October 2007

Emissions Control and the Regulation of Product Markets: The Case of Automobiles

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Department of Economics Working Paper Series

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Working Paper 2007-40

October 2007

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Abstract

The paper investigates alternative policies to regulate emissions from polluting product markets, specifically considering the case of the automobiles market. The two policies we consider are: a quota that limits the quantity produced of the polluting model and a more flexible average efficiency standard that requires a minimum energy efficiency across all models produced by a firm, similar to the US Corporate Average Fuel Economy (CAFE) standards. We use a duopoly model of vertical differentiation where firms produce both an economy (i.e., low polluting) version and a luxury (i.e., high polluting) version of a given product. We show that while a quota can raise firm profit over a certain range, CAFE always reduces firm profit relative to the pre-regulation. We also show that while the quota reduces emissions, it is possible that emissions increase under CAFE. The optimal policy choice will depend on the magnitude of unit damages. We show that when unit damages are sufficiently high, the quota policy is more efficient than the average efficiency standard. This suggests that instead of tightening CAFE to limit damages from emissions, policy makers can shift to a quota policy which is both welfare enhancing and more profitable for firms.

Journal of Economic Literature Classification: Q48, Q58

Keywords: automobiles market, emission control, green markets, energy/fuel efficiency

I. Introduction

In many contexts environmental damages stem from the consumption of the final product rather than the production process. Examples include products that consume large amounts of energy or water such as household appliances or automobiles. When there are several possible versions of the product, regulation of the polluting product market aims at substituting the polluting versions with the clean ones. Although alternative policies can achieve that end, their impact on firm profit as well as their welfare implications can be quite different.

In this paper we consider two alternative policies to regulate polluting product markets. The first policy tool is a quota policy which sets a limit on the amount produced of the polluting model. The minimum efficiency standard is a special case of the quota policy where the amount produced of the polluting model is set equal to zero. In addition, we consider an alternative more flexible policy tool: an average efficiency standard (AES), which is a limit on the average energy consumption across all models produced by a firm. The US Corporate Average Fuel Economy (CAFE) standard for automobiles is an example, where the average miles per gallon across a firm's fleet of automobiles has to meet a certain standard (Committee on Commerce, Science and Transportation, 2001). Thus, the analysis presented here has relevant implications for the automobiles market, although the results apply more generally to other polluting product markets as well.

It is generally believed that the AES offers firms more flexibility in choice (Committee on Commerce, Science and Transportation, 2001). Under regulations like CAFE firms can meet the standard by producing more fuel efficient models or increasing sales of models that are above the standard (Gayer, 2005). Furthermore, the AES allows the continuation of models that would have been totally eliminated under alternative regulations, *e.g*. minimum efficiency standards (Kwoka, 1983). Thus, the AES allows for a wider product variety and gives consumers more choice, which is particularly important in markets where the polluting models have additional features that are valued by consumers. While the AES is desirable from that perspective, we show that in an oligopoly market, the flexibility of the AES is detrimental to firm profit as it intensifies competition between firms.

We use a product line model where each firm has an exogenous menu of product models that differ in their energy efficiency. Each firm chooses how much to supply of each model. While most of the literature on quality choice focuses on product differentiation, in this case firms' quality choices are identical, which is consistent with product line models where identical firms have identical quality choices.[1] This is also consistent with empirical observation where, for example, most automobile companies produce both luxury and economy models.

The product line exhibits a tradeoff between the energy efficiency of the product and its overall performance or quality. In some contexts, firms can improve energy or water efficiency with the same or even better performance. For example, improvements in energy consumption of washing machines do not negatively affect performance (CECED, 2002). However, in some cases firms can produce the energy efficient products only by sacrificing other quality attributes of the product. As in Plourde and Bardis (1999) and Chen (2001), we assume that improvement in environmental quality, *i.e.,* energy efficiency in this case, negatively affects other quality attributes. This is especially true in the short run when firms do not have access to superior technologies for improving efficiency. For example, in automobile production using conventional technologies firms usually achieve greater fuel economy by using lighter materials, which can negatively affect safety (Crandall, 1989; Crandall, 1992; Godek, 1997; Plourde and Bardis, 1999; Chen, 2001; Kleit, 2002). Automobile manufacturers have also produced cleaner automobiles through downsizing, *e.g.*, producing compact automobiles. This tradeoff exists not only for automobiles but also for many other green products for which the environmental attributes can conflict with the product performance, *e.g.*, recycled paper (Chen, 2001).[2]

When there is a tradeoff between the environmental attribute and the overall product quality, the flexibility of an AES becomes particularly desirable from the consumers' perspective. As mentioned before, the AES would allow the higher quality models to exist in the market. This provides an explanation for why automobiles were not covered under the Energy Conservation Program for Consumer Products. The Program imposes minimum efficiency standards on consumer products other than automobiles (Department of Energy, 2001). If automobiles were subject to such standards, production of luxury and large automobiles not meeting the standard would have ceased and overall automobiles quality and safety would have declined.

Given the product line structure described here, we model the firms' short run response to the policy where each firm changes its product mix. In this setting firms do not introduce new models to the existing product line. This is justified based on previous findings that show that automobile manufacturers complied with CAFE standards mostly by changing the numbers they sell of the existing models rather than introducing new models into the market (Greene, 1991). The time frame of the model is similar to Kleit (1990), Greene (1991), Thorpe (1997) and Goldberg (1998), who analyze the impact of the US CAFE standard on market outcomes in the short run. In the long run, however, the firms can respond to the policy by changing the product technology (see Kleit, 2004). The impact of the regulation on the market outcome would be different in each scenario. In this paper we only focus on the short run policy impact.[3]

We analyze the impact of each regulation on firm profit in a duopoly market. Most of the literature on CAFE assumes a monopoly or a perfectly competitive market and thus the impact of the regulation on firm profit is not an interesting one. It is clear a priori that the monopolist is always worse off under the regulation and that in a perfectly competitive market the regulation would leave firm profit unaffected after entry/ exit occurs. The question of the impact of regulation on firm profit becomes more interesting in an oligopoly setting where the strategic behavior of firms may render the regulation profitable. It is also more consistent with the empirical evidence where, for example, the appliances market and the automobile market are supplied by few sellers. In fact, studies by Bresnahan (1987), Alley (1997), Ramrattan (2001) and Yamawaki (2002) present evidence supporting the existence of imperfect competition in the US automobile industry.

We show that, although the two policies result in substitution of the polluting product with the clean one, their impact on competition and thus firm profit is quite different. In particular the quota can be profitable over some range, while the AES is always profit reducing. Even over the range where the quota results in a lower profit equilibrium, the profit level is still higher than under a comparable AES. This is consistent with the empirical evidence that CAFE regulation has negatively affected producers' profit and that the automobiles industry continues to resist all attempts to tighten CAFE (Kleit, 1990, Leone and Parkinson, 1990, Goldberg 1998 and Kleit, 2002). Automakers claim that the new regulation that requires raising CAFE to 35mpg by 2020, will cost them $83 billion (Taylor III, 2007). We also find that a given level of environmental quality can be achieved with less cost to firms under the quota. Thus, the quota policy may be politically more feasible to implement than CAFE since the automobiles industry would perceive it as a less costly regulation or even as a profitable opportunity. This is specifically important given the current policy deadlock under CAFE, which signals the need for a different policy that does not unite the automobiles industry in opposition to it (Dunn, 2007).[4]

Besides the impact on firm profit, we also show that the impact of each policy on consumers, environmental quality and social welfare is quite different. The quota always reduces consumer surplus while the AES raises consumer surplus over a certain range. On the other hand, the quota always guarantees a reduction in total energy consumption, which is not necessarily true under the AES. Thus, regulations like CAFE can be detrimental to environmental quality in addition to having a negative impact on firm profit. The optimal policy that addresses both the externality problem as well as the imperfect competition problem will ultimately depend on the magnitude of damages per unit of energy consumption. When unit damages are high enough, a quota is superior in terms of welfare to the AES as it reduces output of both models. Thus, the quota is a superior alternative to tightening the current CAFE standard if damages from energy consumption, in terms of emissions or dependence on foreign sources of oil, are high.

The organization of the paper is as follows. Section II outlines the basic model structure. Section III and section IV present the market equilibrium under each regulation. Section V compares the different policies. The welfare implications are discussed in section VI. Section VII concludes.

II. The Model

We use the basic structure of the product line model where there are two possible versions of a product: a low efficiency and a high efficiency model. To illustrate the tradeoff between energy efficiency and overall product quality, we assume that the low efficiency model (denoted by L) is of a higher overall quality than the high efficiency model (denoted by E). In the automobiles context, for example, the low efficiency model represents the luxury automobile and the high efficiency model represents the economy or the compact automobile, where the compact automobile consumes less energy per mile than the luxury automobile but the luxury automobile provides greater power, comfort and safety.

We assume there are N consumers of the product who vary in their intensity of use, denoted θ, which is uniformly distributed on [0, 1]. We can think of θ as, for example, the number of miles driven, which we assume is determined by exogenous factors.[5] Each consumer has the option to buy a single unit of the product, *i.e.,* either the luxury model or the economy model, or not to buy. The utility of a consumer of type θ who purchases a unit of model s (s=L *or* E) is given by:

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

where ω_s is the quality of model *s*, with $\omega_L > \omega_E$, p_e is the unit price of energy, x_s is the energy consumption per unit of use by the type-*s* model where $x_E < x_L$, and P_s is the price of the type-*s* model. All consumers derive higher utility from quality and energy efficiency. The utility function can be simplified as follows:

(2) $$V_s^\theta = \alpha_s \theta - P_s,$$

where $\alpha_s = \omega_s - p_e x_s$ represents the net benefit per use.[6] By assumption $\alpha_E < \alpha_L$,[7] which indicates that, although it consumes more energy per use, the net benefit per use, and therefore overall quality, is higher for the luxury model as its quality is much better than the economy model.[8] If the two models were offered for sale for the same price, all consumers would buy the luxury model. The marginal rate of substitution between overall quality and price is constant for each consumer as shown in (2). As in Bresnahan (1987), this yields demand equations that are linear in price as shown below.

Each consumer chooses to buy the model that yields the highest utility. The heterogeneity in use implies that consumers buy different models. A consumer of type θ will buy the luxury model if and only if

(3) $$\theta \geq \theta_L \equiv \frac{P_L - P_E}{\alpha_L - \alpha_E}.$$

Likewise, he will buy the economy model if and only if

(4) $$\theta_L > \theta \geq \theta_E \equiv \frac{P_E}{\alpha_E}.$$

Finally, consumers for whom $\theta < \theta_E$ choose not to buy the product at all.[9] In this case utility is $\overline{U(\theta)}$, which is normalized to zero. Since $\alpha_E < \alpha_L$ and given equation (3), in equilibrium $P_E < P_L$.[10] Otherwise, only the luxury model would be traded in equilibrium. This is consistent with the empirical observation that luxury automobiles are more expensive than economy automobiles. Thus, the prices of the two models (along with the other parameters) induce a partitioning of consumers. The associated inverse demand equations are as follows:

(5) $$P_L = \frac{\alpha_L}{N}(N - Q_L) - \frac{\alpha_E}{N}(Q_E)$$

and

(6) $$P_E = \frac{\alpha_E}{N}(N - Q_L - Q_E)\,.$$

We normalize and assume *N*=1. Finally, we assume that production costs are quadratic. This implies

(7) $$C_s(q_s) = c_s(q_s)^2,$$

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

We will compare the equilibrium in the pre-regulation scenario to that under the regulation. Specifically, we will consider the equilibrium under two types of regulations: a quota that imposes an upper limit on the output of the polluting model, and an AES that imposes an upper limit on the average energy consumption across the models produced.[11] The quota is given by

(8) $$q_L^i \le K\,,$$

where q_L^i is firm *i*'s output of the luxury model. This is the constraint used in Ahmed and Segerson (2007a). Note that a sufficiently high value of *K*, set above the unconstrained output level, is a non-binding regulation corresponding to the free market scenario, while a value of *K* equal to zero represents a regulation that completely eliminates the luxury model from the market. On the other hand, the AES is given by

(9) $$\frac{x_E q_E^i + x_L q_L^i}{q_E^i + q_L^i} \leq \eta,$$

where η is below the free market level of weighted average energy consumption across models.[12] The constraint can be simplified to $\frac{q_L^i}{q_E^i} \leq Z$ where $Z = \frac{\eta - x_E}{x_L - \eta}$.[13] It does not directly restrict production of any model. Firms can freely set the amounts of each as long as this ratio is below *Z*. The CAFE standard is also an AES that mandates an upper limit on the harmonic average of miles per gallon across the different models. The CAFE standard can be written in terms of energy consumption as follows

(10) $$\frac{q_E^i + q_L^i}{\frac{q_E^i}{x_E} + \frac{q_L^i}{x_L}} \leq \eta,$$

which simplifies to $\frac{q_L^i}{q_E^i} \leq H$ where $H = \frac{x_L(\eta - x_E)}{x_E(x_L - \eta)}$.[14] For simplicity, we will represent the average efficiency regulation by an upper limit on the ratio of the luxury to the economy models that a firm produces.

The market is supplied by two firms that have identical costs and are Cournot competitors.[15] Thus, given the inverse market demands in (5) and (6), firm *i* chooses q_E^i and q_L^i so as to maximize

(11) $$\Pi^i = P_E q_E^i + P_L q_L^i - c_E (q_E^i)^2 - c_L (q_L^i)^2 .$$

We will use superscript $i0$ to denote the equilibrium quantities and profit of firm *i* under the pre-regulation scenario. The following proposition describes the pre-regulation market equilibrium.[16]

Proposition 1: *(i)* $P_L^0 > P_E^0$, *(ii)* $q_s^{10} = q_s^{20} = q_s^0$ *for s=E or L.*

In equilibrium each firm produces both models, *i.e.,* there is no quality specialization.[17] As expected, it can be shown that in equilibrium the price of the luxury model is higher than that of the economy model. Because the economy model provides lower net benefit per use, in equilibrium it must have a lower purchase price in order to induce any consumers to buy it. The price differential creates a partitioning of the market such that the high use consumers end up buying the higher energy consuming model as shown in Figure 1, which intensifies the emissions problem. For the rest of the paper the superscript *i* for the firm will be dropped since all the equilibria are symmetric.

III. Market Equilibrium under Quota

Under the quota, each firm maximizes profit in (11) subject to the constraint that $q_L \leq K$, where *K* is below q_L^0. The effect of this reduction is summarized in Proposition 2, where the superscript *K* denotes equilibrium values under the quota.

Proposition 2: *The quota results in:*

(i) *an increase in production of the economy model by each firm and hence in total (i.e.,* $\frac{\partial q_E^K}{\partial K} < 0$ *and hence* $\frac{\partial Q_E^K}{\partial K} < 0$*), and*

(ii) *an increases in the prices of both models (i.e.,* $\frac{\partial P_L^K}{\partial K} < 0$ *and* $\frac{\partial P_E^K}{\partial K} < 0$*).*

The quota results in a substitution towards the economy model.[18] Limiting the output of the luxury model below the market equilibrium reduces competition between firms in that market and raises the price of the luxury model. This causes some consumers of the luxury model to switch to the economy version, which in turn raises its price. Due to the increased demand output of the economy model increases.

We consider the impact of the quota on profits by examining $\pi^K(K)$, the individual firm's maximum profit as a function of *K*. In particular, we ask how profit varies with reductions in *K*. The relationship between $\pi^K(K)$ and *K* is summarized in Proposition 3.

Proposition 3: *$\pi^K(K)$ is single peaked and reaches a maximum at a value of K given by K^*, where $K^* < q_L^0$.*

Proposition 3 implies that a quota on the production of the luxury cars can actually be profitable. To provide some intuition, we first show that, at the pre-regulation equilibrium, a marginal decline in *K* allows firms to reach a higher profit equilibrium point. The equilibrium quantity of the economy model under the quota is given by

$$q_E^K = \frac{\alpha_E(1-3K)}{3\alpha_E + 2c_E}. \qquad (12)$$

Substituting $K = q_L^K$, (12) gives the equation of the equilibrium locus (q_L^K, q_E^K) for varying values of *K*, depicted in Figure 2. Note that the equilibrium locus is linear. Figure 2 also depicts an iso-profit line through the pre-regulation equilibrium point *O*. This iso-profit line provides a profit ranking of all the quantity choices assuming symmetry, *i.e.,* both firms produce the same quantities of each model, which is always true in equilibrium. The equation of the iso-profit line is derived by setting $\Pi^i = \overline{\Pi^i}$, $q_E^i = q_E^j$ and $q_L^i = q_L^j$ in (11). The slope of the iso-profit line is given by

(13) $$\frac{dq_E}{dq_L} = -\frac{\dfrac{\partial \Pi}{\partial q_L}}{\dfrac{\partial \Pi}{\partial q_E}}.$$

To show that a marginal decline in *K* will always increase firm profit, we show that the equilibrium locus is flatter than the iso-profit line at point *O*. Using the inverse demand equations in (5) and (6) and evaluating (13) at (q_E^0, q_L^0) shows (after simplification) that the slope of the iso-profit line at the pre-regulation equilibrium is $\frac{dq_E}{dq_L} = -\frac{\alpha_L}{\alpha_E}$, which is less than $-\frac{3\alpha_E}{3\alpha_E + 2c_E}$, the slope of the equilibrium locus. Thus the iso-profit line is steeper than the equilibrium locus at point *O* (as depicted in Figure 2), implying that a marginal decline in *K* will put the firm on an iso-profit line corresponding to a higher profit level.

More formally, we can decompose the effect of changing *K* on firm profit as follows. Firm *i*'s maximum profit is given by the Lagrangian function

(14) $$\Phi^{iK} = P_L q_L^i + P_E q_E^i - c_L (q_L^i)^2 - c_E (q_E^i)^2 + \varepsilon (K - q_L^i),$$

where ε is the Lagrangian multiplier. The impact of a reduction in *K* on firm profit is given by

(15) $$\frac{\partial \pi^{iK}}{\partial K} = \frac{d\Phi^{iK}}{dK} = \underbrace{\varepsilon}_{\substack{restriction \\ effect}} + \underbrace{\left.\frac{dP_L}{dK}\right|_{\overline{q_L^i}, \overline{q_E^i}} q_L^i + \left.\frac{dP_E}{dK}\right|_{\overline{q_L^i}, \overline{q_E^i}} q_E^i}_{strategic\ \ effect}$$

where $\left.\frac{dP_s}{dK}\right|_{\overline{q_L^j}, \overline{q_E^j}} = \frac{\partial P_s}{\partial Q_L}\frac{dq_L^j}{dK} + \frac{\partial P_s}{\partial Q_E}\frac{dq_E^j}{dK}$ for *s*=*L*,*E* and $j \neq i$.

This decomposition shows that the regulation has two effects on firm profit: a restriction effect and a strategic effect.[19] The restriction effect represents the effect on firm *i*'s profit as a result of restricting its own quantity choices. The restriction effects is always positive for values of K below q_L^0, indicating that limiting firm *i*'s choices, all else equal, is always detrimental to its profit. Thus, in the absence of competition, *i.e.*, in a monopoly market, the quota would always reduce profits. However the existence of competition generates a second effect, the strategic effect, which represents the gain in profit to firm *i* as a result of limiting 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 firm *j*'s quantity choices. Thus, the strategic effect captures the impact of the constraint on competition between firms.

While the restriction effect is always positive for $K < q_L^0$, the sign of the strategic effect is generally ambiguous.[20] The constraint can increase or decrease competition depending on the specific demand functions as well as the type of restriction imposed on firms.[21] With the linear demand and quadratic cost assumed here, the restriction effect is given by

$$\varepsilon = \alpha_L - \frac{3\alpha_E^2}{3\alpha_E + 2c_E} - K(2c_L + 3\alpha_L - \frac{9\alpha_E^2}{3\alpha_E + 2c_E}), \tag{16}$$

while the strategic effect, denoted by τ, is given by

$$\tau = \frac{1}{(3\alpha_E + 2c_E)^2}[-2\alpha_E^2 c_E - K((9\alpha_E^2 + 12\alpha_E c_E)(\alpha_L - \alpha_E) + 4\alpha_L c_E^2)]. \tag{17}$$

The strategic effect in (17) is always negative over the range $K < q_L^0$, suggesting that limiting the quantity of the luxury 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 thus depend on the value of K.

The relationship between profits and K implied by Proposition 3 is depicted in Figure 3. It shows that up to a given level, the quota will actually increase firm profit relative to the pre-regulation equilibrium, although beyond a certain point further restriction of the quota will decrease profit. In fact firm profit when the luxury model is completely eliminated is lower than at the pre-regulation level.

IV. Market Equilibrium under the Average Efficiency Standard (AES)

Under this policy, we assume that each firm faces an upper limit on the weighted average of energy consumption across the models it produces. Each firm maximizes profit in (11) subject to the constraint in (9). The impact on the market equilibrium is summarized in Proposition 4.

Proposition 4: *A tightening of the AES results in:*

(i) *an increase in production of the economy model by each firm and hence in total (i.e.,* $\frac{\partial q_E^Z}{\partial Z} < 0$ *and hence* $\frac{\partial Q_E^Z}{\partial Z} < 0$*),*

(ii) *a decrease in production of the luxury model by each firm and hence in total (i.e.,* $\frac{\partial q_L^Z}{\partial Z} > 0$ *and hence* $\frac{\partial Q_L^Z}{\partial Z} > 0$*),*

(iii) *an increase in the price of the luxury model(i.e.,* $\frac{\partial P_L^Z}{\partial Z} < 0$*), and*

(iv) *a decline in the price of the economy model (i.e.,* $\frac{\partial P_E^Z}{\partial Z} > 0$*) up to a certain level of Z and then an increase in its price.*

The average efficiency constraint allows firms more flexibility in the output choice. While it would be possible for firms to meet the standard by expanding production of both models such that the ratio of the luxury to the economy model is Z, in equilibrium firms choose to comply by limiting the output of the luxury model and substituting towards the economy model as under the quota.[22]

Initially tightening the AES will always reduce the price of the economy model, in comparison to its pre-regulation level as shown in Figure 4.[23] The reduction in price allows the firm to sell the necessary amount of the economy model required to offset sales of the luxury model. This causes some consumers who were either buying the luxury model or not buying at all to start buying the economy model. The impact of the standard on the partitioning of consumers by purchase decisions is shown in Figure 1. However, with a further tightening of the standard the reduction in the price of the economy model ceases. As the market of the economy model reaches a given size, tightening the standard further requires a smaller increase in output of the economy model for a given reduction in output of the luxury model.[24] This results in a rise in the price of the economy model as depicted in Figure 4 and a reduction in market coverage. As Z is reduced to zero, the price of the economy model reaches a higher level than the pre-regulation level. Several empirical studies that estimate the impact of CAFE on automobile prices find that it led to an increase in large automobile prices and a decline in small automobile prices (see, for example, Agras (1999)). This is consistent with our prediction for standards that are not too stringent.

The impact of the AES on firm profit, given by $\pi^Z(Z)$, is stated in Proposition 5.

Proposition 5: $\pi^Z(Z)$ *is monotonic and increasing in* Z.

Proposition 5 implies that, regardless of its stringency, the AES always reduces firm profit, *i.e.,* $\pi^Z < \pi^0$ for all values of *Z*. The equilibrium locus under the AES in (q_E, q_L) space is shown in Figure 2 and is implicitly defined by the following equation:

(18) $$\alpha_E q_E + \alpha_L q_L = q_E^2(3\alpha_E + 2c_E) + q_L^2(3\alpha_L + 2c_L) + 6\alpha_E q_E q_L .$$

The slope of the equilibrium locus is given by

(19) $$\frac{dq_E}{dq_L} = -\frac{\alpha_L - 2q_L(3\alpha_L + 2c_L) - 6\alpha_E q_E}{\alpha_E - 2q_E(3\alpha_E + 2c_E) - 6\alpha_E q_L} .$$

At the pre-regulation equilibrium, the slope of the iso-profit line is flatter than the slope of the equilibrium locus, as shown in Figure 2, indicating that a marginal tightening of the AES results in equilibrium points with lower profit.

As with the quota, we can decompose the effect of the AES on firm profit. Firm *i*'s profit under the AES is given by the Lagrangian function

(20) $$\Phi^{iZ} = P_L q_L^i + P_E q_E^i - c_L(q_L^i)^2 - c_E(q_E^i)^2 + \rho(Z - \frac{q_L^i}{q_E^i})$$

where ρ is the Lagrangian multiplier. The impact of a reduction in *Z* on firm profit is given by

(21) $$\frac{\partial \pi^{iZ}}{\partial Z} = \frac{d\Phi^{iZ}}{dZ} = \underbrace{\rho}_{\substack{restriction \\ effect}} + \underbrace{\left.\frac{dP_L}{dZ}\right|_{\overline{q_L^i}, \overline{q_E^i}} q_L^i + \left.\frac{dP_E}{dZ}\right|_{\overline{q_L^i}, \overline{q_E^i}} q_E^i}_{strategic\ \ effect}$$

where $\left.\frac{dP_s}{dZ}\right|_{\overline{q_L^i}, \overline{q_E^i}} = \frac{\partial P_s}{\partial Q_L}\frac{dq_L^j}{dZ} + \frac{\partial P_s}{\partial Q_E}\frac{dq_E^j}{dZ}$ for *s*=*L, E* and $j \neq i$.

The restriction effect is given by

(22) $$\rho = \frac{(\alpha_E + Z\alpha_L)(2c_L Z\alpha_E - 3\alpha_E(\alpha_L - \alpha_E) - 2c_E\alpha_L)}{(2c_E + 2c_L Z^2 + 3\alpha_E(1 + 2Z) + 3Z^2\alpha_L)^2},$$

which is always positive for values of $Z < Z^0$. The strategic effect, denoted by δ, is given by

$$(23) \quad \delta = -\frac{(\alpha_E + Z\alpha_L)}{(2c_E + 2c_L Z^2 + 3(\alpha_E + 2Z\alpha_E + Z^2\alpha_L))^3}\{2c_E(\alpha_E{}^2 + 2Z^2\alpha_L{}^2 + \alpha_E\alpha_L(1+4Z))$$

$$+(\alpha_E + Z\alpha_L)[\alpha_E(3(\alpha_L - \alpha_E)(\alpha_E + 2Z\alpha_E + Z^2\alpha_L) - 2c_L Z(\alpha_E(2+3Z) + Z\alpha_L(1+2Z)))]\}$$

Initially tightening the standard gives rise to a positive strategic effect, suggesting that tightening the standard reduces firm profit, all else equal. This is the range where tightening the standard increases competition between firms, which results in a decline in the price of the economy model. Further tightening of the standard gives rise to a negative strategic effect.[25] At that point tightening the standard reduces competition between firms. While this is beneficial to firms, the gain in profit from reduced competition is outweighed by the loss in profit due to the regulation becoming too restricting. According to this specification, the net effect of tightening the AES is always a reduction in firm profit since the restriction effect always outweighs the strategic effect.

Proposition 5 suggests that regulations like CAFE are always profit reducing. Kleit (1990) shows that initially tightening CAFE may increase firm profit depending on the parameter values. Absent any substitution between models, Kliet shows that CAFE can enforce a cartel like outcome by limiting the output of the luxury model. In this paper, such an outcome is not possible due to substitution between models, which adversely affects the profit gain from limiting the supply of luxury automobiles. This is especially true as CAFE initially reduces the price of the economy model.

V. Comparison of Market Equilibria

The previous sections compare equilibrium under each policy to the pre-regulation equilibrium. This section compares the equilibrium under the quota to that under the AES in terms of how they affect prices, quantities and, in turn, firm profit. We will first compare the two policies holding the average energy consumption constant. This will help us better understand the role of competition between firms. We then compare the two policies holding total energy consumption constant to determine which policy achieves a target level of environmental quality with lower cost to firms.

To fix a given level of average energy consumption across the two models, we will assume that Z is equal to $\frac{q_L^K}{q_E^K}$. Proposition 6 compares the equilibrium quantities and prices under both policies.

Proposition 6: *(i)* $q_E^K < q_E^Z$, *(ii)* $q_L^K < q_L^Z$, *(iii)* $P_E^K > P_E^Z$, *(iv)* $P_L^K > P_L^Z$ *and (v)* $\pi^K > \pi^Z$ *for a given level of average efficiency.*

While both policies cause a substitution towards the economy model, the impact on prices and quantities is different. The quota fixes the quantity that each firm can produce of the luxury model at *K*, and thus limits competition between firms in that market. Figure 2 shows the equilibrium locus under the quota and the AES. Point A is the equilibrium under the quota, *K*, and point B is the equilibrium under a comparable AES, *Z*, *i.e.,* both points A and B achieve the same level of average energy consumption. Thus, under a comparable AES output of each model is higher and price is lower than under a quota. While A and B achieve an identical level of average efficiency, point A is more profitable (*i.e.*, lies on a higher iso-profit line) than B. However, although it is feasible, point A is not the equilibrium point under the AES, Z. Firms are in a Prisoners' Dilemma situation where competition drives firms to the lower profit equilibrium point B.[26]

A given level of average energy consumption can be achieved with less reduction in firm profit by a quota than an AES. However, total energy consumption is higher under B since output of each model is higher. To achieve the same level of total energy consumption as under A, further tightening of the AES is needed, which reduces profit even more. Proposition 7 follows.

Proposition 7: $\pi^K > \pi^Z$ *for a given level of total emissions.*

Thus, a given level of total energy consumption can be achieved at lower cost to firms under the quota than the AES. This suggests that a quota may be politically more feasible than an AES, if policy makers are concerned about the impact of regulation on firms.[27]

VI. The impact on social welfare

There are two sources of market imperfections in this model: the Cournot competition and the externality. The former imperfection implies that there is underproduction of automobiles while the latter suggests that the market output is higher than the socially optimum level. Since the policies we consider have a different impact on total output, the policy choice will depend on which market imperfection dominates, which in turn depends on the magnitude of the parameters and on the damages resulting from a unit of energy consumption, *d*.

For a given partitioning of consumers, social welfare is defined as follows

(24) $$SW = \int_{\theta_L}^{1} \theta\alpha_L^S d\theta + \int_{\theta_E}^{\theta_L} \theta\alpha_E^S d\theta - c_L(1-\theta_L)^2 - c_E(\theta_L - \theta_E)^2 ,$$

where α_L^S and α_E^S are the net benefit per use to society defined by $\alpha_L^S = \omega_L - (p_e + d)x_L$ and $\alpha_E^S = \omega_E - (p_e + d)x_E$. Given the uniform distribution of θ, this simplifies to

(25) $$SW(Q_L, Q_E) = \alpha_L^S Q_L(1 - \frac{Q_L}{2}) + \alpha_E^S Q_E(1 - Q_L - \frac{Q_E}{2}).$$

The social welfare under the quota, $SW^K \equiv SW^K(K,d)$, is obtained by substituting the equilibrium quantities, Q_L^K and Q_E^K, into (25). This depends on both the stringency of the quota and the magnitude of unit damages. Similarly, we derive the social welfare under the AES, $SW^Z \equiv SW^Z(Z,d)$. We will analyze how changing *K* or *Z* affects welfare for a given level of *d*, and compare that to the pre-regulation level of social welfare, $SW^0 \equiv SW^0(d)$, which is obtained by substituting the pre-regulation equilibrium values Q_L^0 and Q_E^0 into (25).

First, we consider the impact of each policy on social welfare when *d=0*. This will show how each policy can address the imperfect competition problem. We will then analyze the welfare impact of each policy for positive values of *d*.

Proposition 8: *When d=0, the AES can increase social welfare while the quota is always welfare reducing.*

Because of imperfect competition, the market will always supply an output level of each model below the socially optimal level denoted by point S_o in Figure 5. The quota results in further reduction in total output. Although this raises industry profit over a certain range, it will always decrease consumer surplus since prices of both models are higher, and result in a reduction in social welfare. This is clear in Figure 5 where tightening the quota always results in a lower welfare point when d=0. Tightening the AES, on the other hand, initially increases total output and raises social welfare.[28] In Figure 5 the iso-social welfare line corresponding to d=0 that passes through point O intersects the equilibrium locus under the AES, suggesting that higher welfare equilibrium points can be achieved. This shows that AES, which is usually adopted in contexts of environmental regulation and quality controls, is actually capable of addressing problems of imperfect competition.

We turn next to the impact of each policy when d>0. We first consider the effect of the quota on social welfare.

Proposition 9: *For a high enough value of d, the quota is welfare improving.*

Whether the quota improves social welfare will depend on whether the gains to society from reduced environmental damages offsets the resulting loss in market surplus. The magnitude of the gain will depend on the value of d. When d is high enough, there is over production of both models relative to the socially optimal levels of output, point S_H. This is shown in Figure 5 where there is more production of both models at point O than point S_H. Thus, the quota, by reducing total output, can raise social welfare. This is depicted in Figure 5 where the iso-social welfare line corresponding to high levels of d that passes through point O intersects the equilibrium locus under the quota, indicating that higher welfare equilibrium points can be achieved.

Next, we turn to the impact of the AES on social welfare. Whether the standard raises welfare will depend on its impact on total emissions as well as the magnitude of d.

Proposition 10: *If* $\frac{\partial E}{\partial Z} > 0$ *for all values of Z, then the AES is always welfare improving.*

If tightening the standard results in a reduction in total emissions, then the AES is welfare enhancing. While tightening the quota reduces market surplus, a marginal reduction in *Z* at the pre-regulation equilibrium always improves market surplus. This is because the gain in consumer surplus outweighs the associated losses in firm profit. If total emissions decline with a reduction in *Z*, then the AES always improves social welfare.[29] This is true regardless of the value of *d* (although *d* determines the optimal value of *Z*).

Proposition 11: *If* $\frac{\partial E}{\partial Z} < 0$ *at* Z^0*, then the AES raises SW only for low enough values of d.*

When total emissions increase initially under the standard, then whether the standard raises social welfare will depend on the value of *d*. The standard raises social welfare if the gains in market surplus outweigh the damages associated with the increased emissions level that accrue from a marginal reduction in *Z*. When *d* is low, the damages to society from emissions are relatively low and the gains from a marginal decline in Z outweigh the cost to society. However, for high enough values of *d,* as shown in Figure 5, the environmental damages exceed any possible gains in market surplus, and thus tightening the standard is welfare reducing.

The above analysis was based on exogenous values of *K* and *Z*. To determine the optimal policy, we compare social welfare when *K* and *Z* are endogenously chosen.[30] We use $SW^{Z*} \equiv SW(Z^*(d), d)$ and $SW^{K*} \equiv SW(K^*(d), d)$ to denote social welfare under each policy given that the policy is optimally adjusted to the value of *d*. Based on the above analysis whether the quota or the AES is more efficient will depend on the value of *d*. Thus, for a given *d* the quota is superior to the AES if $SW^{K*} > SW^{Z*} \geq SW^0$ and vice versa.

Proposition 12: *When d is high enough, the quota policy is more efficient than the AES, i.e.,* $SW^{K*} > SW^{Z*} \geq SW^{0}$.

If the stringency of the policy is chosen optimally, then even when the AES is always welfare improving, the quota can still be a superior policy. Figure 6 illustrates Proposition 12 for the case where the AES is welfare improving for all values of *d* (see proposition 10), and thus SW^{Z*} will always be higher than SW^{0}. As illustrated, when *d* is low enough, the optimal quota is non binding, and hence $SW^{K*} = SW^{0}$. However, SW^{K*} is higher than SW^{0} when *d* is high enough, *i.e.,* higher than some cutoff value d^{K}. When *d* is high enough, *i.e.*, *d* exceeds d^{*} in Figure 6, then the quota is superior to the AES.[31]

VII. Conclusion

When environmental damages result from the use of the final product, the policy objective is to substitute cleaner products for the polluting ones. While the quota and the AES can achieve that end, they vary in their impact on firms, consumers, environmental quality and social welfare. In this paper we show that, while it is generally believed that the increased flexibility that an AES provides is beneficial to firms, this flexibility in an oligopoly model is, in fact, detrimental to firm profit. A quota that defines the maximum amount that can be produced of the polluting model reduces competition between firms and thus can, over a certain range, raise firm profit in comparison to the pre-regulation level. This is in contrast to the AES which initially increases competition between firms and always reduces firm profit. In addition, we show that a quota achieves a given level of environmental quality at a lower cost to firms than an AES. Thus, a quota policy should be preferred by firms.

The AES does not guarantee an improvement in environmental quality, which is the objective of the regulation in the first place. If the economy model is not sufficiently fuel efficient, total emissions can actually increase under the AES, as the standard increases total market sales, and therefore, all else equal, overall energy consumption. In contrast the quota always reduces emissions. This suggests that policies like CAFE can actually result in a deterioration in environmental quality, if the alternative fuel economy automobiles available in the market are not significantly fuel efficient.

Taken together, both findings suggest that the quota can outperform the AES in terms of environmental quality and profit. However, it does not necessarily imply that the quota should be the policy choice. The policy choice should consider the impact of each on consumer surplus and ultimately social welfare. Relative to the pre-regulation equilibrium consumers are better off under the AES over a certain range, while consumer surplus always declines under a quota. Since there are two sources of market imperfection, the imperfect competition and the externality, the socially optimal policy will be determined by the magnitude of unit damages. At low levels of damages an AES achieves higher values of social welfare than a quota. When damages are high enough, the quota is a superior policy since the gains from improved environmental quality outweigh any reduction in market surplus.

The results have important implications for policy making. It is important to understand the different choices available. For example, advocates of tightening the CAFE standards believe that this is necessary if further improvements in environmental quality are to be achieved. However, when damages are high enough tightening CAFE is not the only option available, and in fact it may be welfare reducing. Switching to a quota-based regulation guarantees an improvement in environmental quality and delivers the maximum improvement in social welfare.

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X. Appendix :

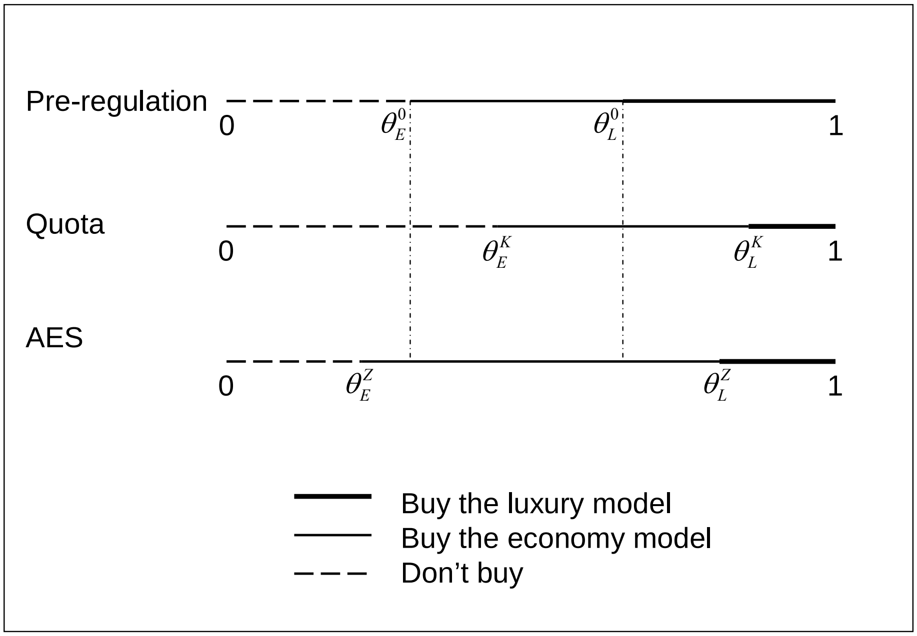

Figure 1
The market segmentation under the quota and the AES in comparison to the pre-regulation equilibrium.

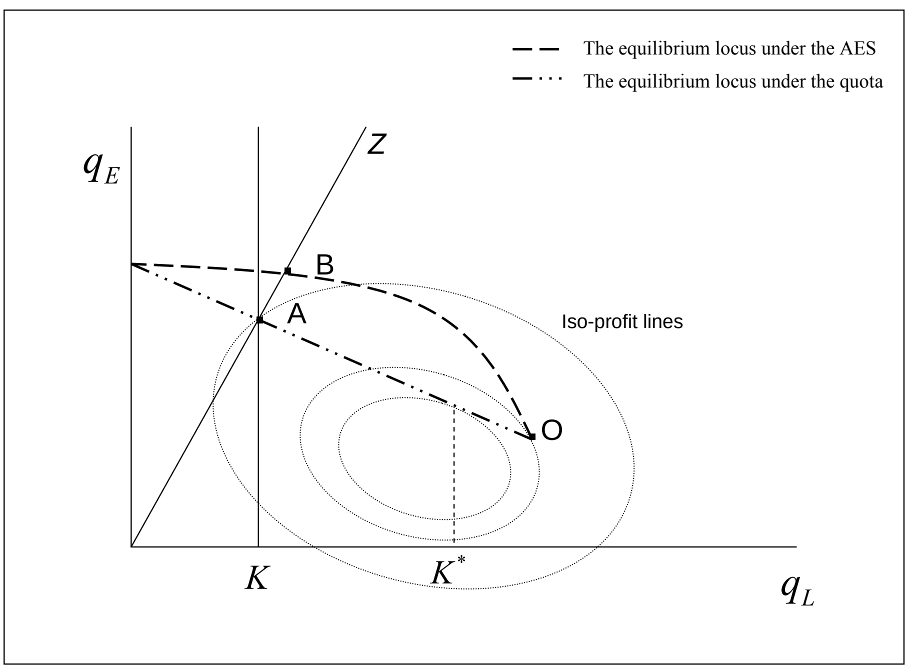

Figure 2
The equilibrium locus and the iso-profit lines under each policy.

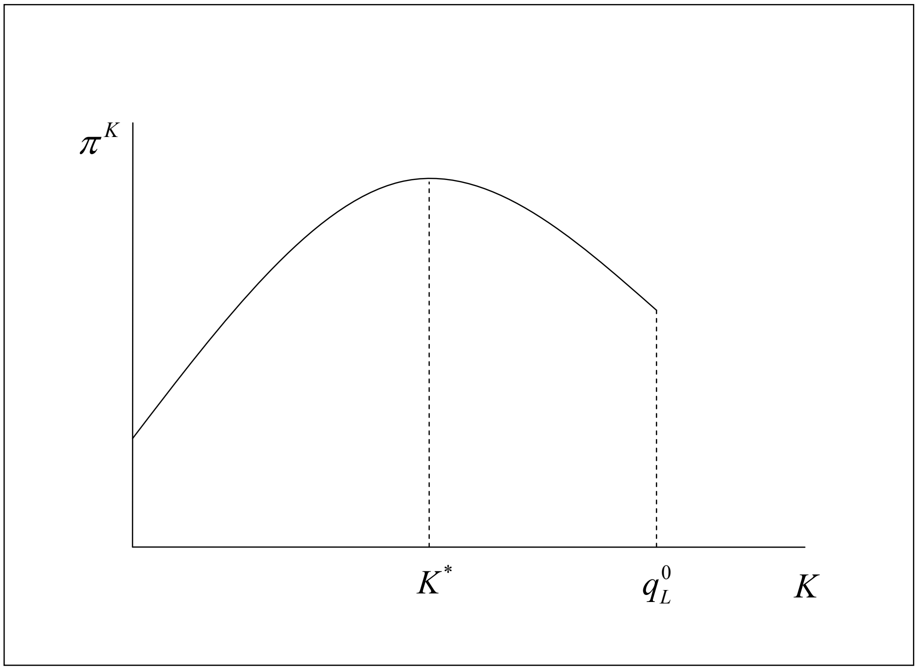

Figure 3
The impact of the quota on the firm profit.

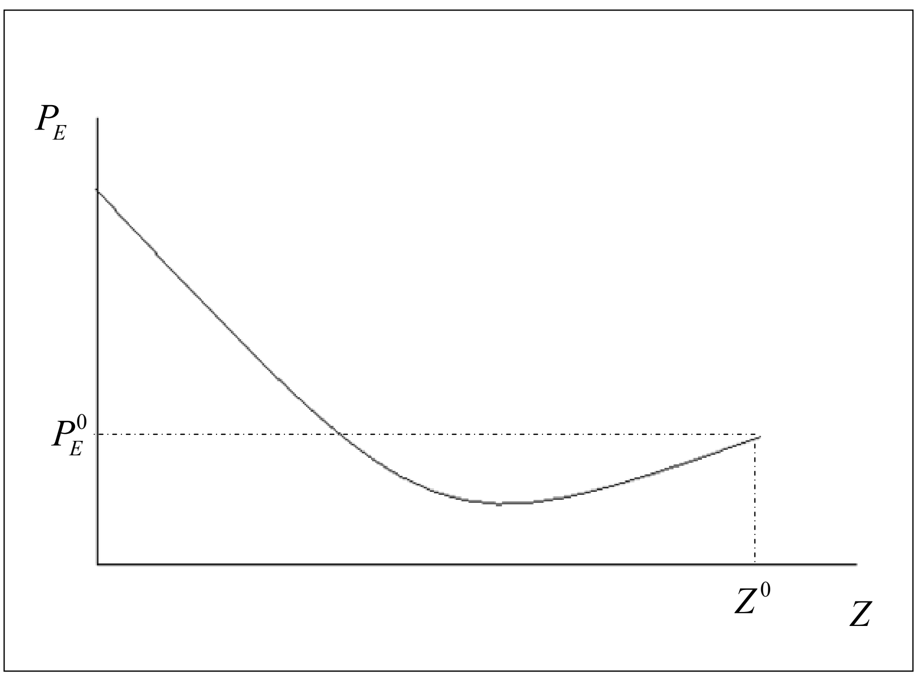

Figure 4
The impact of the AES on the price of the economy model.

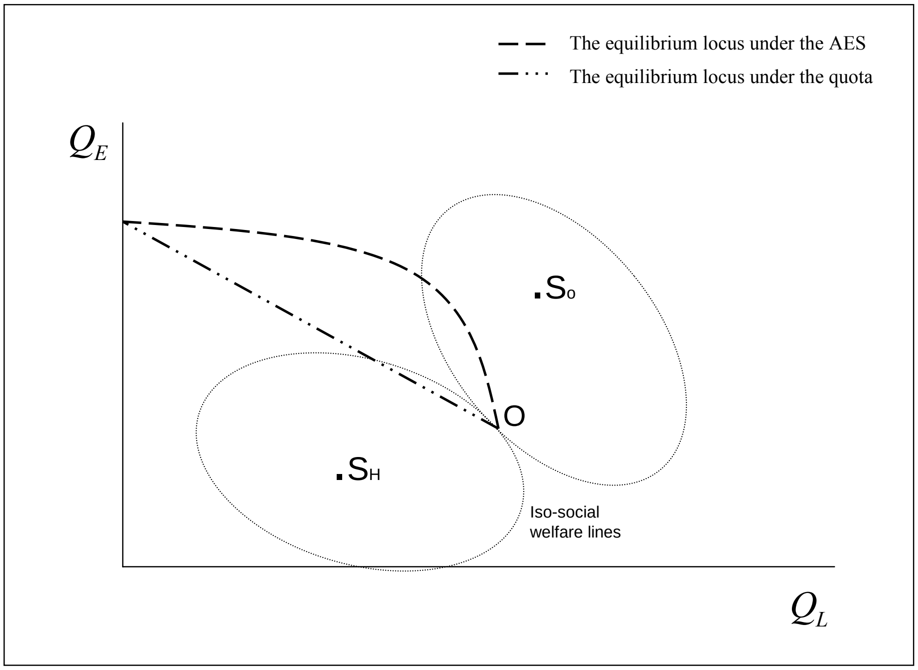

Figure 5
Iso-social welfare lines for different values of *d*.

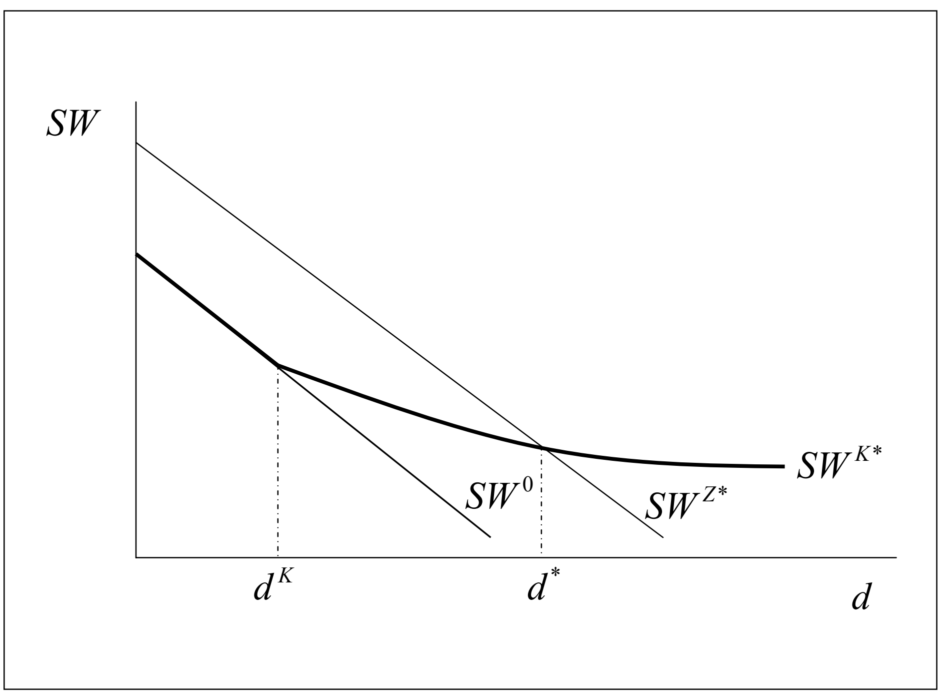

Figure 6
Social welfare under the average efficiency regulation and the quota when the AES is always welfare improving.

[1] Examples of models with product lines include Gal-Or (1983), Brander and Eaton (1984), Bresnahan (1987), Champsaur and Rochet (1989), De Fraja (1996) and Johnson and Myatt (2003).

[2] In a related paper, Ahmed and Segerson (2007a) consider the effect of a voluntary industry agreement for products where there is no tradeoff between energy efficiency and product quality, such as some appliances.

[3] For a detailed analysis of the impact of the standard and the quota on firm profit when firms change the energy efficiency of the products, see Ahmed and Segerson (2007b).

[4] The fact that a quota policy can increase firm profit in markets where competition is not perfect may represent a significant drawback especially in contexts where policy makers are mainly concerned about consumers' welfare. It can be shown that a system of auctioned permits gives rise to the same equilibrium outcome as under the quota without raising firm profit. The gains in profit accrue to the government through the sale of the permits, which can then be redistributed to consumers. In addition to its role as a means of distributing surplus, the permit system can potentially enhance efficiency if trade in permits is allowed. However, since firms are identical in this model, the well-known efficiency gains from allowing trade do not arise here.

[5] Empirical analysis suggests that the elasticity of use with respect to price per mile is small, if not insignificant. See Goldberg (1998).

[6] We restrict analysis to positive values of α to ensure that the products are traded in the market. Otherwise when $\alpha_s \leq 0$ there will be no demand for the products.

[7] We assume that $\frac{\omega_L}{x_L} > \frac{\omega_E}{x_E}$. Thus, over the range of p_e where both models are traded, the net benefit per use is always higher for the luxury model, *i.e.,* $\alpha_L > \alpha_E$.

[8] It is possible to have a tradeoff between energy efficiency and quality and still have $\alpha_E > \alpha_L$. In this case, consumer preferences over the two models would be identical to that of Ahmed and Segerson (2007a) where there was no tradeoff and the analysis would be the same.

[9] It is possible that consumers who do not buy either a luxury or an economy automobile will end up driving a used automobile where the utility of driving a used automobile is normalized to zero. This assumes that the price of a used automobile is unaffected by changes in prices of other models, which is consistent with Bresnahan (1987).

[10] See Proposition 2.

[11] This is equivalent to mandating that weighted average energy consumption across the fleet not exceed a given value.

[12] The binding range of η is $[0,\eta^0)$ where $\eta^0 = \dfrac{2(\alpha_L c_E x_L + \alpha_E c_L x_E) + 3\alpha_E x_L(\alpha_L - \alpha_E)}{2(\alpha_L c_E + \alpha_E c_L) + 3\alpha_E(\alpha_L - \alpha_E)}$.

[13] The binding range of Z is $[0, Z^0)$ where $Z^0 = \dfrac{q_L^0}{q_E^0} = \dfrac{3\alpha_E(\alpha_L - \alpha_E) + 2\alpha_L c_E}{2\alpha_E c_L}$.

[14] The CAFE regulation imposes a fine on non-complying firms. We assume that firms comply with the regulation and are not subjected to the fine.

[15] Although the US automobiles market is supplied by both domestic and foreign firms, we assume that firms are identical since they are all subject to the same standard. Although domestic and foreign firms may have different cost advantage, the simplifying assumption here helps to better emphasize how each policy affects the market outcome differently.

[16] Proofs of all propositions will be provided upon request.

[17] Most of the literature on quality competition show a quality specialization equilibrium where each firm tends to differentiate its products from competitors, which is not the case here since this is a product line model where each firm produces all models. See, for example, Shaked and Sutton (1982), Besanko, Donnenfeld and White (1987), Motta (1993), DeFraja (1996), Wauthy (1996), Lehman-Grube (1997), Valetti (2000) and Wang and Yang (2001).

[18] The quota policy is equivalent to a tax on the luxury model where firms keep the tax revenue. The Lagrange multiplier can be interpreted as the tax rate.

[19] This is an application of the general principle that, in the presence of strategic behavior, the shadow price of a constraint is not simply the Lagrange multiplier (see Caputo 2006).

[20] Without specific functional forms, the sign of $\left.\frac{dP_s}{dK}\right|_{\overline{q_{iH}},\overline{q_{iL}}}$ will be ambiguous since $\frac{\partial P_s}{\partial Q_H}>0$, $\frac{\partial P_s}{\partial Q_L}>0$, $\frac{dq_H^{jK}}{dK}<0$ and $\frac{dq_L^{jK}}{dK}>0$.

[21] For an illustration of a constraint that can increase competition between firms and gives rise to a positive strategic effect, *i.e.,* changes production decisions of firm *j* such that firm *i*'s profit decreases, see Ahmed and Segerson (2007b).

[22] The AES is equivalent to a tax on the luxury model where its revenue is used to subsidize production of the economy model. This explains why total market output can increase under the AES but not under the quota.

[23] In a model with no substitution between product models Kleit (1990) finds that the price of the economy automobiles may decline initially depending on the value of certain parameters of the model. We show here that this always holds regardless of any parameter values.

[24] Totally differentiating the constraint $\frac{q_L^i}{q_E^i}=Z$, we get that the extra production of the economy model for a marginal decline in the luxury model to meet the reduction in Z is $\frac{dq_E}{dq_L}=\frac{1}{Z}(1-q_E\frac{dZ}{dq_L})$. The expansion in the economy model, $\frac{dq_E}{dq_L}$, is inversely related to q_E. This implies that, for a large enough q_E , the demand effect outweighs the increased production effect and the price of the economy model rises.

[25] The strategic effect, according to this model's specification, is

$$\frac{8c_L^3\alpha_E^4(\alpha_L-\alpha_E)}{(4c_Lc_E+6(\alpha_Ec_L+\alpha_Lc_E)+9\alpha_E(\alpha_L-\alpha_E))^2(2(c_L\alpha_E{}^2+c_E\alpha_L{}^2)+3\alpha_E\alpha_L(\alpha_L-\alpha_E))}>0 \text{ at}$$

$Z=Z^0$ and is $\frac{-3\alpha_E{}^3(\alpha_L-\alpha_E)-2\alpha_E{}^2c_E(\alpha_L+\alpha_E)}{(2c_E+3\alpha_E)^3+3\alpha_E\alpha_L(\alpha_L-\alpha_E))}<0$ at $Z=0$.

[26] In the monopoly case, we can show that a given level of average efficiency can be achieved with less cost to firms under an AES than under a quota. In contrast to the duopoly market, a point like B would be more profitable than a point like A under a monopoly market indicating that the flexibility of the AES is beneficial to firms in the absence of competition.

[27] Tightening the quota always results in a reduction in total emissions since the elimination of a unit of the luxury model under the quota increases production of the economy model by less than one unit. This is not always possible under the AES where total emissions can initially increase. Whether this is possible or not will depend on, all else equal, the magnitude of x_E relative to x_L. For a one unit reduction of the luxury model, initially tightening the AES increases production of the economy model by more than one unit. If the economy model is not significantly more fuel efficient, then the savings in energy per use will be outweighed by the increased total use from increased sales, resulting in increased energy consumption. This is consistent with Kwoka (1987), who shows that CAFE regulation can potentially increase energy consumption depending on miles per gallon of both models. Kliet (1990) shows through simulations that a similar result is possible.

[28] While the quota always decreases consumer surplus, tightening the AES increases consumer surplus initially. This is because the loss in consumer surplus from the higher price of the luxury model is more than offset by the lower price of the economy model. With further tightening of the standard, consumer surplus reaches a maximum and starts to decline. The fact that CAFE can increase or decrease consumer surplus provides an explanation for the conflicting evidence in the CAFE literature on its impact on consumer surplus. Agras and Chapman (1999) estimate a negative impact on consumer surplus while Kleit (1990) showed that CAFE may initially increase consumer surplus depending on the parameter values.

[29] Parry et al. (2004) show that in the absence of market failures on the consumption side, *i.e.,* when people value improvements in fuel economy, a binding CAFE will always reduce social welfare assuming a perfectly competitive market. The results here are different because we model a duopoly market with Cournot competition. The results we derive here suggest that in the absence of a consumption externality, *i.e.,* when *d*=0, the AES can still increase social welfare because it corrects the market failure associated with the Cournot competition.

[30] Alternatively, we could fix the emissions level and compare social welfare under each policy. The results are consistent with the above analysis.

[31] It is possible that there is a range of *d* over which neither policy improves welfare. This will be true when the AES initially increases emissions and when $d^K > d^Z$. Thus for $d^K < d < d^Z$, neither policy is welfare improving. An AES would reduce welfare since the total damages from increased energy consumption outweigh any gains in market surplus. Also, a quota would reduce welfare since the gain from the reduction in total damages is outweighed by the loss in market surplus due to the output restriction.