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## **Environmental Quality in a Differentiated Duopoly**

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# **Environmental Quality in a Differentiated Duopoly**

## **Summary**

In a duopoly industry with environmentally differentiated products, we examine the effects of introducing a mandatory environmental quality standard on firms' environmental quality choices, profits, and the average environmental quality offered by the industry. We show that at low standard levels, both firms choose to overcomply regardless of the standard level. At intermediate levels, the mandatory standard can reduce the profit of the low-cost firm while increasing that of the high-cost firm, and that it can lower the industry's average environmental quality below what it would be without the standard.

**Keywords:** Duopoly, Environmental Quality, Mandatory Environmental Standard, Overcompliance, Product Differentiation

**JEL Classification:** Q58, L13, I51, D43

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## Environmental Quality in a Differentiated Duopoly

### 1. Introduction

The past three decades have witnessed two broad trends in concerns about environmental quality. On the one hand, consumers have become increasingly concerned about the environmental quality and impact of products they consume. They have often expressed these concerns both by showing willingness to pay a price premium for the so called “green” or environmentally-friendly products and by pressuring policymakers to subject the polluting industries to environmental quality standards. On the other hand, responding to the consumers’ preferences and public pressure for environmental regulations, producers have more than ever become environmentally proactive.<sup>1</sup> At the same time, firms have been increasingly competing with one another on the basis of environmental quality either directly, by adopting more environmentally friendly technologies to improve the environmental quality of their production processes and products, or indirectly, by engaging in, or supporting, pro-environment activities in general to enhance their environmental image or reputation (see, for example, Videras and Alberini (2000) and Antona *et al.* (2004)). In these fashions, firms have been increasingly tending to environmentally differentiate their brands and public image from those of their rivals. Examples indicating these trends abound and include agricultural products differentiated by the degree of their genetically modified (GM) content, or by the degree of their organic content (organic versus conventionally produced product), or the extent of their bio-degradability (recyclability). Gasolines of different octane or lead content, electricity generated by different processes (fossil fuel-based, solar based, hydro or thermal based) or inputs (coal, oil, natural gas, biomass), and cars driving on different mixes of bio-fuel (ethanol) and gasoline, or electricity, are all few among numerous other examples. In this last respect, it is perhaps interesting to note that to further differentiate itself environmentally from its rival auto companies such as Toyota,

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<sup>1</sup> For an interesting historical account of corporate environmentalism, see Hoffman (1997). For an economic and financial view of corporations’ environmental pro-activism, see Heal (2005), who presents several interesting examples of the corporations (such as British Petroleum (BP), Dow Chemical, and Heniz) whose pro-environment actions have benefited them both financially and in reputation, thereby giving them a competitive edge over their rivals, and those (such as Shell oil company, McDonalds, and Monsanto) whose less environmental-friendly approaches have harmed their public image and profitability.

Honda Motor Co. has just announced that it “is to mass-produce compact cars that run solely on bioethanol, becoming the first Japanese automaker to do so.” Bioethanol has attracted attention as a carbon-neutral fuel that does not contribute to global warming. Furthermore, Honda R&D Co. and Japan’s Research Institute of Innovative Technology for the Earth “have developed a new process to efficiently produce ethanol fuel from soft biomass, a renewable resource derived from plants” (*The Daily Yomiuri*, Tokyo, Friday, September 15, 2006, p.8).

The trends noted above raise several important questions. For example, what factors determine the firms’ choice of environmental quality of their brands if they are left to freely compete by differentiating their products? More importantly, faced with a mandatory quality standard, do firms have an incentive to overcomply? How does the introduction of a mandatory standard affect the firms’ degree of environmental differentiation, their profitability, and the average environmental quality provided by the industry? This paper explores these questions by adopting a simple differentiated duopolistic model of a polluting industry that faces a mandatory standard set exogenously by a regulating agency. We take a purely positive approach and as such do not deal with social welfare effects of either the regulator’s choice of the standard level or the industry’s choice of environmental quality. The two firms are assumed to differ only with respect to their costs of environmental quality, perhaps due to having access to different pollution abating technologies. Each of the firms produces a brand of a commodity that consumers deem to be different only in their environmental quality attribute.

Although there is an extensive literature dealing with various aspects of interaction between corporations and environmental regulations [see, for example, one or two references here], rather few theoretical economic research have explored the specific question of firms’ environmental quality choice in a differentiated industry facing a mandatory standard. Maloney and McCormick (1982) study the effect of a mandatory environmental quality regulation on profits in an atomistic competitive industry where the regulation increases a typical firm’s costs but has no direct effect on industry demand. They show that with restricted entry to the industry, the regulation can result in increased profits for all firms in the industry creating a scarcity rent from the right to use the environmental assets. Further, they show that when the firms differ in

their production costs, the environmental regulation may increase the profits of the low-cost firms while lowering those of the high-cost firms, and that this intraindustry transfer can happen even if entry is not restricted. Farzin (2003) examines the effect of a mandatory pollution standard on a polluting oligopolistic industry with identical firms where a higher environmental quality standard raises both the firms' compliance costs and the demand for the industry's output. He shows the conditions under which a stricter standard leads to a larger profit in the industry, a larger number of firms, a greater industry output, and a lower total pollution in the long run. However, none of these studies considers strategic environmental quality differentiation and possibility of voluntary overcompliance with the standard. On the other hand, Arora and Gangopadhyay (1995) analyze a model in which firms overcomply in order to attract high-income consumers, and thereby raise consumers' welfare.<sup>2</sup> As such, in their model overcompliance derives from the demand side due the heterogeneity of consumers' willingness to pay for environmental quality, which arises from differences in income levels. In contrast, our model explains overcompliance from the supply side by considering heterogeneity of firms' pollution control technologies, which lead to differences in their unit costs of environmental quality improvement.

Salop and Scheffman (1983) (1987) consider a dominant firm-competitive fringe model of an industry where a lower-cost dominant firm acts as price leader. They show that a cost-raising action controlled by the dominant firm, which could be interpreted as controlling product standards or other government regulations, or expenditures on advertising or research and development, can increase the dominant firm's profit at the expense of the fringe's profit and possibly consumer welfare.<sup>3</sup> Interestingly, however, in our model of environmental-quality differentiated duopoly, raising the mandatory quality standard can increase the profits of the

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<sup>2</sup> A strand of literature on motives for corporate environmentalism has emphasized self-regulation as a strategic means of preempting otherwise higher future government regulations. For a survey of this literature, see Lyon and Maxwell (2000).

<sup>3</sup> For a review of the literature on the use of regulation as a cost-raising strategy, see McCormick (1984). In a related but different model, Lutz *et al.* (2000) consider situations where a high quality firm in the industry takes the role of quality leader by credibly committing to a quality level that is higher than the anticipated standard to be set by the regulator. They show that by such a strategic action, the high-quality firm can influence the regulator to set lower standards, thereby leading to a *lower* social welfare than would be the case if the regulator were to lead in setting the industry standard.

*high-cost* firm while lowering those of the low-cost one.

The rest of the paper proceeds as follows. In section 2 we set out the model and present the firms' equilibrium choices of environmental quality of their products in the absence of regulation. Section 3 examines the effect of introducing a mandatory environmental quality standard on the firms' quality choices, where we show that depending on the level of the standard, either both, or only one, or none of the firms may overcomply with the standard. Sections 4.1 and 4.2 respectively examine the effects of the mandatory standard on the firms' profits and the average environmental quality offered by the industry. We show that for intermediate levels of the standard the mandatory standard can reduce the profits of the low-cost firm while increasing those of the high-cost firm, and that it can lower the industry's average environmental quality below what it would be without regulation. Concluding remarks are presented in section 5.

## **2. The Model: Environmental Quality in the Absence of Regulation**

Consider an industry consisting of two firms, labeled  $i = 1$  and  $2$ , each producing a brand of a product. From consumers' perspective, the products are different only with respect to their environmental quality attributes but are identical in all other respects. Let  $\alpha_i \geq 0$  denote the environmental quality and  $q_i \geq 0$  the quantity of firm  $i$ 's product.

In general, each firm's revenue is a function of the quantity demanded of the firm's own product and that of its rival firm's product. It also is a function of both firms' choices of environmental quality. Formally, the revenue function of firm  $i$  can generally be represented by  $R_i = R_i(q_i, q_j, \alpha_i, \alpha_j) = p_i(q_i, q_j, \alpha_i, \alpha_j)q_i$ . To concentrate on firms strategic behavior with regard to the choice of environmental quality, and their responses to the environmental standard set by an environmental regulatory agency, we abstract from firms' strategic behavior with regard to the choice of output quantity. This simplification can be justified, for example, by considering situations where consumers' aggregate income spent on the products is large enough and the firms make short-run decisions, so that consumers' demand for each product is determined by the

firm's available output capacity, which is assumed to be fixed at  $\bar{q}$  in the short run. Thus, the revenue function of each simplifies to  $R_i = R_i(\bar{q}_i, \bar{q}_j, \alpha_i, \alpha_j) = p_i(\alpha_i, \alpha_j)\bar{q}_i = R_i(\alpha_i, \alpha_j)$ .

The environmental quality of the firm in our model can be interpreted broadly so that it not only can represent the environmental quality associated with any stage of production of the final products (that is, from input acquirement to production processing, packaging, and distribution). It can also represent a firm's environmental activities which may not necessarily be related to its product *per se*, but could be pro-environment activities which, for example, improve the firm's environmental reputation in general. The firm's incentive to engage in such activities is to attract consumers who support its pro-environment stance by their willingness to pay a premium price for the firm's product. In other words,  $\alpha_i$  in our model can be interpreted broadly enough to encompass the notion of firm's environmental responsibility. We are thus treating  $\alpha_i$  in our model as firm's environmental reputation which can from consumers' perspective be distinct from how much of the firm's product they may consume. Accordingly, our notion of the environmental standard set by the regulator may also be interpreted broadly. It may not only represent the environmental standard that firms have to observe in production of their products. It can more generally be viewed as a composite index of a firm's environmental friendliness.

To simplify the model, and without much loss of generality, we make two further assumptions. First, we assume that the choice of environmental quality by a firm does not affect its output level. That is, the firm's environmental quality activity is like end-of-pipe pollution abatement and as such is separate from the firm's production process, so that there is no spillover effect from environmental quality activity into the production activity and vice versa. An implication of this assumption is that the production cost is not affected by choice of environmental quality. This is consistent with the assumption of constant unit production costs of the products that we shall also be making shortly. Second, we assume that inputs employed in production and environmental activities are specific to each activity. An implication of this



assumption is that a firm can not by reallocating some of the inputs from production into environmental quality activity reduce the level of its output to improve the environmental quality of its product, thereby obtaining a higher price for its product.

To be able to proceed analytically, we assume the following quadratic revenue functions:

$$R^i(\alpha_i, \alpha_j) = -\frac{1}{2}a\alpha_i^2 - b\alpha_i\alpha_j + r\alpha_i, \quad i = 1, 2, j \neq i, \quad a, b, r > 0, \quad (1)$$

where  $\partial^2 R^i(\alpha_i, \alpha_j) / \partial \alpha_i^2 = -a < 0$  and  $\partial^2 R^i(\alpha_i, \alpha_j) / \partial \alpha_i \partial \alpha_j = -b < 0$ . The first inequality indicates that for each firm there are diminishing marginal returns from choosing higher environmental quality levels. The second inequality indicates that an increase in one firm's environmental quality lowers the rival firm's marginal revenue, implying that from firms' perspectives the environmental qualities are strategic substitutes.

It is plausible to assume that a firm's marginal revenue is more sensitive to a change in its own environmental quality than to a change in the rival's; that is

$$a > b \quad (2)$$

In fact, for a given value of  $a$ , the magnitude of  $b$  indicates the degree to which the consumers' perceive the two products are differentiated, or inversely, how close strategic substitutes the two products are from the firms' perspectives. In the extreme case of  $b = a > 0$  (*i.e.*,  $a - b = 0$ ) the two products become homogeneous (zero degree of differentiation or strategically perfect substitutes) and the firms' profits would drop to the lowest level. In the other extreme case, when  $b = 0$  (*i.e.*,  $a - b = a$ ), the degree of product differentiation is the highest, and the two products become independent of each other. In this case, each firm behaves like a monopolist in choosing its level of environmental quality. As such, one could consider  $(a - b)$  as an index of product differentiation or the inverse of it as a degree to which the two products are strategic substitutes.

To focus on the role of environmental quality differentiation, we assume that the unit production costs of products are the same, and normalize them to be zero. Let  $A_i$  be the

constant unit cost of achieving environmental quality  $\alpha_i$ .<sup>4</sup> We assume that the two firms differ only with respect to this cost, for example, due to differences in their pollution abatement technologies. More specifically, we assume that firm 1 has an advantage over firm 2 in cost of environmental quality, *i.e.*,

$$A_2 > A_1 > 0. \quad (3)$$

Then, the profit functions are expressed as<sup>5, 6</sup>

$$\pi^i(\alpha_i, \alpha_j) = \left( -\frac{1}{2}a\alpha_i^2 - b\alpha_i\alpha_j + r\alpha_i \right) - A_i\alpha_i \quad (i, j = 1, 2, \quad i \neq j) \quad (4)$$

To ensure that both firms can coexist in the market, we need to assume that

$$r > A_2. \quad (5)$$

Otherwise, the profit of firm 2 will always be negative and thus not entering the market.

The two firms play a Nash-Cournot game in environmental qualities of their products.

The problem of firm  $i = 1, 2$  is

$$\begin{aligned} \max_{\alpha_i} \pi^i(\alpha_i, \alpha_j) &= -\frac{1}{2}a\alpha_i^2 - b\alpha_i\alpha_j + r\alpha_i - A_i\alpha_i, \\ \alpha_j \quad (j \neq i) &\text{ given.} \end{aligned} \quad (6)$$

Suppose that in the absence of any environmental regulation, there exists an equilibrium  $(\alpha_1^*, \alpha_2^*)$ .<sup>7</sup> At equilibrium, the following equation holds:

$$\begin{bmatrix} a & b \\ b & a \end{bmatrix} \begin{pmatrix} \alpha_1^* \\ \alpha_2^* \end{pmatrix} = \begin{pmatrix} r - A_1 \\ r - A_2 \end{pmatrix}. \quad (7)$$

With condition (2) one has  $a^2 - b^2 > 0$ , which ensures that a Nash equilibrium is unique and

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<sup>4</sup>  $A_i$  can also be interpreted, for example, as a constant unit cost of pollution abatement.

<sup>5</sup> Strictly speaking,  $\pi^i$  represents the profit margin (price minus unit cost) for each firm. To simplify the analysis, we focus on the profit margin, instead of profit levels, which depend on  $\bar{q}_i$ ,  $i = 1, 2$ .

<sup>6</sup> We could more generally write the profit function to include a constant term  $c_i$ , as

$\pi^i(\alpha_i, \alpha_j) = R^i(\alpha_i, \alpha_j) - A_i\alpha_i - c_i$ , where  $c_i$  can be interpreted either as a unit cost of production or as a tax or subsidy per unit of output respectively when  $c_i$  is positive or negative. This generalization would not affect the results as long as both firms remain in the market.

<sup>7</sup> It is shown below (see (10)) that the firms' profits at equilibrium are positive. Therefore, both firms can coexist under *laissez faire*.

stable.<sup>8</sup> The firms' equilibrium choices of environmental quality are

$$\alpha_1^* = \frac{a(r - A_1) - b(r - A_2)}{a^2 - b^2} > 0 \quad (\text{by (2) and (3)}), \quad (8.a)$$

$$\alpha_2^* = \frac{a(r - A_2) - b(r - A_1)}{a^2 - b^2} \quad (8.b)$$

Notice that whereas  $\alpha_1^*$  is always positive, to ensure that  $\alpha_2^*$  is positive we need the condition

$$\frac{b}{a} < \frac{r - A_2}{r - A_1} < 1, \quad (9)$$

that is, the adverse effect of an increase in the rival's quality on the firm's marginal revenue should not be too large, or, equivalently, the two products should be sufficiently differentiated.

As to be expected, from (8.a) and (8.b) it is seen that the equilibrium choice of the quality by each firm varies inversely with its own cost of environmental quality and directly with that of its opponent.

The associated profits at the equilibrium are calculated as

$$\pi^i(\alpha_i^*, \alpha_j^*) = \frac{a}{2} \left( \frac{a(r - A_i) - b(r - A_j)}{a^2 - b^2} \right)^2 > 0, \quad i = 1, 2, \quad j \neq i, \quad (10)$$

which ensures that both firms will coexist in the market.

An interesting finding here is (from (8.a) and (8.b))

$$\alpha_1^* - \alpha_2^* = \frac{A_2 - A_1}{a - b} > 0 \quad (11)$$

which enables us to state the following proposition:

**Proposition 1:** *In the absence of any environmental quality regulation, in a differentiated duopoly, (i) the firm with the lower environmental quality cost ( $A_1 < A_2$ ) adopts a higher environmental quality than that chosen by its high-cost rival ( $\alpha_1^* > \alpha_2^*$ ), and (ii) the extent of environmental quality differentiation in the market varies directly with the environmental cost differential and the degree to which the products are strategic substitutes.*

This result parallels that of output quantity choices in a differentiated duopoly (see, for example, Dixit, 1979, Singh and Vives, 1984, and Shy 1995.) As we shall see in the next

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<sup>8</sup> See Dixit (1986).

section, when a mandatory environmental standard is introduced, the asymmetric equilibrium quality choices, (8.a) and (8.b), give rise to a situation where one of the firms complies with the standard whereas the other overcomplies.

### 3. Mandatory Standard and Duopoly Choices of Environmental Quality

In this section we analyze the equilibrium quality choices of the duopoly facing an environmental quality standard. Let  $\hat{\alpha} > 0$  denote the minimum environmental quality standard mandated by the environmental regulatory agency. Taking this standard and the rival firm's choice of environmental quality as given, the profit maximization problem for firm  $i$  is written as

$$\begin{aligned} \max_{\alpha_i} & \left( \frac{-1}{2} a\alpha_i - b\alpha_j + r - A_i \right) \alpha_i, \\ \text{subject to } & \alpha_i \geq \hat{\alpha}, \quad \alpha_j (j \neq i) \text{ given.} \end{aligned} \quad (12)$$

At equilibrium  $(\alpha_1(\hat{\alpha}), \alpha_2(\hat{\alpha}))$ , it holds that

$$\begin{aligned} - \begin{bmatrix} a & b \\ b & a \end{bmatrix} \begin{pmatrix} \alpha_1(\hat{\alpha}) \\ \alpha_2(\hat{\alpha}) \end{pmatrix} + \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} &= - \begin{pmatrix} r - A_1 \\ r - A_2 \end{pmatrix}, \\ (\alpha_1(\hat{\alpha}) - \hat{\alpha})\mu_1 &= 0, \quad (\alpha_2(\hat{\alpha}) - \hat{\alpha})\mu_2 = 0 \end{aligned} \quad (13)$$

where  $\mu_1, \mu_2 \geq 0$  are the Lagrange multipliers. Notice that for now we have left aside the possibility that the standard may render production by one or both firms unprofitable. Later, we will take this possibility into account and analyze how the standard affects the market structure.

Using the Kuhn-Tucker conditions (13), the equilibria are classified into three types:

(a) *Both firms overcomply*: In this case,  $\mu_1 = \mu_2 = 0$ , implying that  $\alpha_1(\hat{\alpha}) = \alpha_1^* > \hat{\alpha}$  and  $\alpha_2(\hat{\alpha}) = \alpha_2^* > \hat{\alpha}$ , where, as before,  $\alpha_1^*$  and  $\alpha_2^*$  are given by (8.a) and (8.b). The equilibrium exists if  $\min[\alpha_1^*, \alpha_2^*] = \alpha_2^* \geq \hat{\alpha}$ . We term the interval  $[0, \alpha_2^*]$  as *Interval I*. Thus,

**Proposition 2:** *Over Interval I, (i) both firms overcomply, (ii) they choose equilibrium quality levels that are the same as those in the absence of any standard, implying that within this interval the mandatory standard has no effect on the firms' voluntary choices of environmental quality, and (iii) the low-cost firm overcomplies by a larger extent than the high-cost firm does. (See Figure 1).*

An important implication of (ii) is that since the mandatory standard does not affect the firms' laissez faire choices of environmental quality of their products, to the extent that monitoring the firms' environmental quality levels and enforcing the standard involve social costs, zero mandatory standard should be preferred to weak standards (*i.e.*,  $\hat{\alpha} < \alpha_2^* = [a(r - A_2) - b(r - A_1)] / (a^2 - b^2)$ ).<sup>9</sup>

(b) *Only one of the firms overcomplies*: In this case  $\mu_1 = 0$  and  $\mu_2 > 0$ , so that  $\hat{\alpha} < \alpha_1(\hat{\alpha}) = (-b\hat{\alpha} + r - A_1) / a$  and  $\alpha_2(\hat{\alpha}) = \hat{\alpha}$ .<sup>10</sup> This equilibrium exists if  $\alpha_2^* \leq \hat{\alpha} \leq \hat{\alpha}^U$ , where  $\hat{\alpha}^U$  is defined by

$$\hat{\alpha}^U = \frac{r - A_1}{a + b} > \alpha_2^*. \quad (14)$$

So, calling  $[\alpha_2^*, \hat{\alpha}^U)$  as *Interval II*, we have

**Proposition 3**: *If the environmental quality standard lies within the Interval II, then whereas the high-cost firm just complies with the standard, the low-cost firm still chooses to overcomply, although by a lesser extent than if the standard was lower. As a result, the standard reduces the quality differentiation in the market. (See Figure 2).*

The economic reason for firm 2 refraining from overcompliance is clear. Being the high-cost firm, at higher standard levels (*i.e.*, higher than  $\alpha_2^*$ ), the cost of overcomplying would be too high for firm 2 to afford it. On the other hand, the low-cost firm 1 still continues to overcomply, but as the mandatory standard is raised over Interval II, it *lowers* its environmental quality, and does so at the rate of  $b/a < 1$ , which is smaller the more strongly the two products are strategic substitutes (or, equivalently, the less differentiated they are). The reason for this behavior of firm 1 is simple: since its rival now adopts, and sticks to, a higher standard than it would over Interval

<sup>9</sup> Also, see Farzin (2004) who analyzes the social welfare effects of a stricter environmental standard and identifies situations in which the regulator may prefer no standard to weak ones.

<sup>10</sup> The other overcompliance case where  $\mu_1 > 0$ ,  $\mu_2 = 0$  implying that  $\alpha_1(\hat{\alpha}) = \hat{\alpha}$ ,  $\alpha_2(\hat{\alpha}) > \hat{\alpha}$  can never happen because otherwise one would have  $a\hat{\alpha} + b\alpha_2(\hat{\alpha}) = r - A_1$ ,  $b\hat{\alpha} + a\alpha_2(\hat{\alpha}) > r - A_2$ . By (2), this implies that  $a\hat{\alpha} + b\alpha_2(\hat{\alpha}) > b\hat{\alpha} + a\alpha_2(\hat{\alpha})$ . Since  $a - b > 0$ , we have a contradiction:  $\alpha_2(\hat{\alpha}) < \hat{\alpha}$ .

<sup>11</sup>  $\hat{\alpha}^U - \alpha_2^* = \frac{r - A_1}{a + b} - \frac{a(r - A_2) - b(r - A_1)}{a^2 - b^2} = \frac{a(A_2 - A_1)}{a^2 - b^2} > 0$  (since  $A_1 < A_2$  and  $a > b$ ).

I (i.e.,  $\alpha_2(\hat{\alpha}) = \hat{\alpha} > \alpha_2^*$ ), and since the best response of firm 1 is negatively related to firm 2's choice of environmental quality (recall that  $\alpha_1(\alpha_2) = (-b\alpha_2 + r - A_1)/a$ ), it follows that the best strategy of firm 1 is to still overcomply but to reduce its environmental quality below the level it would choose over Interval I. As such, by mandating a sufficiently high standard, the regulatory agency also causes the environmental quality differentiation in the market to narrow. At the limit when  $\hat{\alpha} = \hat{\alpha}^U$ , even for the low-cost firm 1 the cost of overcomplying becomes so large that environmental differentiation no longer pays off and therefore both firms just comply with the minimum standard.

(c) *None of the firms overcomplies*: In this case,  $\mu_1 > 0, \mu_2 > 0$ , implying that  $\alpha_1(\hat{\alpha}) = \hat{\alpha}$  and  $\alpha_2(\hat{\alpha}) = \hat{\alpha}$ . This equilibrium occurs on *Interval III*, defined as  $[\hat{\alpha}^U, \infty)$ . We therefore have:

**Proposition 4:** *At sufficiently high environmental standards ( $\hat{\alpha} > \hat{\alpha}^U = (r - A_1)/(a + b)$ ), none of the firms has an incentive to environmentally differentiate itself by overcomplying. Therefore both firms choose to comply with the minimum standard. (See Figure 1).*

The economic explanation of this result is simple. As noted before, when the environmental standard is too high, it becomes too costly even for the low-cost firm 1 to differentiate itself through overcompliance as a strategic means of competition.

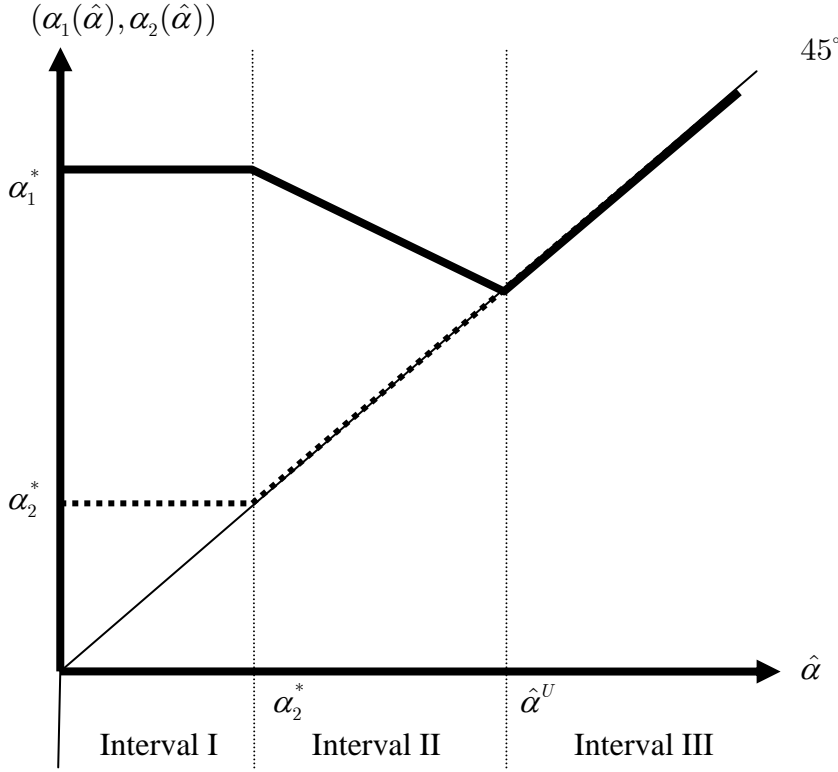


Figure 1. Firms' equilibrium quality responses to environmental standard  $\hat{\alpha}$

#### 4. Profits and average environmental quality under the mandatory standard

##### 4.1 Profits under the mandatory standard

It would be interesting to examine the corresponding behavior of the duopoly profits in response to the mandatory standard over the three intervals.

Over Interval I, the mandatory standard is ineffective, so the firms' profits remain constant at the laissez fair levels, given by (10), regardless of the standard level. It is easy to verify from (10) that  $\pi^{*1} > \pi^{*2}$ . (See Figure 2).

Over Interval II, the profits of the two firms, denoted by  $\pi_{II}^{*1}(\hat{\alpha})$  and  $\pi_{II}^{*2}(\hat{\alpha})$  and illustrated by solid and dashed lines in Figure 2, are calculated as.

$$\pi_{II}^{*1}(\hat{\alpha}) = \frac{-1}{2} a [\alpha_1(\hat{\alpha})]^2 + (-b\hat{\alpha} + r - A_1) \alpha_1(\hat{\alpha}) \quad (15.a)$$

$$\pi_{II}^{*2}(\hat{\alpha}) = \frac{2b^2 - a^2}{2a} \hat{\alpha}^2 + \frac{a(r - A_2) - b(r - A_1)}{a} \hat{\alpha} \quad (15.b)$$

Using (15.a) and the envelop theorem, we have for Firm 1's profit

$$\frac{d\pi_{II}^{*1}(\hat{\alpha})}{d\hat{\alpha}} = -b\alpha_1(\hat{\alpha}) < 0. \quad (16)$$

That is, the low-cost firm 1's profit monotonically *declines* as the standard is tightened over interval II, although the profit always remains positive over this interval. (See Appendix 1)

The response of firm 2's profit to the standard over this interval is more complicated and, as shown formally in Appendix 2, it depends on  $b/a$ , the degree to which the products are strategic substitutes, on  $(r - A_1)/(r - A_2)$ , the degree of the cost differential of the two firms, and on the sign of the expression  $2b^2 - a^2$ , which determines the curvature of firm 2's profit function. Figure 2 illustrates possible responses of firm 2's profit to the level of the standard in Interval II. As can be seen, there are four possible cases, labeled A, B, C, and D. Figure 3 shows the sets of combinations of  $b/a$  and  $(r - A_1)/(r - A_2)$  values that correspond to each of the four cases (see Appendix 2 for derivations).<sup>12</sup>

One notable result of our analysis can be stated as

Proposition 5: *There is always a sub-range of the mandatory standard level in Interval II for which as the standard is tightened the profit of the high-cost firm 2 increases while that of the low-cost firm 1 always decreases.*

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<sup>12</sup> Notice that the relevant values of  $b/a$  and  $(r - A_1)/(r - A_2)$  are those to the left of the 45-degree line to ensure positive  $\alpha_2^*$  as well as positive corresponding firm 2's profit.



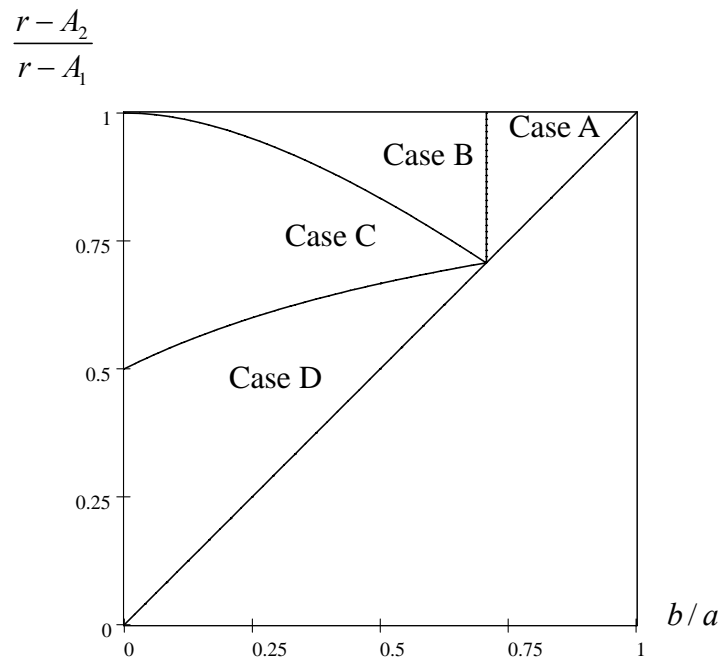
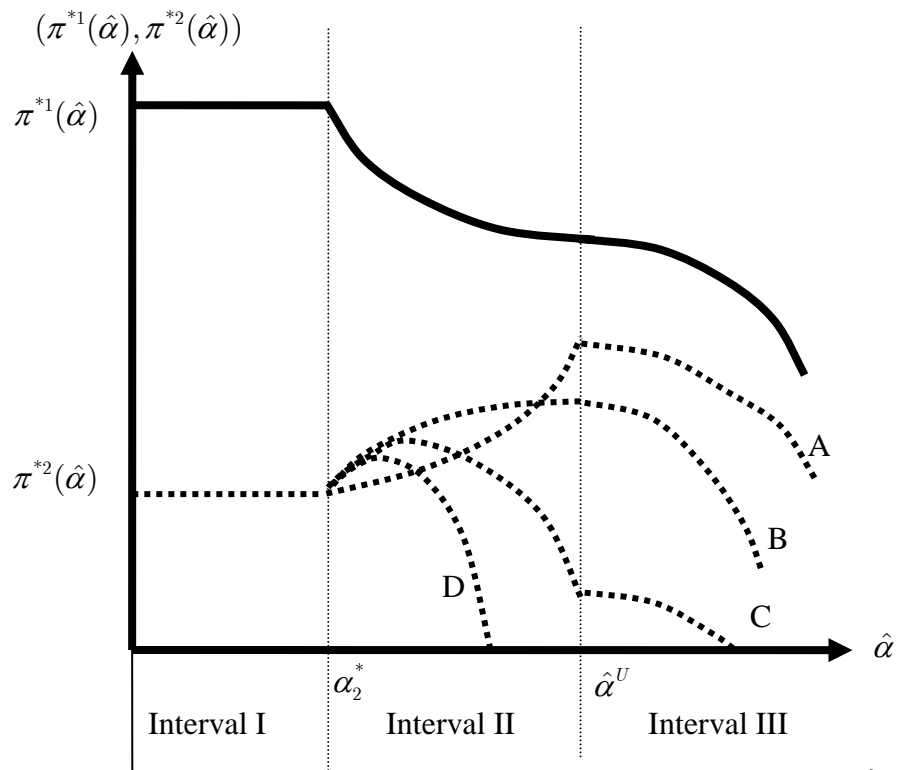


Figure 3: *Classification of the response of firm 2's profit to the standard level in Interval II*

That by raising the environmental standard, the regulator causes the profit of the high-cost firm to increase but that of the low-cost firm to decrease is both interesting and counter intuitive for two reasons. First, it shows that the industrialists' claim that a higher environmental standard reduces a firm's profit is not generally true. Second, following Salop and Shceffman's (1983) argument of "raising the rivals' cost", one may have expected that by raising the environmental cost of the high-cost firm, a more stringent standard should benefit the low-cost firm and not the high-cost one. The explanation for our counter-intuitive and contrasting result is as follows. By mandating a high enough standard ( $\hat{\alpha} > \alpha_2^*$ ), the regulator sends the credible signals to the low-cost firm 1 that the high-cost firm 2 has to, at least, comply with this higher standard. Therefore, contrary to the equilibrium choices over Interval I (or the laissez-fair equilibrium), the low-cost firm 1 can no longer by choosing a much higher standard (and hence a greater environmental differentiation) disadvantage firm 2 to lower its quality below  $\hat{\alpha}$  ( $> \alpha_2^*$ ) and thereby increase its own profit at the expense of firm 2's. In fact, the introduction of a relatively high mandatory standard in Interval II alters the nature of the strategic game of environmental quality competition from a Nash-Cournot one to a game akin to the Stackleberg's leader-follower game in that, by complying with the regulator's standard, firm 2 sets its quality choice at the standard level ( $\alpha_2(\hat{\alpha}) = \hat{\alpha}$ ) and lets firm 1 react to this strategy. As such, firm 1's cost advantage no longer gives it an incentive to choose as high an environmental quality as it would have chosen in the absence of the standard. Consequently, we see that over Interval II, the mandatory standard lowers the degree of environmental differentiation in the market relative to that over Interval I (or the laissez-fair equilibrium) and raises profits of firm 2 while lowering those of firm 1.

The contrast between Salop and Shceffman's (1983) argument and our result derives from the fact that whereas they model the game of quality competition as the Stackleberg's leader-follower variety in which a *low-cost* dominant firm raises the costs for a high-cost competitive fringe, our model characterizes the market as a Nash-Cournot differentiated duopoly in Interval I, and a kind of leader-follower game in interval II *but* with the difference that over

Interval II it is the high-cost, and not the low-cost firm that leads by setting its quality choice at the mandatory standard level and letting the low-cost firm react to it.

Another notable result of our analysis is that

Proposition 6: *The situations where the mandatory standard raises the profits of the high-cost firm 2 over the entire Interval II (Case A and Case B) occur when the two products are highly strategic substitutes (or nearly homogenous,  $b/a$  large) and the cost differential between the two firms is very small  $((r - A_1)/(r - A_2)$  close to one). (See Figure 3)*

The intuition behind this proposition is straightforward: it is precisely under those conditions that the beneficial effect on Firm 2's profits of tightening the standard is the strongest. In the extreme opposite Case D, where the two products are highly differentiated and the cost differential is very large, the favorable effect of a higher standard on firm 2's profit is very weak, thus leading to the possibility of firm 2's profit eventually declining to zero as the standard is raised. Between these extremes is Case C, representing moderate degrees of product differentiation and cost differentials.

Over Interval III, the profits of both firms monotonically decrease as the standard is strengthened, although firm 1's profit always exceed firm 2's profit and eventually falls to zero within the interval (See Appendixes 1 and 3 and Figure 2). This case represents the situation where the environmental pollution caused by the industry is deemed too serious to be left to the firms' voluntary choices of environmental quality levels. As such, by mandating a sufficiently high standard, the regulator trades off the firms' profits for higher environmental quality and hence social welfare. In extremely harmful cases of environmental pollution, the regulator may in fact sets the standard so high as to make the high-cost firm 2 unprofitable or even so high as to force both of the polluting firms out of the market. In such extreme cases, the regulator believes that the social gain from improving environmental quality exceeds the resulting losses of firms' profits and consumers' surplus.

## 4.2 Average environmental quality under the mandatory standard

Of particular interest is the effect of a mandatory environmental standard on the average environmental quality enjoyed by consumers. To examine this effect, we define the actual (or realized) environmental quality as the weighted average of the firms' choices of environmental quality of the products  $(\alpha_1(\hat{\alpha}), \alpha_2(\hat{\alpha}))$  under the regulated regime, where the weights are the shares of firms' outputs in total quantity of the products consumed  $(\bar{q}_1, \bar{q}_2)$ , *i.e.*,

$$\bar{\alpha}(\hat{\alpha}) = \frac{\bar{q}_1 \alpha_1(\hat{\alpha}) + \bar{q}_2 \alpha_2(\hat{\alpha})}{\bar{q}_1 + \bar{q}_2}.$$

We then compare this average with the average quality which would have prevailed in the absence of any standard (*i.e.*, the laissez fair average quality), which is calculated as:

$$\bar{\alpha}_{LF} = \frac{(\bar{q}_1 - \bar{q}_2)(a - b)r - (a\bar{q}_1 - b\bar{q}_2)A_1 + (b\bar{q}_1 - a\bar{q}_2)A_2}{(\bar{q}_1 + \bar{q}_2)(a^2 - b^2)}.$$

Figure 4 presents this comparison for different intervals of the mandatory standard.

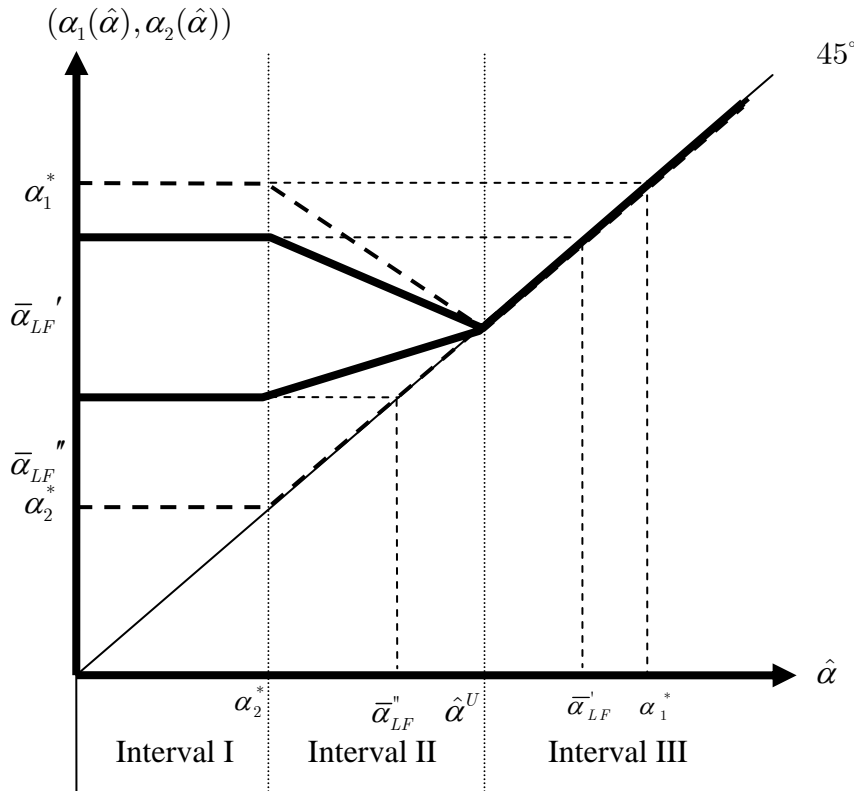


Figure 4: Average environmental quality with and without standard

As can be seen from Figure 4, over Interval I where the environmental standard is relatively weak, the actual average quality in the absence of any regulation would exceed that the mandatory standard. The extent to which the actual average quality would differ from the benchmark (laissez fair) quality depends on whether  $\bar{q}_1 > \bar{q}_2$  as well as on the ratio of  $b/a$ . In Figure 4,  $\bar{\alpha}_{LF}'$  represents the former possibility whereas  $\bar{\alpha}_{LF}''$  denotes the latter case. The solid lines present the actual (or realized) average quality over different intervals of the standard level. In any case, a potential policy implication is that when environmental pollution is not too serious a problem to necessitate very stringent standards, then, as far as average environmental quality is concerned, having no standard at all may serve the society better than imposing a weak standard.

Interestingly, over Interval II, it is ambiguous whether the mandatory standard leads to a higher actual average quality than would be the case under the laissez fair. In fact, it would lead to a *lower* average quality if  $\bar{\alpha}_{LF}' > \hat{\alpha}^U$  (or equivalently,  $b/a > \bar{q}_2/\bar{q}_1$ ). Inversely, it would lead to higher average if  $\bar{\alpha}_{LF}'' < \hat{\alpha}^U$ . Over Interval III, the comparison of the average quality with and without standard is ambiguous too. As long as  $\bar{\alpha}_{LF}' > \hat{\alpha}^U$  and  $\hat{\alpha} < \bar{\alpha}_{LF}'$ , imposing a mandatory standard would *lower* the average environmental quality relative to that under the laissez fair. Together with the similar effect over the interval II, this result cautions the regulator against selecting an environmental standard in the range of

$$[\alpha_2^*, \bar{\alpha}_{LF}'] = \left[ \frac{a(r - A_2) - b(r - A_1)}{a^2 - b^2}, \frac{(\bar{q}_1 - \bar{q}_2)(a - b)r - (a\bar{q}_1 - b\bar{q}_2)A_1 + (b\bar{q}_1 - a\bar{q}_2)A_2}{(\bar{q}_1 + \bar{q}_2)(a^2 - b^2)} \right]$$

However, in Interval III, any standard level such that  $\hat{\alpha} > \bar{\alpha}_{LF}' > \hat{\alpha}^U$  or  $\hat{\alpha} > \hat{\alpha}^U > \bar{\alpha}_{LF}''$  would lead to a higher average environmental quality than would prevail under the laissez fair.

Thus, the behavior of the average environmental quality over Intervals I and II enables us to state the following proposition:

**Proposition 7:** *In a differentiated duopoly, (i) too weak standards will be overridden by the industry's voluntary quality choices, and (ii) for intermediate ranges of the standard, a mandatory standard can lower the average quality below the level that would be voluntarily*

offered by the industry without regulation.

Finally, regardless of the size of  $b/a$  and whether  $\bar{q}_1 \gtrless \bar{q}_2$ , any mandatory standard exceeding  $\alpha_1^* = [a(r - A_1) - b(r - A_2)] / (a^2 - b^2)$  improves the average environmental quality relative to the quality under no standard at all. This explains situations where environmental pollution can be socially a serious problem necessitating sufficiently stringent standards that otherwise firms would not volunteer to adopt.

## 5. Conclusions

In a simple model of a differentiated duopoly industry, we have examined the effects of introducing a mandatory environmental quality standard on the firms' choices of the environmental quality of their products, the firms' profits, and the average environmental quality offered by the industry. We have shown that the effects depend on the degree to which the two products are strategic substitutes, on the firms' environmental costs differential, and critically on the level of the mandatory quality standard.

Specifically, we have shown that at too low standard levels both firms voluntarily overcomply, thus rendering the mandatory standard ineffective and implying that no standard can be better than too weak standards. Interestingly, and contrary to common intuition, we have shown that at the intermediate levels, the mandatory standard can benefit the *high-cost* firm and hurt the *low-cost* one and that it can also lower the average environmental quality offered by the industry. Thus, we have identified the conditions regarding the degrees of product differentiation, the industry's environmental costs differential, and, most importantly, the level of standard setting, under which the regulation of the industry by introducing a mandatory quality standard can result in some unintended effects. Besides alerting regulators to exercise caution in setting the standard level, our results can explain (i) why in situations where environmental quality and reputation of firms matter to consumers, the "greener" firms may prefer voluntary pollution control to a mandatory environmental regulation, and (ii) why environmental advocacy groups cry for strict environmental regulations, fearing that weak standards can alter the behavior of an

otherwise more environmental friendly firm (motivated, of course, to outcompete its rivals) to become less environmental friendly by becoming content with merely complying with the standard.

Obviously, our analysis and the results have been based on a simplified model of the industry, thus suggesting extensions and further research in several important respects. As a natural and straightforward extension, it would be interesting to see whether the main results derived here for a duopoly industry would significantly change if the model is generalized to a differentiated oligopoly. A more important extension will be to allow the environmental-brand producing firms to compete not only by environmental quality differentiation but also in output quantities. The interplay of the firms' quantity and quality strategies could lead to interesting equilibrium possibilities. For example, firms may choose to lower their market share but intensify their environmental quality differentiation or vice versa. Further more, in this paper we have restricted ourselves to a positive analysis of the response of the duopoly to a mandatory environmental standard. In an extension of the model, we introduce social welfare and investigate the regulator's trading off the social welfare gain from a more competitive market with that from a higher quality standard. In such a setting, we investigate the conditions under which the regulator may prefer a low-cost monopoly operating under a relatively high environmental quality to a duopoly industry surviving under a low standard. Another direction for further research would be to combine a model of heterogeneous consumers with different willingness to pay for environmental quality (along the work of Arora and Gangopadhyay (1995)) with the present model of environmental differentiation to examine situations in which each firm may produce both a low and a high quality product to attract both segments of the market, or one in which firms specialize either in low or in high quality product to appeal only to one segment of the market. Finally, of particular value will be to empirically test firms' environmental differentiation as implied by the present analysis.

## Appendix 1. Firm 1's profit in Interval II

Firm1's profit in Interval II,  $\pi_{II}^{*1}(\hat{\alpha})$ , is

$$\pi_{II}^{*1}(\hat{\alpha}) = \max_{\alpha_1 \geq \hat{\alpha}} \pi^1(\alpha_1; \hat{\alpha}) = \pi^1(\alpha_1(\hat{\alpha}), \hat{\alpha}) = \left( \frac{-1}{2} a \alpha_1(\hat{\alpha}) - b \hat{\alpha} + r - A_1 \right) \alpha_1(\hat{\alpha}). \quad (\text{A.1})$$

Applying the envelop theorem, we have

$$\frac{d\pi_{II}^{*1}(\hat{\alpha})}{d\hat{\alpha}} = \frac{\partial \pi^2(\alpha_1(\hat{\alpha}), \hat{\alpha})}{\partial \hat{\alpha}} = -b \alpha_1(\hat{\alpha}) < 0. \quad (\text{A.2})$$

That is, the low-cost firm 1's profit monotonically decreases as the standard is raised.

The minimum profit is attained at  $\hat{\alpha} = \hat{\alpha}^U$ . Since

$$\pi_{II}^{*1}(\hat{\alpha}^U) = \frac{a(r - A_1)}{a + b} \frac{\alpha_1(\hat{\alpha})}{2} > 0, \quad (\text{A.3})$$

we conclude that Firm 1's profit remains positive over Interval II.

## Appendix 2. Firm 2's profit in Interval II

Interval II is defined as  $[\alpha_2^*, \hat{\alpha}^U)$ , where

$$\alpha_2^* = \frac{a(r - A_2) - b(r - A_1)}{a^2 - b^2},$$

and 
$$\hat{\alpha}^U = \frac{r - A_1}{a + b} > \alpha_2^*$$

$\alpha_2^*$  is positive if and only if

$$\frac{b}{a} < \frac{r - A_2}{r - A_1} < 1. \quad (\text{A.4})$$

The firm2's profit in Interval II,  $\pi_{II}^{*2}(\hat{\alpha})$ , is given by

$$\pi_{II}^{*2}(\hat{\alpha}) = \max_{\alpha_2 \geq \hat{\alpha}} \pi(\alpha_2; \alpha_1(\hat{\alpha})) = \pi^2(\hat{\alpha}, \alpha_1(\hat{\alpha})) = \left( \frac{-1}{2} a \hat{\alpha} - b \alpha_1(\hat{\alpha}) + r - A_2 \right) \hat{\alpha} \quad (\text{A.5})$$

By substituting  $\alpha_1(\hat{\alpha}) = \frac{-b\hat{\alpha} + r - A_1}{a}$ , we have

$$\pi_{II}^{*2}(\hat{\alpha}) = \frac{2b^2 - a^2}{2a} \hat{\alpha}^2 + \frac{a(r - A_2) - b(r - A_1)}{a} \hat{\alpha}. \quad (\text{A.6})$$

The second term on the right hand side is always positive by (A.4). Therefore, we have the following four cases:

$$\text{If } 2b^2 - a^2 \geq 0,$$



(Case A):  $\pi_{II}^{*2}(\hat{\alpha}) > 0$  over Interval II. Furthermore, the profit is monotonically increasing in the standard ( $d\pi_{II}^{*2}(\hat{\alpha})/d\hat{\alpha} > 0$ ).

If  $2b^2 - a^2 < 0$ , we classify the following three cases:

(Case B):  $\pi_{II}^{*2}(\hat{\alpha}) > 0$  and  $d\pi_{II}^{*2}(\hat{\alpha})/d\hat{\alpha} > 0$  over Interval II.

(Case C):  $\pi_{II}^{*2}(\hat{\alpha}) > 0$  over Interval II. There is  $\tilde{\alpha}$  in the interval such that

$$d\pi_{II}^{*2}(\hat{\alpha})/d\hat{\alpha} > (<)0 \text{ if } \hat{\alpha} < (>)\tilde{\alpha}.$$

(Case D): There is  $\hat{\alpha}_{II}$  in the interval such that  $\pi_{II}^{*2}(\hat{\alpha}) > 0$  if and only if  $\alpha_2^* \leq \hat{\alpha} < \hat{\alpha}_{II}$ . In this interval, there is  $\tilde{\alpha}$  such that  $d\pi_{II}^{*2}(\hat{\alpha})/d\hat{\alpha} > (<)0$  if  $\hat{\alpha} < (>)\tilde{\alpha}$ .

We next derive the conditions under which each of the four cases occurs. The condition for Case B is

$$0 \leq \frac{d\pi_{II}^{*2}(\hat{\alpha}^U)}{d\hat{\alpha}} = \frac{(a^2 + ab)(r - A_2) - (a^2 + ab - b^2)(r - A_1)}{a}. \quad (\text{A.7})$$

That is, Case B happens if

$$\frac{r - A_2}{r - A_1} \geq \frac{a^2 + ab - b^2}{a^2 + ab} > \frac{b}{a}. \quad (\text{A.8})$$

Notice that the last inequality in (A.8) is equivalent to  $2b^2 - a^2 < 0$ , which is the case we are considering.

The conditions for Case C are

$$\frac{a^2 + ab - b^2}{a^2 + ab} > \frac{r - A_2}{r - A_1} > \frac{b}{a}, \quad (\text{A.9})$$

and

$$\frac{r - A_2}{r - A_1} \geq \frac{a + 2b}{2(a + b)}. \quad (\text{A.10})$$

The latter condition follows from

$$0 \leq \pi_{II}^{*2}(\hat{\alpha}^U) = \left( \frac{2a(a + b)(r - A_2) - (a^2 + 2ab)(r - A_1)}{2(a + b)} \right) \frac{\hat{\alpha}^U}{a}. \quad (\text{A.11})$$

Putting (A.9) and (A.10) together, Case C occurs if

$$\frac{a^2 + ab - b^2}{a^2 + ab} > \frac{r - A_2}{r - A_1} \geq \frac{a + 2b}{2(a + b)} > \frac{b}{a}. \quad (\text{A.12})$$

Notice that the last inequality in (A.4) is equivalent to  $2b^2 - a^2 < 0$ , which holds for the case under consideration.

Finally, Case D happens if

$$\frac{a+2b}{2(a+b)} > \frac{r-A_2}{r-A_1} > \frac{b}{a}. \quad (\text{A.13})$$

$$\hat{\alpha}_{II} = \frac{a(r-A_2) - b(r-A_1)}{(1/2)a^2 - b^2} \left( < \hat{\alpha}^U = \frac{r-A_1}{a+b} \text{ if } \frac{r-A_2}{r-A_1} < \frac{a+2b}{2(a+b)} \right) \quad (\text{A.14})$$

### Appendix 3. Firms' profits in Interval III

In Interval III, firm  $i$ 's profit is

$$\pi_{III}^{*i}(\hat{\alpha}) = \max_{\alpha_i \geq \hat{\alpha}} \pi^i(\alpha_i; \hat{\alpha}) = -\frac{1}{2}a(\hat{\alpha})^2 - b(\hat{\alpha})^2 + (r-A_i)\hat{\alpha}, \quad \hat{\alpha} \geq \hat{\alpha}^U. \quad (\text{A.15})$$

Since  $\pi_{III}^{*i}(\hat{\alpha})$  is a concave function,

$$\frac{d\pi_{III}^{*1}(\hat{\alpha}^U)}{d\hat{\alpha}} = -\frac{a+2b}{a+b}(r-A_1) + (r-A_1) = \frac{-b(r-A_1)}{a+b} < 0,$$

and

$$\frac{d\pi_{III}^{*2}(\hat{\alpha}^U)}{d\hat{\alpha}} = -\frac{a+2b}{a+b}(r-A_1) + (r-A_2) = \frac{(a+b)(r-A_2) - (a+2b)(r-A_1)}{a+b} \hat{\alpha}^U < 0,$$

imply that both firms' profits are monotonically decreasing over Interval III. Notice that before firm 1's profit goes to zero, the rival's profit has already dropped to zero, since  $A_1 < A_2$ .

For Firm 2 to be operative over Interval III its profit at the standard level  $\hat{\alpha}^U$  has to be nonnegative:

$$\pi_{III}^{*2}(\hat{\alpha}^U) = \left[ -\frac{a+2b}{2} \frac{r-A_1}{a+b} + (r-A_2) \right] \hat{\alpha}^U = \frac{2(a+b)(r-A_2) - (a+2b)(r-A_1)}{2(a+b)} \hat{\alpha}^U \geq 0.$$

Combining this condition with the positivity condition of  $\alpha_2^*$  ((A.4)), we have

$$\frac{r-A_2}{r-A_1} \geq \max \left[ \frac{a+2b}{2(a+b)}, \frac{b}{a} \right]. \quad (\text{A.16})$$

Under condition (A.16), there is a unique ceiling of the standard on Interval III, at which Firm 2's profit is zero. This ceiling, denoted by  $\hat{\alpha}_{III}$ , is given by

$$\hat{\alpha}_{III} = \frac{r-A_2}{(1/2)a+b} \left( \geq \hat{\alpha}^U = \frac{r-A_1}{a+b} \text{ if } \frac{r-A_2}{r-A_1} \geq \frac{a+2b}{2(a+b)} \right). \quad (\text{A.17})$$

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