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Working Paper

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Nota di Lavoro, No. 15. 2000

Provided in Cooperation with:

Fondazione Eni Enrico Mattei (FEEM)

Suggested Citation: Farzin, Y. H. (2000) : The effects of emissions standards on industry in the short run and long run, Nota di Lavoro, No. 15. 2000, Fondazione Eni Enrico Mattei (FEEM), Milano

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The Effects of Emissions Standards on Industry in the Short Run and Long Run

by

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Abstract

Industrialists often claim that, by rendering firms unprofitable and hence forcing them out of business, stricter emissions standards reduce the industry output and competition. This paper considers situations where firms' pollution reduction increases the industry demand, but, because of inability to coordinate their emissions reductions, and thus free riding problem, they are unable to act in their own *collective* interest. For such situations, the paper studies the effects of emissions standards on the equilibrium in an oligopoly market both at the firm and industry level and in the long run as well as short run. It shows conditions under which a stricter standard leads to a *larger* number of firms in the industry, a *greater* industry output, and a *lower* total pollution in the long run; and to *higher* levels of firms' profits *and* output in the short run. It also shows that for the industry to survive, a *minimum* pollution standard may be necessary.

JEL Classification: H23, D62, D43, Q28

Key Words: environmental standard, abatement cost, demand effect, industry output

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For helpful comments I thank participants at the 1998 annual Conference of the Royal Economic Society, Warwick, U.K., March 31-April 3, the First World Congress of Environmental and Resource Economists, Venice, Italy, June 25-27, 1998, and seminars at the Center for Economic Research (CentER), Tilburg University, University of California at Berkeley, University of California at Davis, University of Maryland, Stanford University, and the World Bank.

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I. Introduction

Environmental quality has now become a prime public concern worldwide. Not surprisingly, the improvement of environmental standards is high on public representatives' agenda. However, the public desire for higher environmental standards has often met with resistance by domestic industrial groups and their lobby. Underlying this resistance has been the industrialists' argument that by raising abatement costs, higher standards raise the polluting firms' overall production costs, thus rendering them uncompetitive and forcing them out of business, with consequent reductions in the industry output, employment, and competition. Ironically, when it comes to negotiations for higher international or global emissions standards, governments also resort to similar arguments.

The central point of the present paper is to show that there are situations in which the very adverse effects that the industrialists attribute to higher emissions standards may *not* hold. Specifically, such situation arise when firms are unable to coordinate their actions to reduce emissions, so that even though doing so would be in their *collective* interest, *individually* they have incentive to free ride. I show that in such situations a higher mandatory standard can enhance the industry's profitability, and hence output, and at the same time reduce total pollution.

To this end, I analyze a simple Cournot quantity-setting model of an industry in which the production of a good by identical firms inflicts a negative environmental externality. A higher emissions standard implies that for any given output level firms should abate a greater portion of their emissions. This, as industrialists correctly argue, increases the abatement cost of the representative firm and therefore its overall production cost. This effect, which I call the "cost" effect of a higher emissions standard, is too familiar and basic to almost all economic analyses of environmental standards. What is, however, novel is what I call the "demand" effect of a higher emissions standard.

This effect accounts for the fact that environmental quality can be directly or indirectly a complement to the consumption of the polluting good, so that enhancing the environmental quality increases the demand for the good. Tourism industry presents a good example. Higher quality standards for urban air, water, and land (e.g., beaches), if adopted by firms, can attract a larger population to touristic and recreational sites and thus boost the demand for tourism industry. Another example is when agricultural chemical run-offs from upland farms into a river stream which serves as source of fishing, drinking water, and irrigation inflict costs on downland fishing and farming communities. Directly by reducing fish and crops harvesting rates and indirectly by reducing labor and land productivity, the use of polluted water causes loss of income by downland communities, which in turn reduces the demand for outputs of upland farms. A third example is the remarkable growth in recent years of the demand for

agricultural products (foods and fibers) that are grown and processed according to a defined set of standards that certify them as organic. This growth draws partly from the higher standards of food safety and hence lower risks of health hazards that consumers attribute to organic products. The point is that when producers fail to coordinate their activities to set standards for organic products and to monitor and enforce them, they may have an incentive to take advantage of consumers' inability to verify if a product is truly organic thereby falsely presenting their products as organic and charging higher prices. In this situation, public setting of standards for organic products and their certification and labeling provides an insurance to consumers. In turn, this increases the industry demand for such products.

The particular characteristics of these examples are the presence of externalities and failure of firms to coordinate their emission abatement efforts, and thus the associated free riding problem. Firms' reduction of pollution has a *positive* feedback effect on the industry demand, but since every firm in the industry benefits from this, in the absence of coordination among firms, none has incentive to reduce pollution as much as it should. The firms' failure to coordinate their pollution reductions for collective benefit and the free riding problem call for a mandatory pollution standard.^{1, 2} By requiring greater reductions in pollution, the regulation can actually benefit the industry.³

Under free entry assumption, the cost effect of a higher emissions standard tends to reduce the number of firms in the industry whereas its demand effect does the opposite. So, the effect of a higher standard on the number of firms and the industry output depends on which of the two effects dominates. The demand effect, however, has been completely ignored in the empirical studies of the effect of environmental regulations (e.g., Pashigian (1984), Hazilla and Kopp (1990)) and by large has also gone unnoticed in the theoretical literature on environmental

¹ See Klibanoff and Morduch (1995) for a formal explanation of why in a large range of cases involving externalities and private information, private coordination fails to occur, or to improve efficiency despite common knowledge of gains from agreement.

² The issue somewhat resembles that of expenditures on advertising, particularly for 'search' goods. If by enhancing consumers' information, advertising benefits all firms in the industry, then, in the absence of regulation, a firm may not have incentive to provide enough information because it is unable to fully appropriate the benefits of its own advertising (see, e.g., Nelson (1970), Schmalensee (1972), and Comanor and Wilson (1974)).

³ That when firms are unable to coordinate their private actions to their own collective benefit, mandatory regulation of industry, in one form or the other, can make all firms better off is well known (see, e.g., the classical works of Olson (1965) and Schelling (1978)). Regulation of the "commons" is a prime example in the literature. However, whereas the literature has been typically concerned with cases of negative externality on *production* side (so that regulation causes the production function to shift out, or, equivalently, lowers the present and/or future marginal costs), the cases studied in this paper are marked by positive externality on the *demand* side, so that regulation makes the industry demand to shift out.

economics. For example, in an insightful paper, Besanko (1987) compares a "performance" standard (one that restricts a firm's total pollution) with a "design" standard (one that mandates a specific pollution control technology) with respect to their effects on individual firms' output and profit. However, his models differs in structure and assumptions from the present model, particularly by abstracting from the demand effect of a stricter emissions standard and hence from firms' entry decisions. Similarly, the theoretical works in Carraro *et al* (1995) and the papers by Katsoulacos and Xepapadeas (1995) and by Conrad and Wang (1993) explore the effect of environmental policy on market structure, but none allows for the effect of environmental quality on industry demand. Furthermore, while, in one form or the other, standard setting is the predominant mode of environmental regulation, this literature is primarily concerned with the effects of emissions *taxes*. Moreover, it examines the effects of emissions taxes when the polluting industry is imperfectly competitive or when other distortionary taxes pre-exist in the economy (see, e.g., Goulder (1995), and Bovenberg and Goulder (1996) for the latter case). As such, most of the results in the literature are essentially of the "second-best" nature (see particularly the original works of Seade (1985) on the effects of taxation of oligopolistic industries and Dixit (1986) on comparative statics for oligopoly).

Of the existing literature, the paper by Carraro and Soubeyran (1996) is the only one that comes close in spirit to the present work. However, although it allows the industry demand to depend on environmental quality, it differs sharply from the present work in several important respects. (i) It analyzes the effects of environmental taxation and not of standards. (ii) By assuming that the number of firms is *fixed*, it abstracts from the effect of environmental regulation on the industry size. (iii) It assumes that *no* abatement technology is available to firms, so that the only way the firms react to the environmental regulation is by changing their output levels. (iv) It considers the case of asymmetric firms which differ in the marginal and fixed costs, whereas in the present paper firms are assumed to be identical. Carraro and Soubeyran show the conditions under which the introduction of an emissions tax, or a raising of the tax rate to the *optimal* level, may benefit *some* firms while hurting others. Further, as a consequence of (ii) and (iii), in their model a tax increase *always* leads to a reduction in firms' and hence industry output levels, implying in turn an inevitable trade-off between industry output and environmental quality. As we shall see later in this paper, relaxing either of these assumptions can alter these results. Specifically, in this model, a tightening of emissions standard need not cause the typical firm's output level to fall, and, in any event, due to entry of new firms to the industry, the industry output may in fact increase. Moreover, the increase in industry output can be accompanied by a *reduction* in total net emissions.

In a different context, Porter (1991) and Porter and van der Linde (1995a)(1995b) have argued that the conception of an inevitable tradeoff between industrial competitiveness and environmental regulations derives from

of a *static* view of environmental regulations whereas by promoting innovations more stringent environmental standards can yield *dynamic* benefits which more than offset the initial higher cost of compliance and therefore enhance industrial competitiveness and profitability. Porter also suggest that regulation can create demands for environmental products and so gives countries a head start in those products. They, however, do not provide an explicit theoretical basis for their claim, which has come to be known as "Porter's hypothesis." And, unfortunately, partly because of this, their claim has been dismissed by some economists (e.g., Palmer *et al* (1995), and Simpson and Bradford (1996)). It should be noted, however, that, despite similarity of the main conclusion, the present model is very different from Porter's hypothesis in that (i) it is a static model whereas Porter's hypothesis rests on dynamic cost effects, and (ii) the "demand" effect in this model is very different from that suggested in Porter's hypothesis.

The rest of the paper is organized as follows. Section II develops the basic model. Adopting a positive analysis approach, it derives conditions under which, with free entry, a stricter emissions standard leads to a *larger* number of firms, a *greater* industry supply, and a *lower* total net pollution. These industry effects, which are often of most concern to policy makers, are different from the standard results of models that do not incorporate the demand effect of a stricter regulation. Section III.a presents a specific parametrization of the general model which allows an explicit solution for the industry equilibrium. There it is shown that for the industry to survive, a *minimum* pollution standard may be necessary, and that this minimum standard will be higher, the *less* efficient the industry is in producing the good or in abating pollution, or the *smaller* the market demand is in the absence of any standards. For a fixed number of firms in the short run, Section III.b examines the effects of a stricter standard on profitability, output, and pollution emissions both at the individual firm and industry levels, and contrasts these effects with those obtained under free entry condition. Here too, it is shown that the individual firm's effects can be different from the standard ones and that the industry's short-run and long-run effects of a stricter standard may conflict, thus suggesting a possible explanation as to why some industries may contest stricter standards that can be in their own interest.⁴ Section IV concludes.

⁴ Another explanation could be the firms' inability to accurately assess the industry's benefits from a higher standard; for example, by underestimating the positive demand effect and/or overestimating the cost effect. Also, when firms in the industry are heterogenous, it is possible that a more stringent regulation increases profits of some firms while reducing those of others, thus the latter's opposition to the regulation (e.g., see Carraro and Soubeyran (1996)).

II. Basic Model

Consider a Cournot industry with n identical firms that produce a homogeneous good and generate pollution as a by-product. For simplicity it is assumed that pollution emissions is a constant proportion of each firm's output, x , so that, by appropriate choice of units, emission and output levels are equal in the absence of abatement. The industry output is $X=nx$. Each firm's production cost is given by $C=C(x)$, with $C'>0$ and $C''\geq 0$. The regulator sets the environmental standard uniformly, requiring that all firms, both the existing ones and potential new entrants, abate a fraction, $0\leq\alpha\leq 1$, of their emissions. Accordingly, the emissions standard does not pose a barrier to entry. The industry demand is taken to depend both on the price of the good, P , and the environmental quality standard, α . It is given generally by the inverse demand function $P=P(X, \alpha) = X^{-1}(X, \alpha)$, where $P_X=\partial P(X, \alpha)/\partial X<0$ and $P_\alpha=\partial P(X, \alpha)/\partial \alpha>0$. The first inequality simply indicates that, for any given emissions standard, the industry demand is downward sloping. The second inequality states that a higher environmental standard induces the industry demand to shift out and to the right. Stated differently, for any quantity demanded, consumers are willing to pay a higher price for the good if its production, distribution, or consumption is associated with improved environmental quality. I assume a large constant population ($M>0$) of identical consumers, which, for simplicity and without loss of generality, is normalized at unity ($M=1$) so that the market demand, X , is identified with the representative consumer's consumption. In Appendix 1, I show that the demand effect, $P_\alpha>0$, derives generally and in a theoretically consistent way from individual utility maximization where the representative consumer derives utility $U=U(X, Z, Y)$ from the consumption of the polluting good X and of a composite of all other goods, Y , but incurs disutility from the net pollution (after abatement), $Z=(1-\alpha)X$. The industry demand is divided equally among the firms, so that each firm's market share is $1/n$.

To be compliant, each firm incurs pollution abatement costs, A , which are assumed to rise with the amount of pollution abated, αx , and at increasing rates; that is, $A=A(\alpha x)$, with $A'>0$, $A''>0$, and $A(0)=0$. Thus, for a given level of output, and hence pollution, a firm's abatement cost rises with the standard, α , as more expensive capital equipment embodying a more efficient abatement technology and/or greater amounts of other relevant inputs will be required.⁵ Notice that, to keep the model tractable, the pollution abatement and the production of the good are taken to be separate activities within each firm, so that a higher environmental standard raises the abatement cost but leaves production cost unchanged. This will be the case, for example, when the inputs used in pollution

⁵ Here abatement technology is interpreted as installation of end-of-the-pipe equipment to reduce pollution after it is generated, thus leaving the emission-output ratio at the source unchanged. It may, however, also be interpreted as changes in production processes resulting in a lower emission-output ratio at the source by enhancing the efficiency of (polluting) input.

abatement are specific to that activity, so that the changes in demand for them resulting from a change in emissions standard do not affect the demand for inputs used in production of the good.

It is important to emphasize that the central objective of this model is to study the industry effects of a stricter emissions standard when the free riding problem and lack of coordination by firms necessitates a *mandatory* industry standard. Accordingly, the assumptions that a homogeneous good is produced by identical firms and consumed by the representative consumer are deliberately made to abstract from situations where, for strategic reasons, firms may voluntarily choose pollution abatement standards (for the case of voluntary abatement and different motives behind it, see Arora and Gangopadhyay (1995) and Maxwell *et al* (1996), among others). Here, in the absence of public regulation, no firm has any incentive to voluntarily adopt an emission standard because each, and every, firm believes that by free riding on abatement efforts of other firms it can enjoy the benefits of the increased industry demand without itself having to incur any abatement cost. So, the minimum voluntary standard is zero, and thus any standard set by the regulator will be binding.

Let us now analyze the effect of a change in emissions standard on the industry equilibrium under the free entry condition. Taking as given the standard set by the regulator and the output levels of other firms, each firm plans its own output so as to maximize its profits, which under the assumption of free entry will be zero in the long-run equilibrium. That is, each firm chooses x to

$$\text{Max}_x \pi(x, n, \alpha) = xP(X, \alpha) - A(\alpha x) - C(x)$$

The first-order conditions for an interior optimum are

$$XP_x + P(X, \alpha) - \alpha A'(\alpha x) - C'(x) = 0 \quad (1)$$

and,

$$P(X, \alpha) - [A(\alpha x) + C(x)]/x = 0 \quad (2)$$

where the zero-profit condition (2) determines the equilibrium number of firms in the industry. Thus, both x and n depend generally on the emissions standard, α . Of particular interest is the question of how the equilibrium number of firms, the representative firm's output level, and therefore the industry's supply would respond to a change in the standard. To work out these comparative statics, note that from $X=nx$ one has

$$\frac{dX}{d\alpha} = n \frac{dx}{d\alpha} + x \frac{dn}{d\alpha} \quad (3)$$

Differentiating (1) and (2) with respect to α , using (3) and (1), and solving the resulting two equations yields, after some calculation

$$\frac{dn}{d\alpha} = \frac{(P_\alpha - A')n\epsilon}{P} \quad (4)$$

and,

$$\frac{dx}{d\alpha} = \frac{A'(\xi + 1/\epsilon) + P/\epsilon^2[(P_\alpha - A')\epsilon_p - \epsilon_\alpha]}{nP_X(1 - 1/\epsilon + P\epsilon_p/\epsilon^2) - (\alpha^2 A'' + C'')} \quad (5)$$

where $\epsilon(X, \alpha) \equiv -P(X, \alpha)/X \cdot dX/dP > 0$ is the absolute value of the price elasticity of market demand, $\xi(\alpha) \equiv \alpha X A''/A' > 0$ is the elasticity of the marginal abatement cost, $\epsilon_p \equiv \partial\epsilon(X, \alpha)/\partial P = \partial\epsilon(X, \alpha)/\partial X$, $\partial X/\partial P \equiv \epsilon_X/P_X$ and $\epsilon_\alpha \equiv \partial\epsilon(X, \alpha)/\partial \alpha$ are the partial derivatives of the demand elasticity with respect to P and α , and where $dX/dP = 1/[dP/dX] < 0$.

Equation (4) reveals that the effect of a change in the emissions standard on the number of firms is generally *ambiguous*, so that, contrary to what common intuition might suggest, raising the standard need *not* necessarily cause a reduction in the number of firms. This is because a rise in the standard has two opposing effects. First, for a given level of the firm's output, it entails a greater amount of emission abatement and therefore raises the unit abatement cost by the extent of $\frac{\partial}{\partial \alpha}[A(\alpha)/x] = A'$. This effect, which is the cornerstone of the industrialists' opposition to stricter standards, tends to reduce the number of firms. Second, for a given quantity of the good produced and demanded, a higher standard means less pollution, thus inducing consumers to pay a higher price for the good. This demand side effect, which is captured by P_α and has been ignored, encourages new entry. Thus, $(P_\alpha - A')$ measures the effect on the firm's unit profit of a change in the emissions standard.

It is then clear that in the presence of the demand effect, a stricter standard has in general an ambiguous effect on firm profitability and hence on entry. In turn, this ambiguity opens up a number of interesting questions. For example, one would like to know under what conditions the demand effect is strong enough to give rise to situations where the effects of a more stringent standard are in contrast to those claimed by industrial lobbyists, thereby providing some light on the political economy of environmental regulation. Further, in the literature, the effect of a more stringent regulation (especially a higher pollution tax) is either conventionally to lower both firms'

output and profitability (as, for example, when each firm faces a perfectly elastic demand), or, when the demand facing each firm is downward sloping, to increase firms' profitability by inducing them to *reduce* their output levels and therefore raise the price to a level which more than outweighs the increase in the unit production cost (see, Buchanan and Tullock (1975), Maloney and McCormick (1982), Seade (1985), Dixit (1986), Conrad and Wang (1993), and Carraro and Soubeyran (1996), among others ⁶). In contrast to conventional models, through the demand effect, a stricter standard could render firms *more* profitable and at the same time *increase* their output level.

From equation (4) it follows that:

Proposition 1. In a Cournot industry with identical firms and free entry, a higher emissions standard leads to a larger or a smaller number of firms depending on whether it raises or lowers the representative firm's unit profit,

i.e., $\frac{dn}{d\alpha} \begin{matrix} > \\ =0 \\ < \end{matrix}$ as $(P_{\alpha} - A') \begin{matrix} > \\ =0 \\ < \end{matrix}$. The rate of entry will be greater the larger the price elasticity of the industry demand.

The implication of this proposition for environmental regulation is clear. It emphasizes the importance of paying due attention to consumers' preferences and their willingness to pay higher prices for goods produced with stricter environmental quality standards, and cautions against limiting attention only to increased costs of compliance with higher standards.

To determine the sign of $dx/d\alpha$, it is noted from (5) that $A'' > 0$, $C'' \geq 0$, and $\epsilon > 1$ for all $X > 0$ and positive marginal revenues, so that the sign of $dx/d\alpha$ depends crucially on the signs of $(P_{\alpha} - A')$, ϵ_p , and ϵ_{α} . Possible signs of $dx/d\alpha$ are presented in Table 1.a and Table 1.b, and the result is summarized in the following proposition:

⁶ Carraro and Soubeyran's paper differs from the others by allowing for the effect of environmental quality on the industry demand. Analyzing an asymmetric oligopoly, however, they show that while a higher emission tax may raise profits of some of the firms it lowers those of the others and that it reduces firms' outputs, and hence, industry's total supply.

Table 1.a : Signs of $\partial x/\partial \alpha$ when $P_{\alpha}-A' \geq 0$

		ϵ_{α}		
		0	-	+
ϵ_p	0	<0	<0	?
	-	?	?	?
	+	<0	<0	?

Table 1.b : Signs of $\partial x/\partial \alpha$ when $P_{\alpha}-A' < 0$

		ϵ_{α}		
		0	-	+
ϵ_p	0	<0	<0	?
	-	?	?	?
	+	?	?	?

Proposition 2: When $P_{\alpha}-A' \geq 0$ (i.e., the number of firms does not decrease with a higher standard), raising the emissions standard will unambiguously lead to a lower firm's output level only if the price elasticity of the market demand neither decreases with the price nor increases with the emissions standard (i.e., if $\epsilon_p \geq 0$ and $\epsilon_{\alpha} \leq 0$), otherwise the effect will be ambiguous. When $P_{\alpha}-A' < 0$, only if the price elasticity of demand remains constant as price changes ($\epsilon_p=0$) and does not increase with the emissions standard ($\epsilon_{\alpha} \leq 0$), will a higher standard lead unambiguously to a lower firm's output level.

Thus, a stricter standard will unambiguously lower firms' output only under a particular configuration of demand characteristics and in particular that they may increase firms' output as long as the demand elasticity is

either a decreasing function of the price ($\epsilon_p < 0$) or an increasing function of the emissions standard ($\epsilon_\alpha > 0$).⁷ These conditions are not implausible. The former may occur when, by virtue of some particular technological or geographical characteristics, the existing substitutes for the good in question have traditionally had the market to themselves, but a lowering of the good's price expands its market share and brings it increasingly into competition with its substitutes. Few examples make this clear. A prime example is the demand for organically grown agricultural products. At lower prices, the demand for these products become more elastic as they make an inroad into the markets traditionally taken up by conventionally grown products. Another example is the demand for private touristic and recreational services where prices are deliberately set so high as to make these services available exclusively to a segment of the market (for example only to members) whose demands are relatively less price elastic. Lowering the prices of such services will bring them in closer competition with rival services (some of them may also be publicly provided), therefore making their demands more price elastic. As another example, consider the demand for coal which becomes more elastic at lower prices as coal becomes a more competitive energy source and takes a larger share of energy market at the expense of substitutes such as natural gas and crude petroleum. The same is also true with the demand for domestic goods that are kept out of foreign markets by imposition of import tariffs. At sufficiently low prices, such goods will be brought increasingly into competition with foreign goods, thus rendering their demands more price elastic.

Whether the price elasticity of the industry demand increases or decreases as the emissions standard becomes more stringent is an open empirical question. On purely theoretical grounds, both possibilities seem equally likely, depending on the manner in which a stricter standard causes the demand for the industry in question to shift. Thus, for example, in the case of food products grown conventionally, subjecting the use of chemical inputs to stricter standards is likely both to increase the demand and, by rendering the products closer substitutes for the organically produced food, the price elasticity also increases at any consumption level, $\epsilon_\alpha > 0$; graphically, the demand curve shifts upward and becomes flatter. Similarly, raising the standards for use of coal in electricity generation (e.g., tougher standards on coal cleaning to reduce its contents of sulphur and other toxic chemicals) would both increase the level of coal demand and its price elasticity.

Perhaps of the most concern to the regulator are the effects of more stringent standards, not on the individual firm's output or pollution level, but on the *industry's* supply and total pollution. Interestingly, as propositions 1 and 2 together imply, for the industry's supply to be unambiguously adversely affected, stricter

⁷ It can be verified from (5) that when a stricter standard causes firms to exit the industry in the long run, i.e., when $P_\alpha - A' < 0$, and $\epsilon_p \geq 0$, then the smaller $\xi > 0$ or the larger $\epsilon_\alpha \geq 0$, the more likely it is that $dx/d\alpha > 0$.

conditions than those just noted in relation to the effect on an individual firm's output need to be satisfied. More specifically, from (3), (4) and (5) one has:

***Corollary 1:** A higher emissions standard will unambiguously lower the industry supply ($dX/d\alpha < 0$) if (a) it does not increase the number of firms (i.e., $P_{\alpha}A' \leq 0$), (b) the elasticity of demand is constant with respect to a price change (i.e., $\epsilon_p = 0$), and (c) the elasticity does not increase with the standard (i.e., $\epsilon_{\alpha} \leq 0$). Otherwise, the effect will be ambiguous.*

Assuming that the conditions needed for a stricter standard to bring about a larger industry output are met, the question arises as to whether this would lead to a degraded or improved overall environmental quality. The following proposition provides the answer.

***Proposition 3:** Beyond a certain level, a higher emissions standard always reduces the total net pollution (improves the environmental quality) even when it increases the industry's total output.*

Proof: Differentiating $Z = (1 - \alpha)X$ w.r.t. to α one has

$$dZ/d\alpha < 0 \quad \text{iff} \quad \eta(X, \alpha) \equiv \alpha/X dX/d\alpha < \alpha/(1 - \alpha) \quad (6)$$

where $\eta(X, \alpha)$ is the elasticity of industry output with respect to the standard. Focusing on the case where a stricter standard raises the industry output, $dX/d\alpha > 0$, it is noted that $dZ/d\alpha < 0$ as $\alpha \rightarrow 1$, because as $\alpha \rightarrow 1$ the RHS of the inequality rises to infinity, whereas η remains bounded (since the marginal cost of eliminating all pollution can be extremely high, implying in turn that $X \rightarrow \bar{X} > 0$ as $\alpha \rightarrow 1$). Thus, there exists some $\alpha = \hat{\alpha} > 0$ such that $dZ/d\alpha < 0$ for all $1 \geq \alpha > \hat{\alpha}$. \parallel

At the level of generality we have been analyzing the issue, this is almost as far as one can go. To proceed, we need to obtain closed form solutions for the industry equilibrium. This is done in the following subsection.

III. A Specific Example

III.a Industry Effects of a Stricter Standard With Free Entry

In this subsection, I consider a simple parameterization of the model by assuming that the industry faces a linear demand function given by $X(P, \alpha) = a(1 + \alpha) - bP$, where $\alpha \in [0, 1]$ and $0 \leq P \leq (1 + \alpha)a/b$. Accordingly, for any quantity demanded/output, X , a reduction in the amount of pollution, $(1 - \alpha)X$ (or equivalently, an increase in the environmental standard, α) leads to parallel and outward shifts of the industry demand curve.

For all $X > 0$, this demand function has the following properties;

$$\epsilon(X, \alpha) = a(1 + \alpha)/X - 1 > 0 \quad (7a)$$

$$\epsilon_\alpha(X, \alpha) = -a \overline{\epsilon(X, \alpha)} / X < 0 \quad (7b)$$

$$\epsilon_p(X, \alpha) = ab(1 + \alpha)/X^2 > 0 \quad (7c)$$

$$P = [a(1 + \alpha) - X]/b \quad (7d)$$

$$P_X = -1/b \quad (7e)$$

$$P_\alpha = a/b \quad (7f)$$

Notice that in order to sharpen the results derived in the preceding section, the demand function is deliberately conservatively chosen to be linear with the properties that $\epsilon_p > 0$ and $\epsilon_\alpha < 0$, so that, by Proposition 2 (see Table 1.a), a higher standard will *unambiguously* lead to a *lower* firm's output level.

Also, both for simplicity and the purpose of highlighting the role of the demand side effects rather than costs as the driving force in the model, it is assumed that the representative firm's production cost is given by $C(x) = cx$, implying constant marginal (=unit) cost, $C'(x) = C(x)/x = c > 0$, and $C''(x) = 0$. The firm's total abatement cost is assumed to take the form $A(\alpha x) = A(\alpha x)^3 - d(\alpha x)^2 + k(\alpha x)$, where A , d , and k are all positive constants, and which by normalization (setting $A \equiv 1$) can be rewritten as $A(\alpha x) = (\alpha x)^3 - d(\alpha x)^2 + k(\alpha x)$. This implies a U-shaped unit cost of abatement, which not only seems plausible but, more importantly, as we will see presently, is a feature necessary for the existence of an interior industry equilibrium. The unit and marginal abatement cost (with respect to the firm's *output* level) are:

$$AC(\alpha x) \equiv A(\alpha x)/x = \alpha^3 x^2 - d\alpha^2 x + \alpha k \quad (8)$$

$$MC(\alpha x) \equiv \partial A(\alpha x) / \partial x = \alpha A'(\alpha x) = 3\alpha^3 x^2 - 2d\alpha^2 x + \alpha k \quad (9)$$

which, since firms are identical, are also the industry's average and marginal costs.

Note that for a solution with $x > 0$ to exist, certain constraints on parameters must hold. First, one must have $AC(\alpha x) + c \geq 0$ for all $x > 0$ and $\alpha > 0$, which implies that $\alpha k + c > \alpha d^2/4$. Second, since the unit aggregate cost curve is U-shaped, for any $\alpha > 0$, the demand's "choke" price, $P(0, \alpha) = (1 + \alpha)a/b$, should not exceed the unit aggregate cost of production and pollution abatement as $x \rightarrow 0$; that is, one must have $k\alpha + c > (1 + \alpha)a/b$, or $\alpha(k - a/b) + (c - a/b) > 0$, and *a fortiori* that $c > a/b$ for $\alpha \rightarrow 0$. Importantly, the condition that $c > a/b$ implies the necessity of a *minimum mandatory* standard for the survival of the industry. This is because, on their own, firms have no incentive to reduce pollution. Consequently, the environmental quality would be so poor, and the demand facing the industry so little, that even with no abatement cost, the representative firm's unit production cost would exceed the choke price, thus causing the industry to go out of business. Formally, for $\alpha = 0$ and $x > 0$, one would

have $AC(\alpha x) + C(x)/x = c > P(0,0) = a/b$, implying that no firm will stay in business without some amount of pollution abatement. We shall shortly determine this minimum mandatory abatement standard.

Substituting into (1) and (2) from (7d-e), (8) and (9) and solving for x and n yields:

$$x^2 = [\alpha(k-a/b) + (c-a/b)]/\alpha^3 \Rightarrow x = [\alpha(k-a/b) + (c-a/b)]^{1/2} \alpha^{-3/2} \quad (10)$$

$$n = b\alpha^2 (d - 2\alpha x) \quad (11)$$

where, as noted above, the inequality condition $\alpha(k-a/b) + (c-a/b) > 0$ ensures that $x > 0$ and where for $n > 0$ the additional condition that $d > 2\alpha x$ must also hold. The latter inequality reconfirms the inadmissibility of abatement cost function specifications for which $d=0$, and hence the choice of the specification used here. Also, since a smaller value of d corresponds to an upward shift in the unit abatement cost curve, the inequality echoes the simple fact that for an equilibrium to exist the unit abatement cost should not be unduly high. Writing this inequality as $d^2/4 > \alpha^2 x^2$ and substituting for x^2 from (10), we can combine the relevant parameter restrictions for the existence of an interior solution, $n > 0$ and $x > 0$, as

$$\alpha d^2/4 > [\alpha(k-a/b) + (c-a/b)] > 0 \quad (12a)$$

or, equivalently

$$\alpha d^2/4 + (1+\alpha)a/b > \alpha k + c > (1+\alpha)a/b > \alpha d^2/4 \quad (12b)$$

An immediate implication of condition (12.a) is that

$$n > 0 \text{ and } x > 0 \Rightarrow \alpha > \underline{\alpha} = (c-a/b) / [d^2/4 - (k-a/b)] \quad (12c)$$

where the condition $d^2 > 4[(k-a/b) + (c-a/b)]$ ensures that $0 < \underline{\alpha} < 1$. Thus,

Proposition 4: In order for the polluting industry to survive, a minimum abatement standard is necessary.

It should be noted that this result is not a necessary implication of the demand side effect introduced here, as it also rests on the assumption of constant marginal cost of production. And clearly in reality one can readily find unregulated industries that have survived. Nonetheless, the result is appealing because it confirms that in the presence of market failure public intervention of some sort is Pareto improving. Here, it questions the perception that *any* environmental regulation would be against industry's interest, particularly when, as in this model, adopting a higher standard renders benefits to the entire industry, which, because of inability to coordinate and individual firm's incentive to free ride, would otherwise not materialize.

It is easy to verify from (12.c) that $\partial \alpha / \partial c > 0$, $\partial \alpha / \partial d < 0$, $\partial \alpha / \partial k > 0$ and $\partial \alpha / \partial (a/b) < 0$. Thus:

Proposition 4': *The minimum abatement standard necessary for industry's survival will be higher the larger the unit cost of production or of abatement and the smaller the industry demand in the absence of any standards.*

The explanation for this rather counter intuitive proposition is that in order to survive, an industry that is characterized by a relatively high unit cost and/or a small market size needs to offset these deficiencies by becoming relatively cleaner as a means of boosting its market.

Next, we determine the effects of a stricter standard on each firm's output level, the number of firms in the industry, the industry's total output and total pollution. Interestingly, we show that even when the effects of a higher standard at the firm level appear to be standard, its industry effects can be very different from those obtained in models that abstract from the demand effect of a higher standard.

Given that here $\epsilon_a < 0$ and $\epsilon_p > 0$, we can determine these effects by invoking the general results furnished in Tables 1.a and 1.b. As noted from the tables the sign of $dx/d\alpha$ depends on that of $P_\alpha - A'(\alpha x)$ which in turn determines the sign of $dn/d\alpha$. Now, from (7f) and (9), one has $P_\alpha - A'(\alpha x) = a/b - [3\alpha^2 x^2 - 2d\alpha x + k] = a/b - [-2\alpha x(d - 2\alpha x) - \alpha^2 x^2 + k]$, which upon substituting for x^2 from (10) simplifies to $P_\alpha - A'(\alpha x) = 2\alpha x(d - 2\alpha x) + (c - a/b)/\alpha$. Recalling that $c > a/b$ and, from (11), that $d - 2\alpha x > 0$ for $n > 0$, we have $P_\alpha - A'(\alpha x) > 0$ and hence, by (4), $dn/d\alpha > 0$.

Thus, in this model, raising the environmental standard *increases*, rather than decreases, the number of firms in the industry. However, with $P_\alpha - A'(\alpha x) > 0$, it is immediate from Proposition 2 and Table 1.a that $dx/d\alpha < 0$, so that the individual firm's output level decreases. These in turn imply that the effect on industry output is ambiguous and a function of parameters chosen. Thus:

Proposition 5: *Even though a higher standard may lead to a lower individual firm's output level, it may well lead to a larger industry output.*

Finally, it would also be interesting to see the effect on total pollution, since the argument for a stricter environmental standard will be particularly strong if it can reduce total pollution and hence improve environmental quality at the same time that it increases the industry output. To this end, differentiate $Z = (1 - \alpha)X$ with respect to α to obtain $dZ/d\alpha = -X + (1 - \alpha) dX/d\alpha$. It can readily be verified from (10) and (11) that for $\alpha = 1$, $x(1) = [(k - a/b) + (c - a/b)]^{1/2} > 0$ and $n(1) = b\{d - 2[(k - a/b) + (c - a/b)]^{1/2}\} > 0$, by (12a), so that $X(1) = n(1)x(1) > 0$ and therefore $Z(1) = 0$, and that for $\alpha = \underline{\alpha} = (c - a/b) / [d^2/4 - (k - a/b)]$ one has $n(\underline{\alpha}) = 0$ (by substitution in (11)) and $x(\underline{\alpha}) > 0$ (by substitution in (10)) so that $X(\underline{\alpha}) = 0$ and hence $Z(\underline{\alpha}) = 0$. Further, using these information, it can readily be

checked that $\lim_{\alpha \rightarrow \underline{\alpha}} dZ/d\alpha = (1-\underline{\alpha})(c-a/b)b/\underline{\alpha} > 0$ and $\lim_{\alpha \rightarrow 1} dZ/d\alpha = -X(1) < 0$, so that by the continuity of Z in α it follows that there must exist some $\hat{\alpha}$, $1 > \hat{\alpha} > 0$, for which $dZ/d\alpha = 0$. This means that the curve of the total pollution function Z is a parabola with a maximum at $\alpha = \hat{\alpha}$ and zero values at $\alpha = \underline{\alpha}$ and $\alpha = 1$. We thus have:

Proposition 6: While at the individual firm level a more stringent standard reduces pollution, at the industry level it leads to a larger total pollution at low standards but a smaller total pollution at sufficiently high standards, even though the industry output (and hence gross emission) increases with the emissions standard.

The observation that for very small values of α , total pollution initially rises with the standard derives from the fact that at too low standards there will be relatively too rapid entry into the industry but too little abatement per unit of output/emission, so firms entry raises industry outputs sufficiently to overwhelm reductions in emissions per unit output. It is important to note that here the increased pollution is *not* because the firm increases its output to dilute the pollution and hence lower its emissions per unit of output; as firm's output *falls*. Rather, the increased pollution is due to the entry decisions which in turn derives from the demand side effect of a stricter standard. Perhaps to the surprise of the environmentalists, Proposition 6 has the interesting implication that from *their* perspective weak standards may be worse than no standards. As such, the proposition illustrates two points. First, that regulation can lead to unintended consequences, a point that economists have consistently tried to point out. Second, it is a stark reminder that firm level effects are not always equivalent to industry level effects.

To give a quantitative feeling for the various effects studied above, we have simulated the model for parameter values of $a=100$, $b=1$, $c=101$, $d=25$, and $k=102$, chosen conveniently and consistent with (12b). Figure 1 depicts the industry's equilibrium values of x , n , X and Z (on the left-hand vertical axis) and P (on the right-hand vertical axis) as a function of α . For these parameter values, the minimum standard is negligible, 0.6 percent, but rises to nearly 10 percent and 24 percent as the value of d is lowered respectively to 7 and 5. This is in line with Proposition 4'; a smaller value of d corresponds to an upward shift in the firm's abatement cost curve, while leaving its production cost unchanged.⁸ In the long-run equilibrium, this would force the firm out of market unless the industry demand and hence price is increased by mandating a higher minimum standard.

⁸ Note from (10) that the equilibrium level of firm's output, x , is independent of d .

[Figures 1.a and 1.b here]

As Figure 1.a shows, through its positive effect on the demand for the good, which in turn reflects the consumers' willingness to pay for improved environmental quality, a higher environmental standard may very well encourage more firms to the industry, and, despite lowering each firm's output level, expand the industry's supply. Further, despite increasing the industry's total output, it is seen that for standards exceeding 44 percent pollution reduction, raising the standard reduces total pollution and hence improves environmental quality too. It is important to note that it is the demand effect rather than costs characteristics that is the driving force behind these industry effects. For, as Figure 1.b shows, the equilibrium unit abatement cost is monotonically increasing in α , thus supporting the industry claim that stricter standards are costly but also supporting the present paper's claim that demand side effects are dominating here.

III.b. Industry Effects of a Stricter Standard in the Short Run

The previous results show clearly that the effect of regulation on firms' output and profitability, and hence on industry size, output, and net pollution is ambiguous. It depends on the relative strength of the countervailing cost and demand effects. This section concentrates on the short-run effects where the number of firms in the industry is fixed. It identifies conditions under which the short-run and long-run interests of the environmentalists and industrialists conflict, thus permitting some insight into political economy aspects and a sense for whether there is a ground for the industry opposition to regulation. To this end, let $n=n_0$ denote the original equilibrium number of firms before the standard is raised.

Differentiating $\pi(x, n, \alpha) = xP(X, \alpha) - A(\alpha x) - C(x)$ w.r.t. α and using the first-order condition (1), gives

$$\frac{d\pi}{d\alpha} \Big|_{n=n_0} = x [P_\alpha - A'(\alpha x)] \quad (13a)$$

$$\text{So that} \quad \frac{d\pi}{d\alpha} \Big|_{n=n_0} \begin{matrix} > \\ = 0 \\ < \end{matrix} \quad \text{as} \quad P_\alpha - A'(\alpha x) \begin{matrix} > \\ = 0 \\ < \end{matrix} \quad (13b)$$

Thus, in general, with a fixed number of firms, the net effect on profitability is *ambiguous*: firms will earn positive profits/rents (incur a loss) if an increase in the standard raises the price more (less) than it raises the unit abatement cost.

To see the effect on a firm's output, differentiate the first-order condition (1) w.r.t. α , holding n fixed at $n=n_0$, to get after simplification

$$\left. \frac{dx}{d\alpha} \right|_{n=n_0} = - \frac{[P_\alpha(1-1/\epsilon)] - A'(1+\xi) + P/\epsilon^2 \epsilon_\alpha}{nP_X(1-1/\epsilon + P\epsilon_p/\epsilon^2) - (\alpha^2 A'' + C'')} \quad (14)$$

Also, to compare the effect of a stricter standard on the firm's output when the industry size is fixed with that when entry is free, subtract (5) from (14) to obtain

$$\left. \frac{dx}{d\alpha} \right|_{n=n_0} - \frac{dx}{d\alpha} = - \frac{(P_\alpha - A')[(1-1/\epsilon) + P\epsilon_p/\epsilon^2]}{nP_X(1-1/\epsilon + P\epsilon_p/\epsilon^2) - (\alpha^2 A'' + C'')} \quad (15)$$

Finally, to simplify the analysis and to be able to illustrate the general results in the context of the parameterized model of Section III.a, we assume that $\epsilon_p \geq 0$. This is a sufficient (but not necessary) condition to ensure that the denominators in (14) and (15) are negative, so that the signs of the expressions are determined by those of respective numerators. We can distinguish two broad cases:

Case I: $P_\alpha - A' > 0$

According to (13b), in this case the barrier to entry in the short-run generates rents for incumbent firms. As is clear from (14), whether the existing firms increase their scales or not depends crucially on the magnitudes of the elasticities of the demand ($\epsilon > 0$) and the marginal abatement cost ($\xi > 0$), as well as on the sign and magnitude of ϵ_α , which measures the change in the *price elasticity* of demand resulting from an increase in emissions standard. To proceed further, we assume that the magnitude of ϵ_α is sufficiently small so that the sign of (14) is predominantly determined by that of the bracketed term in the numerator. The following proposition then follows from (13b) and (14):

Proposition 7: *In the short run, if a stricter emissions standard raises the price more than it raises the unit abatement cost, then it makes firms more profitable. Furthermore, if the market demand is sufficiently elastic (ϵ large) and the marginal abatement cost is sufficiently inelastic (ξ small), a stricter standard can also lead to a larger output by each firm and hence to a larger industry output in the short-run.*

Clearly, despite increasing the industry's total output, a higher standard can reduce the total amount of pollution if the standard exceeds a certain level.

Proposition 7 is important because, assuming that the required conditions hold, it implies that industry pundits may be unduly alarmist, perhaps due to being ill-informed about the possible net effects of higher

standards.⁹ It also contrast the results in the literature that a more stringent regulation (especially a higher pollution tax rate) either reduces both firms' output and profitability or increases firms' profitability by inducing them to *lower* their output levels. In the present model, due to the demand effect of a stricter standard, firms can become more profitable and at the same time *increase* their output level. In fact, as can be verified from (14), the standard results in the literature are the special case of the present model for $P_\alpha = \epsilon_\alpha = 0$.

Next, we compare the effect on firms' output in the short run and long run. Maintaining the conditions of Proposition 7, we have $\frac{dx}{d\alpha}|_{n=n_0} > 0$ and, from (15), $\frac{dx}{d\alpha}|_{n=n_0} - \frac{dx}{d\alpha} > 0$. So, there are two possibilities:

either (i) $\frac{dx}{d\alpha}|_{n=n_0} > \frac{dx}{d\alpha} > 0$, or (ii) $\frac{dx}{d\alpha}|_{n=n_0} > 0 > \frac{dx}{d\alpha}$.

In the first case, each firm expands its scale to the point where the marginal revenue associated with its share of increased market demand equals the increased overall marginal cost of production and abatement. In the long run, as new firms enter the industry, the share of each firm from the market demand shrinks, thus forcing each firm to reduce its output from the no-entry, profit-maximizing level to the free-entry, zero-profit level. However, this latter level is still larger than that prevailing before the standard is raised. So, in this case, a more stringent standard leads to a higher *industry* output *both* in the short run and in the long run. But, since it raises the individual firm's output more in the short run, whether the increase in the industry output is greater in the short run or in the long run depends on how much each firm has to lower its output to accommodate new entrants and on how large is the inflow of new firms. Clearly, this case should not generate tension between environmentalists and industrialists except if the increased standard is still weak ($\alpha < \hat{\alpha}$), causing net pollution to rise.

In the second case, as the demand for each firm shrinks with new firms' entry, firms are forced to reduce their scale from the no-entry, profit-maximizing level by such an extent that their new zero-profit output level is less than that before raising the standard. Thus, in this case, while a stricter standard causes incumbent firms to expand their scale in the short run, it reduces firm' output level in the long run. This is an interesting case because it highlights the tension between environmentalists and industrialists: one that sees the immediate effects of regulation and one that sees the latent effects. While the industry's total output increases in the short run, it *may* or *may not* increase in the long run. The former situation is indeed the one that holds for the specific

⁹ Alternatively, when the industry consists of heterogenous firms, industry pundits may represent a fringe of firms who undergo losses as a result of stricter regulations.

example of the industry studied in Section III.a, namely, a higher standard leads to a larger industry output in the long-run equilibrium.

Table 2.a summarizes the comparisons of the short-run and long-run effects when $P_\alpha - A' > 0$.

Table 2.a : $P_\alpha - A' > 0$

	<u>Case(i)</u> $dx/d\alpha _{n=n_0} > dx/d\alpha > 0$		<u>Case(ii)</u> $dx/d\alpha _{n=n_0} > 0 > dx/d\alpha$	
	SR	LR	SR	LR
x	↑	↑	↑	↓
X	↑	↑	↑	↓
Z	$\alpha > \hat{\alpha}$ ↓	↓	$\alpha > \hat{\alpha}$ ↓	↓

Case II : $P_\alpha - A' < 0$

According to (13b), $\frac{d\pi}{d\alpha}|_{n=n_0} < 0$, implying *negative* profits for firms. Further, by (14), *for all* values

of the elasticities ϵ and ξ , we have $\frac{dx}{d\alpha}|_{n=n_0} < 0$. This is so because to minimize short-run losses, every firm

reduces its output to the point where the marginal revenue from its increased share of market demand equals its increased overall marginal cost of production. We therefore have:

Proposition 8: *In the short-run, if a stricter emissions standard raises the unit abatement cost more that it raises the price, then firms incur losses in the short-run, and both the output level of each firm and hence the industry's total output decline as a result of a stricter standard. Total pollution emission, however, also declines in the short-run.*

Further, for this case, we note from (15) that $\frac{dx}{d\alpha}|_{n=n_0} - \frac{dx}{d\alpha} < 0$, which together with

$$\frac{dx}{d\alpha}|_{n=n_0} < 0 \text{ implies two possibilities: (i) either } \frac{dx}{d\alpha}|_{n=n_0} < 0 < \frac{dx}{d\alpha}, \text{ (ii) or } \frac{dx}{d\alpha}|_{n=n_0} < \frac{dx}{d\alpha} < 0.$$

In the former case, as eventually some of the loss-incurring firms exit the industry, the market demand facing each one of the remaining firms increases, thereby encouraging them to expand their output levels until the price covers the overall unit cost and the zero-profit equilibrium prevails again. Under case (i), a more stringent standard leads to a new long-run equilibrium output by each firm which is larger than the original one. This is another interesting case where the interest of environmentalists who focus on the long-run effects of a stricter standard conflicts with that of industrialists who worry about the immediate effects. In this case, while a stricter standard causes the individual firm's scale and hence the industry output to decline in the short run, in the long run it leads to an industry characterized by fewer firms, each producing at a larger scale, and by a total output that may be larger than that before the standard is raised. Other things being equal, the industry's output is more likely to be larger the smaller is the elasticity of the marginal abatement cost, ξ , and the greater is the price elasticity of demand, ϵ . It can be verified from (5) that a smaller ξ , and hence a smaller A'' , implies a larger $dx/d\alpha > 0$, and from (4) that a larger ϵ implies a smaller magnitude of $dn/d\alpha < 0$.

Under case (ii), although the exit of some of the firms and the resulting larger demand for each remaining firm encourages it to expand its scale to the zero-profit equilibrium level, this level is, however, less than that in the original equilibrium. Therefore, under this case, a more stringent standard reduces each firm's as well as the industry's output both in the short run and long run. Obviously, except for the resulting reduction in net pollution, this case conforms to standard results. It indicates the situation where the demand effect is dominated by the cost effect of a stricter standard, thus giving credibility to industrialists' claims. Tables 2.b summarize the comparison of the effects of a stricter standard in the short run and long run when $P_\alpha - A' < 0$.

Table 2.b : $P_\alpha - A' < 0$

	<u>Case(i)</u> $dx/d\alpha _{n=n_0} < 0 < dx/d\alpha$		<u>Case(ii)</u> $dx/d\alpha _{n=n_0} < dx/d\alpha < 0$	
	SR	LR	SR	LR
x	↓	↑	↓	↓
X	↓	↓	↓	↓
Z	↓	↓ (\forall or $\alpha > \hat{\alpha}$)	↓	↓

IV. Conclusion

This paper has focussed on situations where reductions of pollution by all firms boost the industry demand, but, because firms are unable to coordinate actions to reduce emissions, *individually* free ride on each other's pollution abatement, and therefore fail to act in their own *collective* interest. It has shown that, contrary to industrialists' arguments, in such situations a stricter mandatory standard can lead to a *larger* number of firms in industry, a *greater* industry output, and *less* total pollution. We have examined the short-run effects of a stricter standard on profitability, output, and pollution emissions both at the individual firm level and the industry level, and compared these effects with those obtained under free entry condition. It turns out that the firms' effects emerging from this model are also different from the standard results in the literature; for example, here a stricter standard may well increase both the firms' short-run profits *and* output levels. We have identified the conditions under which the short-run and long-run interests of the environmentalists and industrialists conflict, thus providing some insight as to why the stricter standards that appear to environmentalists to benefit the industry may nevertheless be contested.

As an implication of the coordination failure and free riding problem inherent in the model, it is shown that in order for the industry to survive, a minimum mandatory pollution standard may be necessary.

To focus on the question at hand, the paper has considered only the demand-side externality. A stricter emissions standard may also have positive *cost-side* externalities: for instance, the pool of workers from which firms draw is healthier, and hence more productive, the cleaner is the environment firms provide them, but each firm is unable to fully appropriate the benefits of the health improvements of all workers. More generally, the results of the paper can be extended to a general equilibrium treatment in which each agent might be both a producer and consumer of pollution, but each free rides on pollution reductions of others.

The present model can be extended also by relaxing one or more of the assumptions of identical firms, homogenous goods, and consumer preferences. Whereas the theoretical literature on environmental regulation when firms act strategically has been large and growing, there has been little theoretical or empirical research on how heterogeneity of consumers with respect to preferences, income, or other attributes may affect environmental regulations. It would be also interesting to investigate how the results of this paper may be affected by considering (a) other market structures than Cournot competition and (b) pollution taxes instead of standards and comparing their efficiencies as instruments of environmental regulation. This latter question, of course, requires that firms choose their own abatement standards. Finally, of great value will be empirical research into the direction and extent by which the market demand for specific products may be affected by environmental quality improvements and into the conditions, noted in this paper, under which an industry may or may not contest stricter standards.

Appendix 1

Let $U=U(X, Z, Y)$ denote the representative consumer's utility function, where X is the consumption of the industry's good, $Z = (1-\alpha)X$ is the net pollution, and Y is a composite of all other goods which serves as numeraire. The utility function U is assumed to have the regular properties; in particular, it is assumed to satisfy the following plausible conditions (subscripts denote partial derivatives):

$$U_1 > 0, U_{11} < 0, U_{12} = U_{21} < 0, \quad (A.1)$$

$$U_2 < 0, U_{22} \leq 0 \quad (A.2)$$

$$U_3 > 0, U_{31} = U_{13} \geq 0, U_{32} = U_{23} = 0, U_{33} < 0 \quad (A.3)$$

Condition $U_{12} = U_{21} < 0$ indicates that a reduction in the amount of pollution renders the consumption of good X more valuable, and vice versa. Condition $U_{22} \leq 0$ states that the *disutility* of pollution increases with the amount of pollution, or, stated differently, pollution becomes more unpleasant as its amount increases. Condition $U_{31} = U_{13} \geq 0$ implies that X and the composite good are either unrelated or weakly complements, while $U_{32} = U_{23} = 0$ implies that the pollution does not affect the marginal utility from consumption of the composite good (i.e. utility function is additively separable in Y and Z). Denoting by I , the representative consumer's income, her decision problem is to

$$\max_X U(X, (1-\alpha)X, Y) \text{ s.t. } PX + Y \leq I. \text{ Forming the Lagrangean, differentiating it with respect to } X \text{ and}$$

Y , and eliminating the Lagrangean multiplier from the first-order necessary conditions, routinely yields

$$U_1(X, (1-\alpha)X, Y) + (1-\alpha) U_2(X, (1-\alpha)X, Y) = U_3(X, (1-\alpha)X, Y) P \quad (A.4)$$

This simply states that at the optimum, the *net* marginal utility of consuming the good (that is, taking into account the marginal disutility of pollution associated with *an extra unit of the good*, $(1-\alpha) U_2$, should equal its opportunity cost in terms of foregone utility from spending P dollars on Y . Recalling that for an interior optimum $Y = I - PX$ and substituting this in (A.4) one obtains the demand for X , with I fixed, as an implicit function of P , X and α .

Differentiating (A.4) w.r.t X and P and simplifying gives

$$\partial X / \partial P = [U_{11} + 2(1-\alpha)U_{12} + (1-\alpha)^2 U_{22} - 2(1-\alpha)PU_{32} - PU_{31} + P^2 U_{33}] / [U_3 + X(U_{13} + U_{23} - PU_{33})] \quad (A.5)$$

Which, upon using (A.1), (A.2), and (A.3), reduces to

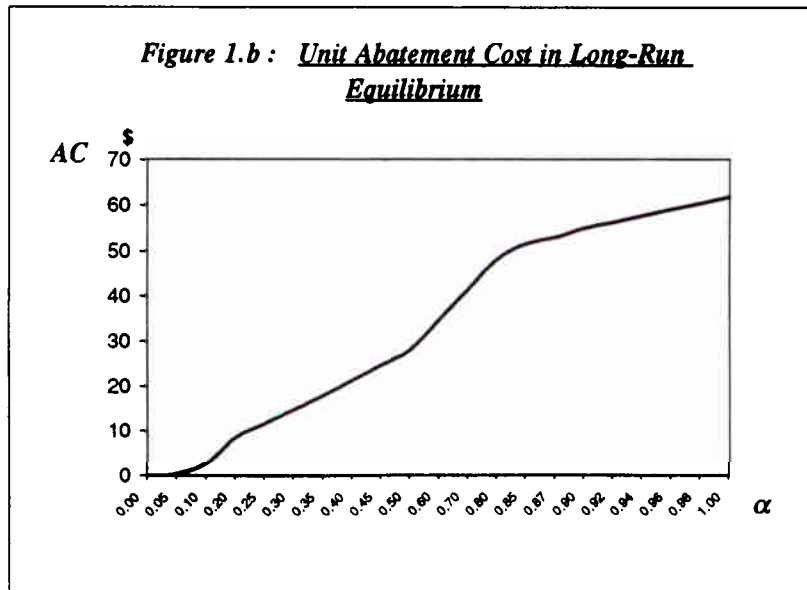
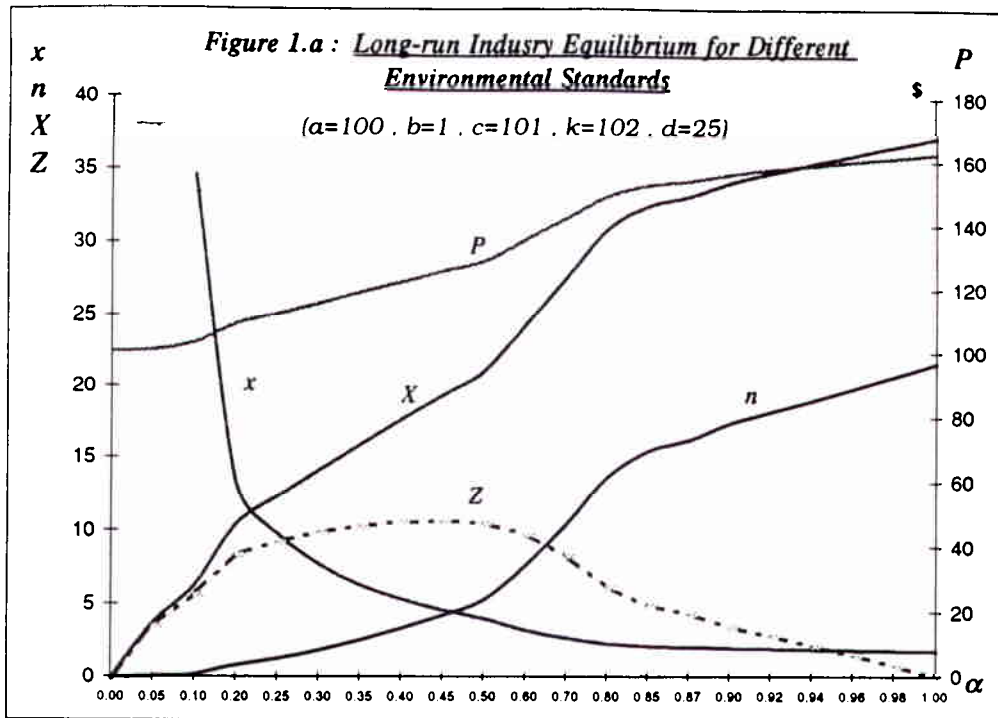
$$\partial X / \partial P = [U_{11} + 2(1-\alpha) U_{12} + (1-\alpha)^2 U_{22} - P U_{31} + P^2 U_{33}] / [U_3 + X(U_{13} - P U_{33})] < 0 \quad (A.5')$$

(arguments of the functions are suppressed for notational ease). Similarly, differentiating (A.4) w.r.t P and α yields

$$\partial P / \partial \alpha = - [U_2 + X(U_{12} + (1-\alpha) U_{22})] / [U_3 + X(U_{13} + (1-\alpha) U_{23} - P U_{33})] \quad (A.6)$$

which, upon using (A.1), (A.2), and (A.3), one has

$$\partial P / \partial \alpha = - [U_2 + X(U_{12} + (1-\alpha) U_{22})] / [U_3 + X(U_{13} - P U_{33})] > 0 \quad (A.6')$$



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