University of Connecticut

Department of Economics Working Paper Series

Collective Voluntary Agreements and the Production of Less Polluting Products

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Abstract

Recently, some industries have collectively agreed not to produce models that do not meet an energy efficiency (and hence an environmental) standard. This paper presents a simple model that can be used to examine a voluntary collective agreement to limit or completely eliminate the low efficiency model of a given product (e.g., a low efficiency washing machine). We show that, when there is competition between firms, a collective agreement to limit or even eliminate production of the polluting model can actually increase profits for all firms in the industry. This suggests that a collective agreement of this type might actually be beneficial to firms, while at the same time improving environmental quality. However, the implicit enforcement that comes from the public nature of the commitment is necessary to ensure this outcome. This suggests that, by promoting such agreements, policymakers may be able to achieve substantial environmental gains with relatively little inducement. The impact on social welfare will then depend on whether these gains are sufficiently large to offset consumer losses from reductions in product variety and the associated price increases.

Journal of Economic Literature Classification: Q48, Q58

Keywords: Voluntary agreements, collective agreements, energy/fuel efficiency

I. Introduction

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

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

When voluntary impacts stem from a product's consumption rather than its production, a voluntary approach might take the form of some firms within an industry choosing voluntarily to produce a more energy or water efficient product. A subset of firms within the industry may seek to do so in an effort to differentiate their product and appeal to green consumers. Alternatively, a voluntary approach could take the form of a firm or group of firms (possibly even an entire industry) agreeing to reduce or eliminate production of products that are not efficient. If they agree to produce only efficient products, all firms produce an identical product and hence there is no product

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

differentiation. An example of this is the European voluntary agreement on washing machines. In April 1996 the principal European producers and importers of clothes washing machines (comprising 95% of the EC market) presented 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 38% in 1996 to around 80% 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). Similar agreements have also been made for household dishwashers, water heaters, household refrigerators, freezers, televisions and radios (International Energy Agency, 2005).

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

In this paper we examine voluntary initiatives that take the form of reducing or eliminating production of polluting products. Our main goal is to seek to explain why

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

collective agreements of this type might emerge. Toward this end, we consider three questions:[3] (a) Do firms have an incentive to reduce or eliminate production of polluting products unilaterally, i.e., without a commitment by other firms to do the same, in an attempt, for example, to differentiate their product? (b) Do firms have an incentive to enter into a collective agreement that commits all firms in the market to reduce or eliminate production of the product? and (c) If firms enter into a collective agreement, do they have an incentive to adhere to it, i.e., is such an agreement self-enforcing?

Our main result is that, while in the context of our model firms do not have an incentive to limit production unilaterally, under some conditions a collective agreement to reduce or eliminate production can actually increase profits for all firms. In addition, we show that a profitable agreement always exists. Thus, there is always the potential for firms to enter into an agreement to limit the production of the polluting model that simultaneously raises profits and improves environmental quality. However, regardless of whether an agreement is profitable, collective agreements are not self-enforcing, i.e., each firm has an incentive to cheat on the agreement. Thus, some enforcement mechanism is needed to ensure that an agreement does not fall apart. We suggest that having the voluntary agreement sufficiently public (rather than simply an internal agreement among firms), coupled with the ability to detect cheating easily, can provide enforcement.

Our results have potentially important policy implications. Most previous analyses of VAs assume that the voluntary actions undertaken by firms are costly and

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[3] Because we are interested in providing an explanation for the emergence of these agreements, we focus here on the impact they have on firms. Alternatively, we could focus on either their environmental or welfare effects. In fact, the potential environmental benefits led the European Commission to grant anti-trust exemptions for the washing machine, dishwasher, and water heater agreements, despite concerns about the implications for competition (Martinez-Lopez, 2000, 2002).

hence reduce producer profits. In the dishwasher and water heater agreements noted above, it was clearly recognized that the agreement would restrict each manufacturer's freedom to produce and market its products (Martinez-Lopez, 2002). For this reason, it is often believed that some external pressure, such as a regulatory threat, is necessary to induce firms to undertake those actions.[4] In fact, Paton (2005) states that participation in the Clothes Washer Energy Star Program was influenced by the threat of regulation. Without any formal analysis, he also claims that such agreements prevent non-participating firms from undercutting the prices of participating firms. Similarly, the manufacturers of washing machines realize that, in order to achieve the energy savings target they set without harming the competitiveness of participants, it is important that as many firms as possible join the agreement (CECED, 2002). Our analysis provides some support for this claim. It suggests that the assumption that voluntary agreements are costly to firms and that some form of government inducement (e.g., cost sharing or threat) is necessary to induce participation is not always correct. Rather, firms might be motivated to enter a public voluntary agreement of this type by the prospect that it would be an enforcement mechanism designed to solve a Prisoner's Dilemma problem faced by the firms.[5] This suggests that by facilitating such agreements, the government can improve environmental quality in a way that could actually be profitable for firms.

Our analysis is based on a simple model of a market in which there are two possible versions (models) of a particular product, a high polluting (low efficiency)

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

[5] The inability of firms to develop an enforcement mechanism that overcomes the Prisoner's Dilemma can discourage firms from participating in VA's. This can be true under strict antitrust regulation. Kappas (1997) states that antitrust liabilities associated with voluntary initiatives in the US have often discouraged industry self-regulation. That may explain why the U.S. clothes washer market is characterized by government regulation rather than an industry-wide VA of the type that emerged in the European market.

model and a low polluting (high efficiency) model.[6] While our approach is motivated by

the examples of energy-efficient appliances given above (and the discussion in the text

reflects this), the analysis is relevant to other context as well (e.g., water use).[7] We

develop a model that is similar to the product line models in De Fraja (1996) and Johnson

and Myatt (2003).[8] In contrast to most of the literature on product quality,[9] these models

assume that identical competing firms simultaneously choose quality and quantity and

quality is modeled as a discrete rather than continuous choice. They predict equilibria in

which firms can produce identical product lines (rather than specializing in a single

quality). Simultaneous choice is more relevant when firms cannot easily change the

product specification (De Fraja, 1996). We adopt this approach because it is consistent

with the observation that for many products an individual firm will produce models of

varying levels of efficiency.[10] We use the model to examine the impacts of voluntary

initiatives to reduce or eliminate production of the low efficiency model.[11]

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[6] Using the washing machine example for concreteness, we can think of the low efficiency model as the top loading machine and the high efficiency model as the front loading machine. According to Consumer Reports energy efficiency ratings, front loading machines score an average of 1.5 while the top loading machines score an average of 3.2 on a scale of 1 to 5 with 1 being most efficient (Consumer Reports, 2006).

[7] An interesting example of products with varying levels of energy efficiency is automobiles. The model in this paper does not directly apply to automobiles, since it implies that the more energy efficient models will sell for a higher price. This is clearly not the case for automobiles, primarily because automobile models with lower fuel economy have other compensating qualities (e.g., comfort, safety) that also affect price. We examine the case of automobiles in a related paper (Ahmed and Segerson, 2006).

[8] Earlier examples of models with product lines include Gal-Or (1983), Brander and Eaton (1984), and Champsaur and Rochet (1989).

[9] The literature on quality choice typically assumes a two-stage game in which competing firms choose quality in the first stage and prices (or output levels) in the second stage. It is usually either assumed that each firm produces a single quality or such a result is predicted in equilibrium. Examples of this literature include Shaked and Sutton (1982), Motta (1993), Wauthy (1996), Lehmann-Grube (1997), Valetti (2000), and Wang and Yang (2001).

[10] See Chen (2001) for a discussion of various examples of "green" and "traditional" product lines.

[11] Our analysis is also related to the literature on minimum quality standards, e.g., Ronnen (1991), Crampes and Hollander (1995), Ecchia and Lambertini (1997), Maxwell (1998), Scarpa (1998), Lutz, et al. (2000), and Valletti (2000). However, this literature also typically assumes that each firm produces a single

The paper is organized as follows. Section II presents the basic structure of our model. For simplicity we derive most of the results in the case where there are two possible versions of a product, the high and the low efficiency versions. In Section III, we consider first the simplest case in which the market is a monopoly and compare the equilibrium where the monopolist is free to produce both models to the equilibrium where it agrees to produce only the high efficiency model. The results here are fairly standard, but they allow us to establish a benchmark regarding the impact of eliminating the competition between the two models. We then examine in Section IV the more interesting case of a duopoly, in which there is the potential for competition not only between the two models as in the monopoly case but also between the two firms. We compare the free market equilibrium to the outcomes under both the unilateral commitment and the collective commitment in terms of prices, quantities and profit. We describe the conditions under which an agreement to limit production of the low efficiency model can be profitable. In Section V we consider in more detail agreements that completely eliminate production of the low efficiency model. For this discussion, we extend our basic model to the case where there are three versions of a product (low, medium and high efficiency), which allows us to derive a more general result regarding product elimination. A summary and conclusion appears in Section VI.

II. The Basic Model Structure

To characterize the demand side of the market, we assume that there are N potential consumers of the product who vary in their intensity of use, denoted θ, which is

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quality. In our context, imposing such an assumption would make the analysis trivial, since clearly if one firm produced only the low efficiency model and the other produced only the high efficiency model, an agreement to eliminate production of the low efficiency model would always be costly to the first firm.

uniformly distributed on [0, 1]. We can think of θ as, for example, the number of hours

that the consumer uses the product (or, in the case of washing machines, the number of

loads of laundry the consumer does in a given period of time), which we assume is

determined by exogenous factors (e.g., family size). This assumption is consistent with

evidence provided by Davis (2004), who showed that household utilization for washing

machines is very price inelastic. Each consumer has the option to buy a single unit of the

product. We first consider the case where two alternative product models are available, a

low efficiency model (L) and a high efficiency model (H).   The utility of a consumer of

type θ who purchases a unit of model i ($i = L,H$) is given by

(1)
$$V_i^{\theta} = U(\theta) - p_E x_i \theta - P_i,$$

where $U(\theta)$ is the associated utility from use of the product,[12] p_E is the per unit price of

energy, x_i is the energy consumption per unit of use (e.g., per hour) by the type-i model,

and P_i is the price of the type-i model. For simplicity we assume that $U(\theta) = \theta$. Thus,

the utility of a consumer of type θ who buys the high efficiency model is $V_H^{\theta} = \lambda\theta - P_H$,

and that of a consumer who buys the low efficiency model is $V_L^{\theta} = \delta\theta - P_L$, where

$\lambda = 1 - p_E x_H$ and $\delta = 1 - p_E x_L$.[13] The low efficiency model uses more energy per unit of

use than the high efficiency model and hence $x_L > x_H$ and $\delta < \lambda$.[14] Note that λ and δ

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[12] We assume that $U(\theta)$ is independent of the type of model consumed. This is consistent with the fact
that improvements in energy consumption does not affect washing machines performance (CECED, 2002).

[13] We restrict our analysis to positive values of λ and δ.

[14] This is consistent with the ratings of Consumer Reports (2006) where 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.   We assume that
these other characteristics are the same across models. However, our results would still hold if we assume
that the high efficiency model is superior along these other dimensions as well.

reflect the net marginal utility of use of the high and the low efficiency models, respectively, which depends on the energy price and the energy efficiency of the models. However, typically low efficiency models are less expensive than high efficiency models, so we would expect $P_H > P_L$, and we will see that in equilibrium this is always true.[15] 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. Under this partitioning, a consumer of type θ will buy the high efficiency model if and only if

$$(2) \qquad \theta \geq \theta_H \equiv \frac{P_H - P_L}{\lambda - \delta},$$

while he will buy the low efficiency model if and only if

$$(3) \qquad \frac{P_L}{\delta} \equiv \theta_L \leq \theta < \theta_H.$$

Consumers for whom $\theta < \theta_L$ choose not to buy the product at all.[16]

Given the distribution of θ, the resulting demands when both models are offered on the market are given by

$$(4) \qquad Q_H = N(1 - \theta_H)$$

and

$$(5) \qquad Q_L = N(\theta_H - \theta_L),$$

where Q_i is the quantity demanded of model i. This implies the following inverse demand functions:

$$(6) \qquad P_L = \delta(1 - Q_H - Q_L)$$

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[15] According to Consumer Reports (2006), the top loading washing machines generally sell for $500 or less while many of the front loaders sell for $1000 and up.

[16] This assumes that utility if the product is not purchased is independent of θ and normalized to zero.

and

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

where we have normalized by setting $N=1$. Alternatively, when only the high efficiency model is produced, the resulting inverse demand is simply given by

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

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

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

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

III. The Monopoly Case

We begin by summarizing the equilibrium when the models are produced by a monopolist in order to provide a reference case that illustrates the nature of demand and the role of competition between the products within the structure of the model. By comparing this to the duopoly case, we can then see the role of competition between firms.

As noted above, we assume that quality and output (or price in the monopoly case) are chosen simultaneously rather than sequentially. Sequential choice does not give rise to symmetric equilibria, which is the case of interest in this analysis (De Fraja, 1996). Formally, this can be captured by assuming the monopolist simultaneously chooses how much of each product (each quality) to produce, i.e., it simultaneously chooses Q_H^M and Q_L^M to

(10) $$\text{maximize } \Pi^M = P_H^M Q_H^M + P_L^M Q_L^M - c_H (Q_H^M)^2,$$

where the superscript M denotes the monopoly and the demand functions are given by (6) and (7). We can represent a commitment by the monopolist to restrict or eliminate production of the low efficiency model by a constraint $Q_L^M \leq K$, where K is the upper limit on the output of the low efficiency model.[17] When the monopolist makes a commitment to restrict or eliminate production of the inefficient model, it maximizes profit given in (10) subject to this constraint. We denote the maximized profit by $\pi^M(K)$. Note that a sufficiently high value of K, set above the unconstrained output level, is a non-binding commitment corresponding to the free market scenario, while a value of K equal to zero represents a commitment to completely eliminate the low efficiency model from the market. Within the range where K is binding, we can easily show the following:[18]

Proposition 1: *A (binding) commitment by a monopolist to restrict production of the low efficiency model will result in:*

(i)   *an increase in the production of the high efficiency model (i.e., $\dfrac{\partial Q_H^M}{\partial K} < 0$);*

(ii)   *increases in the prices of both models (i.e., $\dfrac{\partial P_L^M}{\partial K} < 0$ and $\dfrac{\partial P_H^M}{\partial K} < 0$); and*

(iii)   *a reduction in the monopolist's profits (i.e., $\dfrac{\partial \pi^M}{\partial K} > 0$).*

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[17] Although the washing machines agreement had two components, we only model the first. The second target, reducing the average energy consumption by 20%, was non-binding given the first. The second target was met before the end of the agreement date (CECED, 2000).

[18] Proofs of all propositions are provided in an appendix that is available upon request.

Proposition 1 implies that, when the monopolist commits to limit production of the inefficient model, it simultaneously raises the price and the quantity of the efficient model. The reduction in the quantity of the inefficient model is accompanied by an increase in its price, which causes some of the consumers who previously bought the low efficiency model to switch to the high efficiency model and some to stop buying the product altogether. The reduction in production of the inefficient product effectively reduces competition between the two models, allowing the simultaneous increase in both price and quantity of the other model. However, the new price-quantity combinations cannot yield higher profit, since if they did, they would have been the optimal choices in the absence of the production constraint. Thus, when the market is supplied by a monopolist, the voluntary commitment can never be profitable, implying that some other inducement (e.g., a regulatory threat) is necessary in order to reduce or eliminate production of the polluting model. We show below that this result does not necessarily hold in the context of a duopoly, implying that the competition between firms plays a key role in determining the effect of a voluntary agreement on profits.

IV. The Duopoly Case

IV.1. The Pre-Commitment Equilibrium

We turn next to the primary case of interest where the market is supplied by two firms. We assume that the two firms have identical costs and are Cournot competitors. Thus, given the inverse market demands in (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 j simply chooses q_H^j and q_L^j so as to

(11) $$\text{maximize } \Pi^j = P_H q_H^j + P_L q_L^j - c_H (q_H^j)^2.$$

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 2: *(i)* $P_H^0 > P_L^0$, *(ii)* $q_L^{10} = q_L^{20}$ *and* $q_H^{10} = q_H^{20}$, *and (iii)* $q_L^{j0} = 0$ *if and only if* $c_H = 0$.

As expected, in equilibrium the price of the high efficiency model is higher than that of

the low efficiency model. Because the low efficiency model uses more energy and hence

has higher operating costs, in equilibrium it must have a lower purchase price in order to

induce any consumers to buy it. In addition, the firms produce the same amount of each

of the models, i.e. there is no quality specialization. In addition, without a commitment to

do otherwise, both firms will choose to produce both models unless the high efficiency

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).

Given a characterization of the initial equilibrium, we turn to the three questions

of interest: (a) Does either firm have an incentive to commit *unilaterally* to reduce or

eliminate production of the low efficiency/polluting product? (b) Do the firms have an

incentive to commit *collectively* (i.e., *bilaterally*) to such a restriction? and (c) if the

firms enter a collective agreement, does each firm have an incentive to adhere to the

agreement, i.e., are collective agreements of this type self-enforcing? We consider each

of these questions in turn.

IV.2. A Unilateral Commitment

We analyze this possibility by considering a case where one firm, say firm 1,

unilaterally commits to limit its production of the low efficiency model.   Thus, $q_L^{1U} \leq K$,

where $K \leq q_L^{10}$ and the superscript U denotes the case of a unilateral commitment.   As

before, the firms choose quantities to maximize the profit in (11), given this restriction.

We examine the effect of this limitation by characterizing how the equilibrium responds

as the commitment level becomes increasingly more stringent (starting from the non-

binding level where $K = q_L^{10}$). This response is summarized in Proposition 3.

Proposition 3: A unilateral commitment by firm 1 to reduce its production of the low

efficiency model results in:

(i)   *a shift in production by firm 1 away from the low efficiency model toward the*

        high efficiency model (i.e., $\frac{\partial q_H^{1U}}{\partial K} < 0$);

(ii)   *a shift in production by firm 2 away from the high efficiency model toward the*

        low efficiency model (i.e., $\frac{\partial q_H^{2U}}{\partial K} > 0$ and $\frac{\partial q_L^{2U}}{\partial K} < 0$);

(iii)   *an overall decrease in the production of the low efficiency model and an overall*

        increase in the production of the high efficiency model (i.e., $\frac{\partial Q_L^{U}}{\partial K} > 0$ and

        $\frac{\partial Q_H^{U}}{\partial K} < 0$); *and*

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

Proposition 3 implies that some of the reduction in output of the polluting product by firm 1 is offset by an increase in the output of this product by firm 2. Despite this "leakage" effect, overall output of the polluting product still declines. Thus, firm 1's commitment is effective in reducing energy consumption and hence improving environmental quality,[19] although clearly it is not as effective as it would be without the leakage. In addition, rather than sharing both markets equally as before, firm 1 now supplies a larger share of the high efficiency market while firm 2 supplies a larger share of the low efficiency market. Thus, the commitment does create some (albeit not complete) differentiation and specialization. Finally, as in the monopoly case, firm 1's commitment leads to an increase in the prices of both models, which *ceteris paribus* is beneficial not only to the firm making the commitment but to its competitor as well. The question is then whether the combined effects of these changes increase or decrease profits. The impacts on profitability are given in Proposition 4.

Proposition 4: $\pi_1^U(K) < \pi_1^0 = \pi_2^0 < \pi_2^U(K)$ *for all binding K.*

Here $\pi_i^U(K)$ represents firm *i*'s maximum profit when firm 1 commits to a reduction of stringency *K*. Proposition 4 implies that a unilateral commitment by one firm to reduce production of the polluting product, thereby specializing (incompletely) in production of

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[19] Note that total energy use depends not only on the number of units of each type sold, but also on the use characteristics of the consumers who buy these units.. However, since $\theta_L^U > \theta_L^0$ and $\theta_H^U < \theta_H^0$, the unilateral commitment leads to an unambiguous reduction in energy use.

the less polluting product, would be costly to that firm and beneficial to its competitor. This implies that within the context of our model no firm has an incentive to unilaterally reduce (or eliminate) production of a polluting product. We turn next to the question of whether this result continues to hold if the commitment is collective or bilateral rather than unilateral.

IV.3. A Collective (Bilateral) Agreement

As noted above, we capture the effect of a collective or bilateral agreement to reduce or eliminate production of the low efficiency model by imposing a constraint $q_L^{iB} \leq K$ on each firm's production decisions,[20] where throughout the superscript B denotes a variable in the case where the agreement is bilateral. Although we assume the firms collectively decide to limit the production of the low efficiency model, we continue to model their output choices for the high efficiency model as a Nash equilibrium, since any cooperation on the choice of output levels for this model would likely be in violation of anti-trust laws. Thus, each firm chooses its production levels for both models to maximize the profit given in (11), given this restriction. We model the firms entering the bilateral agreement as a reduction of K below the production level of each firm in the initial equilibrium. Figure 1 illustrates the impact of the agreement on the partitioning of consumers by purchase decision. The impacts on prices and quantities are summarized in Proposition 5.

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[20] This constraint is binding over the range $[0, q_L^{j0}]$, where q_L^{j0} is the pre-agreement level of output of the low efficiency model of firm j. We limit consideration of K to this range.

Proposition 5: *A collective agreement to limit production of the low efficiency model results in:*

(i)   *an increase in production of the high efficiency model by each firm and hence*

$$\text{in total (i.e., } \frac{\partial q_H^{iB}}{\partial K} < 0 \text{ for i=1,2 and hence } \frac{\partial Q_H^B}{\partial K} < 0 \text{), and}$$

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

Proposition 5 implies that the impact of the agreement on prices and quantities is qualitatively similar in the monopoly and duopoly cases. When the output of the low efficiency model is reduced, its price increases. This increases the demand for the high efficiency model as some of the consumers who used to buy the low efficiency model now buy the high efficiency model instead. This increased demand results in an increase in the price of the high efficiency model as well. In addition, some consumers who were buying the low efficiency model before now choose not to buy at all.

Although the impact of the agreement on prices and quantities is qualitatively similar under monopoly and duopoly, the same is not true for the impact on producer profits. In the monopoly case, the firm's commitment to reduce production of the low efficiency model always reduces profit. Similarly, a unilateral commitment by one firm reduced the profits of that firm. However, we show here that in the case of a duopoly a commitment to limit production that is bilateral rather than unilateral can, at least over some range, increase profits for both firms.

We consider the impact of a collective agreement on profits by examining $\pi_i^B(K)$, the individual firm's maximum profit as a function of *K*. In particular, we ask how profit

varies with reductions in *K* and how the value of profit at *K=0* compares to its unrestricted level. The relationship between profit and *K* is summarized in Proposition 6.

Proposition 6: $\pi_i^B(K)$ *is non-monotonic and reaches a maximum at a value of K, $K*$,*

that lies in the range $(0, q_L^0)$.

The relationship between profits and K implied by Proposition 6 is depicted in Figure 2. It shows that up to a given level, a collective commitment to limit production of the low efficiency model will actually increase firm profit relative to the pre-agreement scenario, although beyond a certain point further restriction will decrease profit.

The intuition for the non monotonic relationship between π and K is the following. Starting from the pre-agreement production levels, a binding agreement to limit production of the low efficiency model effectively allows firms to collude in the market for the low efficiency model and thus suppresses competition between firms in this market.[21] This increases profits for both firms. Note that this effect does not exist when output is produced by a monopolist. However, as output of the inefficient product is further restricted, the gains from reduced competition are outweighed by the direct effect of the output restriction, which causes a reduction in profit as in the monopoly case. In this range of K, even though the prices of both models as well as the sales of the high efficiency model increase, the gains from this are more than offset by losses resulting from reduced sales in the other market. Thus, as Proposition 6 states, further reductions in output of the low efficiency model below K^* will cause profits to decline.

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[21] Note that, if firms could effectively collude in both markets rather than just the market for the low efficiency model, the range over which the restriction would be profitable would be reduced.

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

(12)
$$\Phi_i = P_H q_H^{iB} + P_L q_L^{iB} - c_H (q_H^{iB})^2 + \varepsilon(K - q_L^{iB})$$

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

(13)
$$\frac{\partial \pi_i^B}{\partial K} = \frac{d\Phi_i}{dK} = \underbrace{\varepsilon}_{\substack{restriction \\ effect}} + \underbrace{\frac{dP_H}{dK}\bigg|_{\overline{q_{iH}},\overline{q_{iL}}} q_H^{iB} + \frac{dP_L}{dK}\bigg|_{\overline{q_{iH}},\overline{q_{iL}}} q_L^{iB}}_{strategic\ effect}$$

where $\dfrac{dP_s}{dK}\bigg|_{\overline{q_{iH}},\overline{q_{iL}}} = \dfrac{\partial P_s}{\partial Q_H}\dfrac{dq_H^{jB}}{dK} + \dfrac{\partial P_s}{\partial Q_L}\dfrac{dq_L^{jB}}{dK}$ for $s=H, L$.

This decomposition shows that the agreement has two effects on firm profit: a restriction effect and a strategic effect.[22] The restriction effect is always positive, indicating that absent any strategic behavior, the agreement always reduces firm profit as in the monopoly case. The strategic effect represents the gain in profit due to the rise in all prices as the other firm's choices are restricted by the agreement. Given Proposition 5(i) and the downward sloping demand, the strategic effect is always negative.[23] The net effect will depend on the value of K.

The range over which a bilateral agreement is profitable varies with the energy efficiency of the two models as well as the relative cost of production. For example, the more inefficient the low efficiency model is, the greater is the range over which an

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[22] 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).

[23] The strategic effect is always negative since $\dfrac{dP_L}{dK}\bigg|_{\overline{q_{1H}},\overline{q_{1L}}} = -\delta(\dfrac{2c_H}{\beta}) < 0$ and

$\dfrac{dP_L}{dK}\bigg|_{\overline{q_{1H}},\overline{q_{1L}}} = -\delta(\dfrac{3(\lambda - \delta) + 2c_H}{\beta}) < 0$.

agreement would be profitable, i.e. $\frac{\partial K^*}{\partial x_L} < 0$. An increase in the efficiency of the more

efficient model has a similar effect, i.e. $\frac{\partial K^*}{\partial x_H} > 0$. Intuitively, the more dissimilar the

two models are, the greater is the potential to increase profit by reducing output in the

low efficiency market and shifting some of this demand to the high efficiency market.

Likewise, given x_L and x_H, an increase in the price of energy will increase the

importance of the difference in efficiency and hence increase the range over which an

agreement is profitable. This suggests that, *ceteris paribus*, a VA is more likely to

emerge when or in countries where energy prices are high, a result that may explain the

greater prevalence of these types of agreements in Europe than in the U.S.

The non-monotonicity of profit in *K* has an immediate implication given in

Corollary 1.

Corollary 1: *A profitable bilateral agreement always exists.*

This implies that, although not all agreements are profitable, it is always possible to find

output restrictions that would be profitable. In particular, any agreement with a value of

K that is binding but greater than $K *$ will be profitable even though 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.

The above results suggest that, at least over some range, firms have an incentive

to enter into collective agreements that reduce the production of polluting products. This

implies that government inducements may not be necessary to elicit collective

agreements of this type (although, as discussed below, the implicit enforcement provided by the public nature of the commitment is necessary to ensure its success). Since a collective agreement would reduce energy use, the above results suggest the possibility of outcomes where the agreement both increases producer profits and improves environmental quality. Of course, whether this leads to an increase in social welfare will depend on whether these gains exceed the losses to consumers that result from the output restrictions and associated price increases.[24]

Given that at least some collective agreements can be profitable for firms, we turn next to the question of whether firms who enter into collective agreements have an incentive to adhere to those agreements, i.e., whether such agreements are self-enforcing.

IV.4. The Role of Enforcement

We can examine the incentive for each firm to adhere to a collective agreement by reinterpreting the unilateral commitment scenario as a "cheating" scenario, i.e., a scenario under which there is a bilateral agreement and firm 1 chooses to adhere to the commitment while firm 2 chooses not to adhere. With this interpretation, the results in Proposition 3 can be used to show the incentive to cheat. Proposition 3 implies that, as firm 1 commits to lowering its production of the low efficiency model, firm 2's best response is to expand its production. In other words, $q_L^2 = K$ is not an optimal response to $q_L^1 = K$, implying that $q_L^1 = q_L^2 = K$ is not a Nash equilibrium. Thus, if one firm

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[24] It can be shown that restrictions on production of the low efficiency model unambiguously reduce 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.

believes the other will adhere to the agreement, it has an incentive to "cheat" and expand production of the low efficiency product.

The incentive to cheat can also be seen directly from a comparison of profits under unilateral and bilateral commitments. Despite the gain in market share in the high efficiency market that firm 1 realizes when firm 2 cheats, as Proposition 7 states, overall firm 2 can increase its profit by cheating at the expense of firm 1.

Proposition 7: *(i)* $\pi_2^U(K) > \pi_2^B(K)$ *and (ii)* $\pi_1^U(K) < \pi_1^B(K)$ *for all binding K.*

Proposition 7 implies that the incentive to cheat exists even when the collective agreement increases the profits of both firms (relative to their initial levels). This suggests that over the range where such an agreement is profitable, the firms face a Prisoners' Dilemma under which the firms can both increase profits through collectively reducing production of the low efficiency model but neither would have an incentive to adhere to such an agreement. Thus, even when it is profitable, the collective agreement is not self-enforcing. In order for it to be sustained, some means to enforce the commitment is needed. This could explain the emergence of a public voluntary agreement under which firms publicly declare their commitments to reduce production of polluting products. The public nature of the agreement can provide an enforcement mechanism. In this context the cost of monitoring is low and hence cheating on the agreement would presumably be easily detected. As long as there is a sufficiently large cost associated with cheating, for example through damage to the firm's public image, cheating will be deterred.

V. Complete Elimination of the Polluting Product

In the analysis of the effect of the collective agreement on firm level profits, we showed that there exists a range of K over which an agreement to reduce the output of the low efficiency model is profitable for both firms but did not examine in details whether an agreement to eliminate its production completely (as in the European washing machine agreement) would be profitable. The graph in Figure 2 suggests that it would not, i.e., that $\pi_i^B(0) < \pi_i^0 = \pi_i^0(q_L^0)$. However, unlike our other results, this result is not general and depends on the assumption that there are only two models that can be produced (low and high). In this section, we briefly show that when there are three possible models (low, medium, and high), it is possible that even a complete elimination of the low efficiency model from the market can increases profits for both firms, although such a result is not guaranteed (i.e., a decrease in profit is possible as well).

The structure of the model is the same as above except that we assume there are three possible versions of the product: the high, the medium and the low efficiency model. The inverse demand functions become:

$$(14) \qquad\qquad P_H = \lambda(1-Q_H)-\gamma(Q_M)-\delta(Q_L)$$

$$(15) \qquad\qquad P_M = \mu(1-Q_H-Q_M)-\delta(Q_L)$$

$$(16) \qquad\qquad P_L = \delta(1-Q_H-Q_M-Q_L)$$

where the subscript M refers to the medium model, $\mu = 1 - P_E x_M$, and all other variables are as defined previously. Note that the three product model reduces to the two product model considered above if $\delta=0$.

All of the propositions from Sections IV for the two model case carry over to the case when there are three models. However, unlike the case with the two product model, the

agreement to eliminate the low efficiency model from the market completely can now be profitable. Proposition 8 states the conditions under which this is true.

Proposition 8: If $9\mu(\lambda - \mu) > 4c_H c_M$ and δ is sufficiently small, then $\pi_i^B(0) > \pi_i^0$ for $i=1,2$.

To understand the role of the number of models, note that the monopoly profit is always higher under three models than under the two model case. Johnson and Myatt (2003) show that when there are increasing returns to quality provision, the monopolist offers only the highest possible quality. This is consistent with our finding since if $c_H = c_M = c_L = 0$, the monopolist offers only the high efficiency model. A monopolist offers the full range of product qualities when there are decreasing returns to quality provision (Johnson and Myatt, 2003). Although introducing the third model intensifies competition between models which drives prices of the existing models down, it enables the monopolist to cover a larger proportion of the market and raise profit.

However, determining the optimal number of models in a duopoly setting is different due to the competition effect. While the cost structure determines the optimal number of models in a monopoly market, in the duopoly case the relative preferences over the models plays a role as well. If the value of δ is sufficiently low, i.e., the marginal utility of use and therefore price of the low efficiency model is low , then collectively eliminating the low efficiency model from the market is profitable as the losses from sales of that model are offset by the gains from reduced competition between firms (which significantly raises prices). In other words, as the agreement eliminates

competition in the relatively weak markets, firms' profit will be higher.[25] However in equilibrium firms would supply all models since the outcome with the optimal number of models is not Nash equilibrium.

VI. Conclusion

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

In this paper, we have presented a simple model that can be used to examine a voluntary collective agreement to limit or completely eliminate the production of the low efficiency model of a given product (e.g., a low efficiency washing machine). The model incorporates the potential for competition both between firms and between product models (high vs. low efficiency).

Starting from a pre-agreement equilibrium in which each firm supplies an identical product line in response to consumer heterogeneity, we show that, when there is competition between firms, a collective agreement to limit or even eliminate production of the polluting model can actually increase profits for all firms in the industry, an outcome that is not possible without that competition (i.e., in a monopoly model). This

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[25] The fact that this result does not hold under the two product model suggests that the gains from reducing competition and having only one product in the market are outweighed by the reduced market coverage.

suggests that a collective agreement of this type might actually be beneficial to firms, while at the same time improving environmental quality. However, the implicit enforcement that comes from the public nature of the commitment is necessary to ensure this outcome. Absent this enforcement, each firm would have an incentive to cheat on the agreement.

Taken together, our results suggest that in general a collective agreement can be beneficial in terms of both producer profits and environmental quality relative to both the pre-agreement outcome and the outcome if a firm commits unilaterally. This suggests that, by promoting such agreements, policymakers may be able to achieve substantial environmental gains with relatively little inducement. The impact on social welfare will then depend on whether these gains are sufficiently large to offset consumer losses from reductions in product variety and the associated price increases.
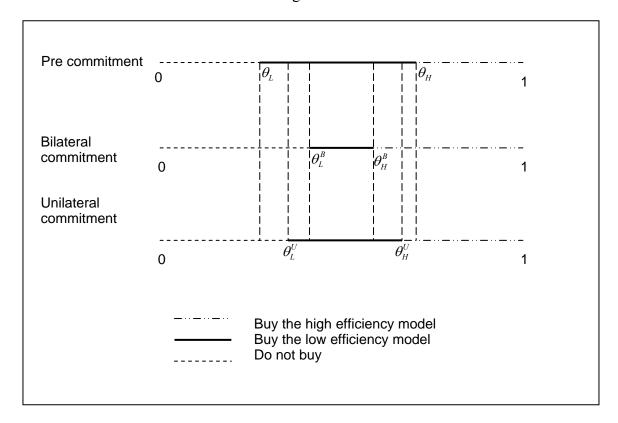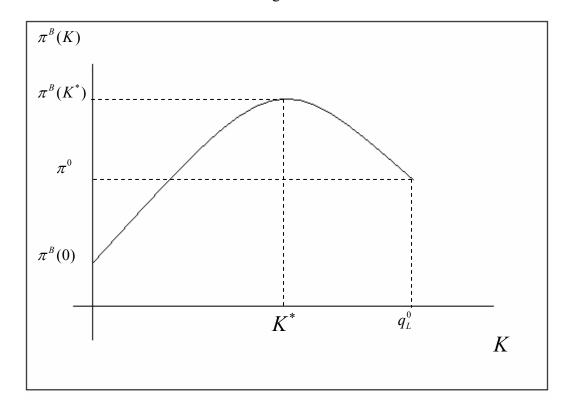
Figure 1

Pre commitment

0   θ_L θ_H 1

Bilateral
commitment

0   θ_L^B θ_H^B 1

Unilateral
commitment

0   θ_L^U θ_H^U 1

Buy the high efficiency model
Buy the low efficiency model
Do not buy

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Figure 2.

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Appendix: Proofs of Propositions (for Reviewers)

Proposition 1: Solving the profit maximization of the monopolist, the equilibrium quantities and prices are:

(A.1)
$$Q_H^M = \frac{\lambda - 2K\delta}{2(\lambda + c_H)},$$

(A.2)
$$Q_L^M = K,$$

(A.3)
$$P_H^M = \lambda[1 - \frac{\lambda - 2K\delta}{2(\lambda + c_H)}] - K\delta \text{ and}$$

(A.4)
$$P_L^M = \delta[1 - K - \frac{\lambda - 2K\delta}{2(\lambda + c_H)}].$$

Taking the partials with respect to K we get $\dfrac{\partial P_H^M}{\partial K} = -\delta(1 - \dfrac{\lambda}{\lambda + c_H}) < 0$,

$\dfrac{\partial P_L^M}{\partial K} = -\delta(1 + \dfrac{\delta}{\lambda + c_H}) < 0$ *and* $\dfrac{\partial Q_H^M}{\partial K} = -\dfrac{\delta}{\lambda + c_H} < 0$.

The profit is given by

(A.5)
$$\pi^M(K) = \frac{\lambda^2 + 4c_H(1 - K)K\delta - 4K^2\delta(\lambda - \delta)}{4(\lambda + c_H)}.$$

Therefore, $\dfrac{\partial \pi^M}{\partial K} = \dfrac{\delta(c_H - 2c_H K - 2K(\lambda - \delta))}{\lambda + c_H}$, which is positive over the binding range of K.

Proposition 2: The equilibrium quantities under the pre-agreement scenario are:

(A.6)
$$q_L^{10} = q_L^{20} = \frac{2c_H}{6c_H + 9(\lambda - \delta)}$$

and

$$(A.7) \qquad q_H^{10} = q_H^{20} = \frac{3(\lambda - \delta)}{6c_H + 9(\lambda - \delta)}.$$

The corresponding equilibrium prices are given by:

$$(A.8) \qquad P_L^0 = \frac{\delta}{3}$$

and

$$(A.9) \qquad P_H^0 = \frac{\lambda(\lambda - \delta) + c_H(2\lambda - \delta)}{2(c_H + \lambda - \delta)}.$$

Comparing (A.8) and (A.9) shows that (i) holds, (ii) is true because of symmetry and (iii) holds if we substitute $c_H = 0$ in (A.6).

Proposition 3: The resulting Nash equilibrium quantities under the unilateral commitment are given by:

$$(A.10) \qquad q_H^{1U} = 1 - \frac{(\lambda - \delta + c_H)(2\gamma + 3\delta K)}{\gamma\beta - \delta\rho}$$

$$(A.11) \qquad q_H^{2U} = \frac{(\lambda - \delta)(2\gamma + 3\delta K)}{2(\gamma\beta - \delta\rho)}$$

$$(A.12) \qquad q_L^{2U} = \frac{2c_H\gamma - K[4c_H^2 + (\lambda - \delta)(3\lambda + 8c_H)]}{2(\gamma\beta - \delta\rho)}$$

where $\beta \equiv 3\lambda + 2c_H$, $\gamma \equiv \lambda + 2c_H$ and $\rho \equiv 3\lambda + 5c_H$. And since $\lambda > \delta$, then $\gamma\beta - \delta\rho > 0$.

The corresponding equilibrium prices are:

$$(A.13) \qquad P_H^U = \frac{\gamma[\lambda(\gamma - \delta) - \delta c_H)] - c_H\delta K(\gamma - \delta)}{\gamma\beta - \delta\rho}$$

and

$$(A.14) \qquad P_L^U = \delta\frac{2\gamma(\lambda - \delta + c_H) - K[4c_H(2(\lambda - \delta) + c_H) + 3(\lambda - \delta)^2]}{2(\gamma\beta - \delta\rho)}.$$

From equation (A.10) we get $\dfrac{\partial q_H^{1U}}{\partial K} = -\dfrac{3\delta(\lambda - \delta + c_H)}{\gamma\beta - \delta\rho} < 0$. From equation (A.11) we get

$\dfrac{\partial q_H^{2U}}{\partial K} = \dfrac{3\delta(\lambda - \delta)}{2(\gamma\beta - \delta\rho)} > 0$. From equation (A.13) we get $\dfrac{\partial q_L^{2U}}{\partial K} = -\dfrac{4c_H^2 + (\lambda - \delta)(3\lambda + 8c_H)}{2(\gamma\beta - \delta\rho)} < 0$.

Adding q_H^{1U} and q_H^{2U} and differentiating with respect to K we get

$\dfrac{\partial Q_H^U}{\partial K} = \dfrac{-3\delta}{2(\gamma\beta - \delta\rho)}(\lambda - \delta + 2c_H)$, which is negative. The total output of the low

efficiency model is $Q_L^U = K + q_{2L}^U(K)$. Differentiating with respect to K we get

$\dfrac{\partial Q_L^U}{\partial K} = \dfrac{\beta(2c_H + \lambda - \delta)}{2(\gamma\beta - \delta\rho)} > 0$. From equation (A.13) we get $\dfrac{\partial P_H^U}{\partial K} = -\dfrac{c_H\delta(\lambda - \delta + 2c_H)}{\gamma\beta - \delta\rho} < 0$.

From equation (A.14) we get $\dfrac{\partial P_L^U}{\partial K} = -\delta K \dfrac{4c_H(2(\lambda - \delta) + c_H) + 3(\lambda - \delta)^2}{2(\gamma\beta - \delta\rho)} < 0$.

Proposition 4: Under the pre-commitment scenario (q_L^{10}, q_L^{20}) is a Nash equilibrium.

q_L^{1U} is not the optimal response to q_L^{20} and thus $\pi_1^U(K) < \pi_1^0$. We can also show that

$\pi_2^U(K)$ is decreasing in K and thus $\pi_2^0 < \pi_2^U(K)$. Also, since both prices rise with the

unilateral commitment, as is clear from (A.13) and (A.14) where prices are inversely

related to K, then the previous result holds as well.

Proposition 5: The resulting Nash equilibrium quantities under the commitment where

$q_L^j \leq K$ are given by:

(A.15)
$$q_H^{1B} = q_H^{2B} = \dfrac{\lambda - 3K\delta}{\beta}$$

and

(A.16)
$$q_L^{1B} = q_L^{2B} = K$$

The corresponding equilibrium prices are:

$$(A.17) \qquad P_H^B = \frac{\lambda}{\beta}(\lambda + 2c_H) - \delta K(2 - \frac{6\lambda}{\beta}) ,$$

and

$$(A.18) \qquad P_L^B = \frac{\delta}{\beta}(\lambda + 2c_H - 2K(\beta - 3\delta)) .$$

From (A.15) we can show that $\dfrac{\partial q_H^{iB}}{\partial K} = \dfrac{-3\delta}{\beta} < 0$ and $\dfrac{\partial Q_H^B}{\partial K} = 2\dfrac{\partial q_H^{iB}}{\partial K} < 0$. From equation (A.17)

we get $\dfrac{\partial P_H^B}{\partial K} = -\delta(2 - \dfrac{6\lambda}{\beta}) < 0$ and from equation (A.18) we get $\dfrac{\partial P_L^B}{\partial K} = \dfrac{-2\delta}{\beta}(3(\lambda - \delta) + 2c_H) < 0$.

Proposition 6: The change in profit of firm i for a change in K is given by:

$$(A.19) \qquad \frac{\partial \pi_i^B}{\partial K} = \frac{2\delta(c_H^2(2 - 8K) - 18K(\lambda - \delta)\lambda + c_H(3K(5\delta - 8\lambda) + 2\lambda)}{\beta^2} ,$$

which will depend on the value of the parameters and the level of commitment K.[26] The

profit of firm i, $\pi_i^B(K)$ reaches a maximum at $K*$ where

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[26]The impact on profit also depends on the underlying distribution of consumers according to θ. In the model we assumed a uniform distribution for simplicity and to ensure a closed form solution. We can derive the results for a general distribution of consumers $F(\theta)$ as follows:

$$Q_H = 1 - F(\theta_H)$$
$$Q_L = F(\theta_H) - F(\theta_L)$$
$$P_L = \delta H(1 - Q_H - Q_L)$$
$$P_H = (\lambda - \delta)H(1 - Q_H) + \delta H(1 - Q_H - Q_L)$$

where $H \equiv F^{-1}$. The effect that a change in K has on firm profit is given by:

$$\frac{\partial \pi_1^B}{\partial K} = -\frac{\partial q_H^2}{\partial K}[(\lambda - \delta)H'(1 - q_H^1 - q_H^2).q_H^1 + \delta H'(1 - q_H^1 - q_H^2 - q_L^1 - q_L^2).(q_H^1 + q_L^1)]$$
$$- [\delta H'(1 - q_H^1 - q_H^2 - q_L^1 - q_L^2).(q_H^1 + q_L^1)] + \eta$$

The above expression will determine the effect of tightening (relaxing) the constraint on firm profit, for a given distribution of consumers. While the agreement reduces firm profit for the monopolist, the impact of the agreement on firm profit for the duopoly is ambiguous. The result will depend, among other factors, on the distribution of consumers $F(\theta)$.

$$(A.20) \qquad K^* = \frac{2c_H(\lambda + c_H)}{8c_H^2 + 3c_H(8\lambda - 5\delta) + 18\lambda(\lambda - \delta)}$$

and $0 < K^* < q_L^{i0}$. Therefore $\pi_i^B(K^*) > \pi_i^0$.

Proposition 7: Under the unilateral commitment scenario $q_L^{1U} = K$ and $q_L^{2U} \neq K$, and therefore (i) holds. The total market output of both models is higher under the unilateral commitment while the prices are lower. Since, for a given level of K, prices are lower under the pre commitment scenario, then (ii) follows.

Proposition 8: We define the difference in profit, $Diff(\delta) = \pi_i^B(0) - \pi_i^0$, to be the extra profit realized by an individual firm as a result of the agreement to eliminate the low efficiency model as a function of δ. Then $Diff(\delta) = 0$ when $\delta = 0$ or $\delta = \delta'$ where

$$\delta' = \frac{[4c_H c_M - 9\mu(\lambda - \mu)][6(c_M\lambda + c_H\mu) + 4c_H c_M + 9\mu(\lambda - \mu)]}{[4c_H c_M - 9\mu(\lambda - \mu)](c_M + c_H) - 9(\lambda - \mu)[3\mu(\lambda - \mu) + c_M\lambda + c_H\mu]} . \text{ If}$$

$9\mu(\lambda - \mu) > 4c_H c_M$, then $\delta' > 0$ and $Diff(\delta) > 0$ for $\delta \in [0, \delta']$.