact of the quota agreement on market segmentation is shown in Figure 2.

**Corollary 2:** *A profitable VA imposing a quota on the brown model always exists.*

Although the quota has qualitatively the same impact on prices, quantities and firm profit for the two different product types, there are two differences to be noted. The first is the firm’s rate of substitution towards the green product, i.e., the increase in the quantity of the green product that firms produce for every unit by which production of the brown product is reduced ($\partial q_G^{kj} / \partial K_j, j = N, T$). When there is a quality-efficiency tradeoff (i.e., $G=L$), the rate of substitution towards the green product is higher than when there is no tradeoff (i.e., $G=H$). With a tradeoff, when one of the buyers of the high quality model (e.g., luxury car) stops buying because the price is higher, he shifts to the lower quality model (e.g., economy car). However, in the absence of a tradeoff, the increase in the price of the brown (now, low quality) model directly induces some consumers to stop buying at all as they are already at the lower end of the market. This suggests that total sales under a VA for a given value of $K$ will be higher when the product exhibits a tradeoff.

The second point of difference is the impact of totally eliminating the brown product on firm profit, i.e., setting $K=0$. While there is always a profitable quota-based agreement to limit sales of the brown model, an agreement to totally eliminate the
polluting model from the market always reduces firm profit relative to the pre-agreement equilibrium. This is true for both types of markets. However, when there is a quality-efficiency tradeoff, eliminating the polluting product is even more costly to firms than when a tradeoff does not exist. This is illustrated in Figure 14. The graph illustrates that complete elimination of the brown product puts the firm on a higher iso-profit line when there is no tradeoff in comparison to the case when a tradeoff exists. This result is summarized in the following proposition and corollary.

**Proposition 6:** \( \pi^0 > \pi^{NK}(0) > \pi^{TR}(0) \).

**Corollary 3:** A profitable VA to eliminate the polluting model does not exist, regardless of whether there is a quality-efficiency tradeoff.

V. The average Efficiency VA vs. the Quota Based VA:

It is clear that in the absence of a tradeoff both agreements raise firm profit relative to the initial equilibrium over a certain range since the iso-profit line through the initial equilibrium crosses both paths. However, as shown in Figure 15, the maximum profit under a quota agreement is higher than that under an average efficiency agreement for both markets. The quota is thus superior to the average efficiency agreement in terms of profit. This is because the quota by, setting an upper limit on the output of the brown model, reduces competition between firms in that market. However, an average efficiency standard does not define the amount of the polluting model a priori and thus leaves more room for competition between firms. Thus the increased flexibility provided by the average efficiency agreement is detrimental to firm profit.
Another point of difference to note between the two types of agreements is the impact on social welfare. A quota based VA always reduces total energy consumption which is not necessarily true under an average efficiency VA. Under the tradeoff market and for given values of the parameters, the average efficiency VA results in higher total energy consumption due to the increased total sales. However consumer surplus is lower under a quota since prices increase while it can be higher under an average efficiency standard. Whether a VA leads to an increase in social welfare will depend on its impact on consumers, producers and environmental quality.  

VI. Conclusion:

It is important to understand the conditions under which a VA is likely to emerge and the conditions under which regulation is needed. The impact of the VA on firm profit will determine whether or not this agreement is likely to emerge, given that commitment by all competitors can be ensured. The fact that, over some range, firms have an incentive to enter into collective agreements implies that government inducements may not be necessary to elicit collective agreements of this type since they are driven by the profit motive. Our results, summarized in Table 1, suggest that the profitability of VAs depends on at least two factors.

The first is the nature of the product and whether there is a quality-efficiency tradeoff, i.e., whether the brown product is the high quality or the low quality product. In

17 It can be shown that a quota based VA unambiguously reduces consumer surplus, and that this loss in consumer surplus exceeds the associated increase in producer profits. Thus, a collective agreement will always lead to a reduction in market surplus. The impact on social welfare will then depend on whether this loss is more than offset by the reduction in the external environmental damages generated by the associated reduction in energy use. For a detailed welfare analysis see Ahmed and Segerson (2007b).
some contexts, firms have to sacrifice other quality attributes to produce a greener product. In other contexts, a green product can perform at least as well (or possibly better) along other quality dimensions. In the former case, a VA designed to improve environmental quality will seek to limit sales of the high quality product, while in the latter case it will seek to limit sales of the low quality product. VAs are likely to be more costly to firms when they entail limits on the high quality product.

The second factor that affects the profitability of the VA is the nature of the constraint it imposes on firms. We analyzed two types of agreements: the quota agreement and the average efficiency agreement. We find that, even with a quality-efficiency tradeoff, the quota agreement can raise firm profit over a certain range. This is because the quota reduces competition between firms and results in an equilibrium that is closer to the collusion outcome. This result does not depend on the position of the brown product; it is true for all product lines. Alternatively, a VA can limit the energy consumption across the fleet of products of a single manufacturer. This approach gives the manufacturers more flexibility in choosing their product mix. While it does so, we have shown that the increased flexibility is not necessarily beneficial to firms. Firms’ ability to limit competition is higher under a quota than an average efficiency standard. Firm profit under an average efficiency constraint is always lower than under a quota. Specifically, when the brown product is the high quality product, firm profit always declines under an average efficiency standard, while in the absence of the tradeoff firm profit rises over a certain range. This result suggests that the position of the brown product in the product line will affect whether firm profit rise or not under an average efficiency standard.
The European washing machine VA is an example of a VA that used a quota-based restriction applied to a product that does not involve a quality-efficiency tradeoff. Our results suggest that this combination yields a VA that is relatively less costly to firms. In such a context, we might expect to see a successful VA emerge. In contrast, the European automobile VA is an example of a VA that uses an average efficiency standard and applies to a product with a quality-efficiency tradeoff. Our analysis shows that this combination is particularly costly to firms. Thus, under these conditions, in the absence of a strong regulatory threat, the prospects for a successful VA might be less promising. This suggests that in the future we might continue to see successful VAs for appliances, but regulatory solutions to reducing emissions from products such as automobiles.
Figure 1:
The market segmentation under both types of VAs for the no tradeoff market.

Figure 2:
The market segmentation under both VAs for the tradeoff market. The market segmentation under the average efficiency standard is drawn in the range where market coverage is expanding.
Figure 3:
Market output of each model and total output under different values of $Z$.

Figure 4:
Prices of both models under different values of $Z$. 

The tradeoff market
The no tradeoff market

$Q$
$Q_H$
$Q_L$

$Z^0$
$Z$

$P_{H}^{z}$
$P_{L}^{z}$
Figure 5: Firm profit under different values of $Z$.

Figure 6: The gain in profit from a marginal increase in $Z$ due to the strategic effect and the restriction effect $\eta$. 
Competition between Firms

The tradeoff market

The no tradeoff market

Figure 7:
Competition between firms under different values of $Z$.

The equilibrium path under the average efficiency standard when $2c_H < 3\alpha_H$.

Figure 8:
The equilibrium path under the average efficiency standard when $2c_H < 3\alpha_H$. 
Figure 9:
The impact of the quota on output in the absence of a tradeoff.

Figure 10:
The impact of the quota on prices in the absence of a tradeoff.
Figure 11:
The strategic effect and the restriction effect, $\varepsilon$, under the quota in the no tradeoff market.

Figure 12:
The impact of the quota on profit in the no tradeoff market.
Figure 13:
The equilibrium path under the quota in the no tradeoff market.

Figure 14
The equilibrium path under the quota for both types of markets.
The equilibrium locus under the average efficiency standard.

The equilibrium locus under the quota for the tradeoff market.

The equilibrium locus under the quota for the no tradeoff market.

Figure 15:
The equilibrium path under the quota and the average efficiency standard for the no tradeoff market.
Table 1: Summary of results

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<thead>
<tr>
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<th>The No tradeoff market</th>
<th>The tradeoff market</th>
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<tbody>
<tr>
<td><strong>A quota constraint</strong></td>
<td>A profitable VA exists</td>
<td>A profitable VA exists</td>
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<tr>
<td><strong>An average efficiency constraint</strong></td>
<td>A profitable VA exists</td>
<td>A profitable VA does not exist</td>
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References


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