Environmental Product Differentiation: Eco-labels and Environmental Awareness

Roberto Rodriguez-Ibeas*
Universidad de La Rioja

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Abstract

In this paper, we have considered a simple duopolistic model of environmental product differentiation to analyze how pollution changes when the population of ecological consumers increases. The model captures in a simple way the following stylized facts: 1) some consumers are willing to pay a premium for enviromental quality; 2) enviromental quality is a "credence" good, and therefore, it can not be directly observed by consumers, even after purchase and 3) consumers rely on eco-labeling to assess environmental quality. We find that more environmental awareness may not be good news for the environment as more pollution is generated. In particular, when the degree of product differentation is not large enough, sales by the non ecological firm increases and so does the level of pollution.

Key words: Eco-labels, Ecological Consumers, Pollution

*Departamento de Economía y Empresa. Universidad de La Rioja. Logroño-26004 (Spain). Tel.: +34 941 299 397, Fax: +34 941 299 393. E-mail address: roberto.rodriguez@dee.unirioja.es

1 Introduction

Over the last decade environmental awareness has been growing up in developed economies. There is evidence that some consumers care about the environment and are willing to pay a premium for products manufactured by methods friendly to the environment.[1] However, environmental attributes are observable neither before nor after purchasing and consuming the goods. Products whose attibutes are not ex-post verifiable have been called "credence goods".[2] Even ex-post, consumers are unable to perceive whether the product is ecological or not. Environmental claims by firms have then become a widely used marketing strategy. Firms try to environmentally differentiate their products to attract consumers who are willing to pay a higher price. However, "green" claims by firms are not credible. One way of signalling that products have been produced according to some ecological criteria is third-party certification of environmental quality. These "eco-label" programs are voluntary, and typically, run by governement agencies.[3] The so-called "seal-of-approval" programs award or license the use of a logo to products that the program considers to generate less environmental damage.[4]

From the perspective of the firms, applying for an eco-label may be valuable as they may gain market share and increase their profits. At he same time, eco-labels can be used to improve the environmental quality of products[5] The attractiveness of the eco-label for a firm depends on several factors, namely the number of rivals awarded the label, the size of the population who value the environment, the cost of obtaining the eco-label and the

[1]A 1996 survey in France found that 54 per cent of the households would be willing to pay up to 10 per cent more for ecological products. (EPA 1998) Similar surveys in other countries show evidence of the existence of consumers willing to pay a premium for environmental sound products.

[2]Darbi and Karni (1973) coined the name to refer to goods whose attibutes were not verifiable even after consumption.

[3]A exception is the U. S., where the main programs are run by private companies.

[4]The oldest program is Germany's Blue Angel. There are environmental labeling programs in 29 countries (EPA 1998).

[5]Cason and Gangadharan (2002) found that eco-labels were the only reliable way to improve product quality when consumers lacked information about environmental quality. Teisl, Roe and Hicks (2002) found evidence that consumers responded to eco-labels in the tuna market.

premium consumers are willing to pay for labeled products. It has been argued that eco-labeling may be used as a policy tool instead of command-and-control regulation, although its effectiveness has not been throughly studied (EPA 1998). An exception is Mattoo and Singh (1994) that warned against the use of eco-labels as they could lead to an adverse effect on the environment by increasing the sales of products made by environmental unfriendly methods.

Eco-label programs help consumers evaluate the environmental attibutes of the product they buy, shifting the market towards products that minimize the environmental impact. At the same time, they educate consumers on environmental values as it is taken for granted that the more consumers care for the environment, the less pollution will be generated. In this paper, we consider a duopoly model of environmental product differentiation to analyze whether this assertion holds or not. The model captures the main features of a market with eco-labels and consumers who care for the environment. In our model, the use of eco-labels as a tool to differentiate products is good for the environment. In that sense, we depart from Mattoo and Singh (1994). The model, formally, is close to that by Moraga-González and Padrón-Fumero (2002), although they consider that environmental quality is observable and focus on the determination of environmental quality. [6]We model eco-labels as the mechanism through which firms signal perfectly environmental quality to consumers.[7]We have two different kind of consumers. Ecological consumers care for the environment and they are willing to pay a higher price for an environmental sound product. Non-ecological consumers do not value environmental quality. We are interested in analyzing the impact on pollution when the size of the population of ecological consumers increases. Intuition tells us that we should expect a reduction in the level of pollution when more consumers care for the environment. We show in a simple model that the intuition can be misleading. We find the counterintuitive result that pollution emissions can be higher.

The paper is structured as follows: section 2 describes the model. Section

[6]Arora and Gangopadhyay (1995) also consider a similar model of environmental product differentiation with observable quality.

[7]Kirchhoff (2000), in a two period model, analyzes the role played by eco-labeling programs as random monitoring mechanisms to check firms' environmental claims. A firm providing high environmental quality is unable to signal its quality unless it is monitored. Our model is different in the sense that when a firm is awarded the eco-label, the consumers knows that the firm is providing high environmental quality.

3 characterizes the equilibrium prices. In section 4 we analyze how pollution changes when the population of ecological consumers varies. Section 5 concludes.

2 The model

We consider a duopoly model in which the firms can environmentally differentiate their products. The firms can voluntarily participate in an exogenous certification program run by an independent third party. If the firm uses a production technology friendly to the environment, it is granted an ecolabel.[8] There is a continuum of consumers, each of which buys, at most, one unit of the good. Let θs_l be the valuation of the good by the consumers if the firm does have the ecolabel, where s_l denotes quality and θ represents the marginal valuation of quality. We assume that θ is uniformly distributed on the interval $[0, 1]$. For each θ, a proportion $\alpha \in (0, 1)$ are ecological consumers who care for the environment. These consumers are willing to pay a higher price if the firm has been granted the ecolabel. Let θs_h be their valuation of the good, where $s_h > s_l$. Adopting the ecolabel is costly. Let the marginal cost of a firm that has been granted the ecolabel be $c > 0$.[9] For simplicity, we assume that the marginal cost is zero if the firm does not adopt the ecolabel. Each unit of the product generates one unit of pollution unless the firm has the ecolabel. Implicitly, we assume that monitoring is perfect, and the firm, once certificated as ecological, produces with a technology that does not pollute. Before buying, consumers observe which firm(s) has (have) the ecolabel and take their purchasing decision. If one firm only obtains the eco-label, product quality differs accross firms, at least for the ecological consumers. They are willing to pay a premium for higher quality. For the non-ecological consumers, the product is homogeneous and they buy from the firm whose price is lower. We assume that $\Delta s = s_h - s_l > c$ and $s_h > c$.

[8] We do not model the process by which the eco-label is granted. We implicitly assume that, in order to apply for the eco-label, the firm must adopt, irreversibly, a production technology that complies with the environmental standard specified in the certification program.

[9] When a firm participates in a certification program, it has to pay a fee. Once granted the eco-label, marginal costs are larger as the firm produces with a less-polluting technology. Including the fee in the model does not change the results.

We consider a two-stage game. In the first stage, firms simultaneously decide whether to apply for the ecolabel. In the second stage, they choose simultaneously the prices. Given the specification of the problem, in equilibrium, there is only one firm that adopts the ecolabel, say firm 1. Note that if both firms adopt the ecolabel, the product is homogeneous, and profits are zero. Besides that, in equilibrium, firm 1 must charge a higher price $p_1 > p_2$. Otherwise, firm 2 has incentives to deviate as nobody buys from firm 2 if $p_1 < p_2$. Also, $p_1 = p_2$ can not be an equilibrium as firm 1 has incentive to deviate and charge less than firm 2.

Let us first derive the firms' demands. Given (p_1, p_2) with $p_1 > p_2$, the indifferent ecological consumer has a marginal valuation for environmental quality $\hat{\theta}$ that satisfies:

$$\hat{\theta} s_h - p_1 = \hat{\theta} s_l - p_2$$

Therefore, $\hat{\theta} = \dfrac{p_1 - p_2}{\Delta s}$. Consumers with $\theta > \hat{\theta}$ buy from firm 1 if they are ecological and from firm 2 if they are non-ecological.[10] Consumers with $\theta < \hat{\theta}$ buy as long as $\theta s_l - p_2 \geq 0$. Let $\underline{\theta} = \dfrac{p_2}{s_l}$ be the marginal valuation of the consumer indifferent between buying from firm 2 or not buying. Note that $\hat{\theta} \geq \underline{\theta}$ if $p_1 s_l \geq p_2 s_h$. If $p_1 s_l < p_2 s_h$, the ecological consumer with parameter $\hat{\theta}$ does not buy as $\hat{\theta} s_h - p_1 = \hat{\theta} s_l - p_2 < \underline{\theta} s_l - p_2 = 0$. Let $\tilde{\theta} = \dfrac{p_1}{s_h}$. Ecological consumers with $\theta \geq \tilde{\theta}$ buy from firm 1. Therefore, firm 1's demand is given by:

$$D_1(p_1, p_2, \alpha) = \begin{cases} \alpha\left(1 - \hat{\theta}\right) = \alpha\left(\dfrac{\Delta s - p_1 + p_2}{\Delta s}\right) & if\ p_1 \geq \dfrac{p_2 s_h}{s_l} \\ \alpha\left(1 - \tilde{\theta}\right) = \alpha\left(\dfrac{s_h - p_1}{s_h}\right) & if\ p_1 < \dfrac{p_2 s_h}{s_l} \end{cases}$$

Firm 1 sells only to ecological consumers. Note that they get a positive surplus if $p_1 s_l \geq p_2 s_h$. Firm 2's demand is given by:

$$D_2(p_1, p_2, \alpha) = \begin{cases} (1-\alpha)\left(1 - \hat{\theta}\right) + \left(\hat{\theta} - \underline{\theta}\right) & if\ p_2 \leq \dfrac{p_1 s_l}{s_h} \\ (1-\alpha)\left(1 - \underline{\theta}\right) & if\ p_2 < \dfrac{p_1 s_l}{s_h} \end{cases}$$

[10] As non ecological consumers do not value environmental quality they buy from firm 2 as its price is lower.

Some ecological consumers buy from firm 2 when p_1 is too high. When p_1 is low enough, the firm 2 only sells to non ecological consumers. Although $p_1 > p_2$, the higher environmental quality offsets paying a higher price.

Let us now find the firms' best response functions. Given p_2, firm 1 chooses p_1 to maximize its profits: max $(p_1 - c) D_1(p_1, p_2, \alpha)$. When $p_1 \geq \frac{p_2 s_h}{s_l}$, a solution for this problem is given by $\frac{\Delta s + p_2 + c}{2}$, as long as $p_2 \leq \frac{s_l(\Delta s + c)}{\Delta s + s_h}$. If $p_2 > \frac{s_l(\Delta s + c)}{\Delta s + s_h}$, we have a corner solution at $\frac{p_2 s_h}{s_l}$ as firm 1's profit function is strictly decreasing in p_1. For $p_1 < \frac{p_2 s_h}{s_l}$, an interior solution is $\frac{s_h + c}{2}$ as long as $p_2 > \frac{s_l(s_h + c)}{2 s_h}$. For $p_2 \leq \frac{s_l(s_h + c)}{2 s_h}$, we have a corner solution at $\frac{p_2 s_h}{s_l}$ as firm 1's profit function is strictly increasing in p_1. Note that $\frac{s_l(\Delta s + c)}{\Delta s + s_h} < \frac{s_l(s_h + c)}{2 s_h}$.

Lemma 1 *Firm* 1*'s best response function is given by:*

$$p_1(p_2) = \begin{cases} \dfrac{\Delta s + p_2 + c}{2} & if\ p_2 \leq \dfrac{s_l(\Delta s + c)}{\Delta s + s_h} \\ p_2 \dfrac{s_h}{s_l} & if\ p_2 \in \left(\dfrac{s_l(\Delta s + c)}{\Delta s + s_h}, \dfrac{s_l(s_h + c)}{2 s_h} \right] \\ \dfrac{s_h + c}{2} & if\ p_2 > \dfrac{s_l(s_h + c)}{2 s_h} \end{cases} \qquad (1)$$

Proof. *If* $p_2 \leq \frac{s_l(\Delta s + c)}{\Delta s + s_h}$, *we have two candidates for firm* 1*'s best response:* $\frac{\Delta s + p_2 + c}{2}$ *and* $\frac{p_2 s_h}{s_l}$. *Evaluating firm* 1*'s profit function at each candidate yields:*

$$\pi_1\left(\frac{\Delta s + p_2 + c}{2}, p_2, \alpha\right) = \frac{\alpha(\Delta s + p_2 - c)^2}{4\Delta s}$$
$$\pi_1\left(\frac{p_2 s_h}{s_l}, p_2, \alpha\right) = \alpha\left(\frac{p_2 s_h - s_l c}{s_l}\right)\left(\frac{s_l - p_2}{s_l}\right)$$

At $p_2 = \frac{s_l(\Delta s + c)}{\Delta s + s_h}$, *both profits levels are equal. When* $p_2 = 0$, *firm* 1*'s best response is to choose* $\frac{\Delta s + c}{2}$. *As both profit functions are strictly* *increasing in* p_2 *for this range, it follows that* $p_1(p_2) = \dfrac{\Delta s + p_2 + c}{2}$. *For* $p_2 \in \left(\dfrac{s_l(\Delta s + c)}{\Delta s + s_h}, \dfrac{s_l(s_h + c)}{2s_h}\right]$, *the above analysis implies that* $p_1(p_2) = \dfrac{p_2 s_h}{s_l}$. *Finally, for* $p_2 > \dfrac{s_l(s_h + c)}{2s_h}$, *we have two candidates:* $\dfrac{s_h + c}{2}$ *and* $\dfrac{p_2 s_h}{s_l}$. *Note that for* $p_2 = \dfrac{s_l(s_h + c)}{2s_h}$, *both candidates coincide, and so do firm* 1*'s profits. As* $\pi_1\left(\dfrac{s_h + c}{2}, p_2, \alpha\right) = \dfrac{\alpha(s_h - c)^2}{4s_h}$ *and* $\pi_1\left(\dfrac{p_2 s_h}{s_l}, p_2, \alpha\right)$ *is strictly decreasing in* p_2 *for this range, it follows that* $p_1(p_2) = \dfrac{s_h + c}{2}$. ■

Let us now derive firm 2's best response function. Given p_1, firm 2 chooses p_2 to maximize its profits. If $\dfrac{p_1 s_l}{s_h} \geq p_2$, firm 2 solves

$$\max p_2 D_2(p_1, p_2, \alpha) = p_2 \left(\frac{(1-\alpha) s_l (\Delta s - p_1 + p_2) + p_1 s_l - p_2 s_h}{s_l \Delta s}\right)$$

where the expression for firm 2' demand is obtained after plugging $\hat{\theta}$ and $\underline{\theta}$ into $D_2(p_1, p_2, \alpha)$. Let $\hat{p}_2(p_1, \alpha)$ denote the solution for this problem. Then:

$$\hat{p}_2(p_1, \alpha) = \frac{s_l[(1-\alpha)\Delta s + \alpha p_1]}{2(\Delta s + \alpha s_l)}$$

as long as $p_1 \geq \tilde{p}_1(\alpha)$, where $\tilde{p}_1(\alpha) = \dfrac{s_h(1-\alpha)\Delta s}{(2-\alpha)\Delta s + \alpha s_l}$. Note that $\tilde{p}_1(\alpha) < \dfrac{s_h}{2}$ $\forall \alpha > 0$ and $\tilde{p}_1(0) = \dfrac{s_h}{2}$. If $p_1 < \tilde{p}_1(\alpha)$, we have a corner solution $p_2 = \dfrac{p_1 s_l}{s_h}$ as the objective function is strictly increasing in p_2. For $\dfrac{p_1 s_l}{s_h} < p_2$, firm 2 solves $\max p_2 D_2(p_1, p_2, \alpha) = p_2(1-\alpha)\left(\dfrac{s_l - p_2}{s_l}\right)$. An interior solution is given by $\dfrac{s_l}{2}$ as long as $p_1 < \dfrac{s_h}{2}$. For $p_1 \geq \dfrac{s_h}{2}$, we have a corner solution at $p_2 = \dfrac{p_1 s_l}{s_h}$ as the objective function is strictly decreasing in p_2 in the relevant range.

Lemma 2 *Firm* 2*'s best response function is given by:*

$$p_2(p_1,\alpha) = \begin{cases} \dfrac{s_l}{2} & if\ p_1 < \bar{p}_1(\alpha) \\ \hat{p}_2(p_1,\alpha) & if\ p_1 \geq \bar{p}_1(\alpha) \end{cases} \qquad (2)$$

where $\bar{p}_1(\alpha)$ satisfies $(1-\alpha)(s_h - 2\bar{p}_1(\alpha))\Delta s - \alpha^2 \bar{p}_1^2(\alpha) = 0$.
Proof. For $p_1 < \tilde{p}_1(\alpha)$, we have two candidates for best response: $\dfrac{p_1 s_l}{s_h}$ and $\dfrac{s_l}{2}$. Firm 2's profits at each candidate are:

$$\pi_2\left(p_1, \frac{p_1 s_l}{s_h}, \alpha\right) = (1-\alpha)\frac{p_1 s_l}{s_h}\left(\frac{s_h - p_1}{s_h}\right)$$
$$\pi_2\left(p_1, \frac{s_l}{2}, \alpha\right) = (1-\alpha)\frac{s_l}{4}$$

When $p_2 = \dfrac{s_h}{2}$, both profits levels are equal. As $\pi_2\left(p_1, \dfrac{p_1 s_l}{s_h}, \alpha\right)$ is strictly increasing in p_1 for this range and $\tilde{p}_1(\alpha) < \dfrac{s_h}{2}$, it follows that $p_2(p_1,\alpha) = \dfrac{s_l}{2}$ for $p_1 < \tilde{p}_1(\alpha)$. For $p_1 \in \left[\tilde{p}_1(\alpha), \dfrac{s_h}{2}\right)$, we have two candidates for best response: $\dfrac{s_l}{2}$ and $\hat{p}_2(\alpha)$. After some algebra, we have:

$$\pi_2\left(p_1, \frac{s_l}{2}, \alpha\right) - \pi_2(p_1, \hat{p}_2(\alpha), \alpha) = \frac{\alpha\left[(1-\alpha)(s_h - 2p_1)\Delta s - \alpha^2 p_1^2\right]}{2\Delta s(\Delta s + \alpha s_l)}$$

It can be shown that $(1-\alpha)(s_h - 2\tilde{p}_1(\alpha))\Delta s - \alpha^2 \tilde{p}_1(\alpha)^2 > 0$. As the numerator of the above expression is negative for $p_1 = \dfrac{s_h}{2}$, it follows that $\exists\ \bar{p}_1(\alpha) \in (\tilde{p}_1(\alpha), \dfrac{s_h}{2})$ such that for $p_1 \in [\tilde{p}_1(\alpha), \bar{p}_1(\alpha))$, firm 2's best response is given by $\dfrac{s_l}{2}$ and for $p_1 \in \left[\bar{p}_1(\alpha), \dfrac{s_h}{2}\right)$, the best response is $\hat{p}_2(p_1,\alpha)$. Finally, for $p_1 \geq \dfrac{s_h}{2}$, we have two candidates for best response: $\dfrac{p_1 s_l}{s_h}$ and $\hat{p}_2(p_1,\alpha)$. Clearly, $\pi_2(\dfrac{s_h}{2}, \dfrac{s_l}{2}, \alpha) < \pi_2\left(\dfrac{s_h}{2}, \hat{p}_2(p_1,\alpha), \alpha\right)$. As $\pi_2\left(p_1, \dfrac{p_1 s_l}{s_h}, \alpha\right)$is strictly decreasing in p_1, it follows that $\pi_2\left(p_1, \dfrac{p_1 s_l}{s_h}, \alpha\right) < \pi_2\left(p_1, \dfrac{s_l}{2}, \alpha\right) < \pi_2(p_1, \hat{p}_2(p_1,\alpha), \alpha)$. Thus, for $p_1 \geq \dfrac{s_h}{2}$, firm 2's best response is $\hat{p}_2(p_1,\alpha)$. ■

3 The equilibrium

Once we have characterized both best response functions, we are ready to determine the equilibrium prices. A pair of prices $(p_1^*(\alpha), p_2^*(\alpha))$ constitutes an equilibrium of the game if

$$\begin{aligned} p_1^*(\alpha) &= p_1(p_2^*(\alpha)) \\ p_2^*(\alpha) &= p_2(p_1^*(\alpha)) \end{aligned}$$

Proposition 1
Let $2c \geq s_l$. Then, $\forall\alpha$, the unique equilibrium of the game is:

$$p_1^*(\alpha) = \frac{s_l[(1-\alpha)\Delta s + 2\alpha(\Delta s + c)] + 2\Delta s(\Delta s + c)}{4\Delta s + 3\alpha s_l} \tag{3.a}$$

$$p_2^*(\alpha) = \frac{s_l[2(1-\alpha)\Delta s + \alpha(\Delta s + c)]}{4\Delta s + 3\alpha s_l} \tag{3.b}$$

Proof. *When $2c \geq s_l$, it follows that $\frac{s_l}{2} < \frac{s_l(\Delta s + c)}{\Delta s + s_h}$. Note that $p_2^*(\alpha) < \frac{s_l(\Delta s + c)}{\Delta s + s_h}$ $\forall\alpha$ as*

$$p_2^*(\alpha) - \frac{s_l(\Delta s + c)}{\Delta s + s_h} = \frac{\Delta s[(1-\alpha)(s_l - 2c) - s_h\alpha] - cs_h(2-\alpha)}{(\Delta s + s_h)(4\Delta s + 3\alpha s_l)}$$

By plugging $p_2^*(\alpha)$ into the firm 1's best response function given in (1) we have $p_1(p_2^*(\alpha)) = \frac{\Delta s + p_2^*(\alpha) + c}{2} = p_1^*(\alpha)$.

Note that $p_1^*(\alpha) < \frac{s_h(\Delta s + c)}{\Delta s + s_h}$ $\forall\alpha$ as

$$p_1^*(\alpha) - \frac{s_h(\Delta s + c)}{\Delta s + s_h} = \frac{\Delta s(s_l - 2c) + s_h\alpha(c - s_h) - \alpha s_l(2c - s_l)}{(\Delta s + s_h)(4\Delta s + 3\alpha s_l)}$$

It remains to show that $p_1^*(\alpha) \geq \bar{p}_1(\alpha)$ as $p_2^*(\alpha) = p_2(p_1^*(\alpha))$. It suffices to show that $p_1\left(\frac{s_l}{2}\right) > \frac{s_h}{2}$ as this implies that the horizontal segment of the firm 2's best response function does not cross firm 1's best response. As $p_1\left(\frac{s_l}{2}\right) = \frac{\Delta s + \frac{s_l}{2} + c}{2} = \frac{2s_h + 2c - s_l}{4}$, it follows that $p_1\left(\frac{s_l}{2}\right) - \frac{s_h}{2} = \frac{2c - s_l}{4} > 0$. ■

The equilibrium of the game is depicted in Fig. 1 below.

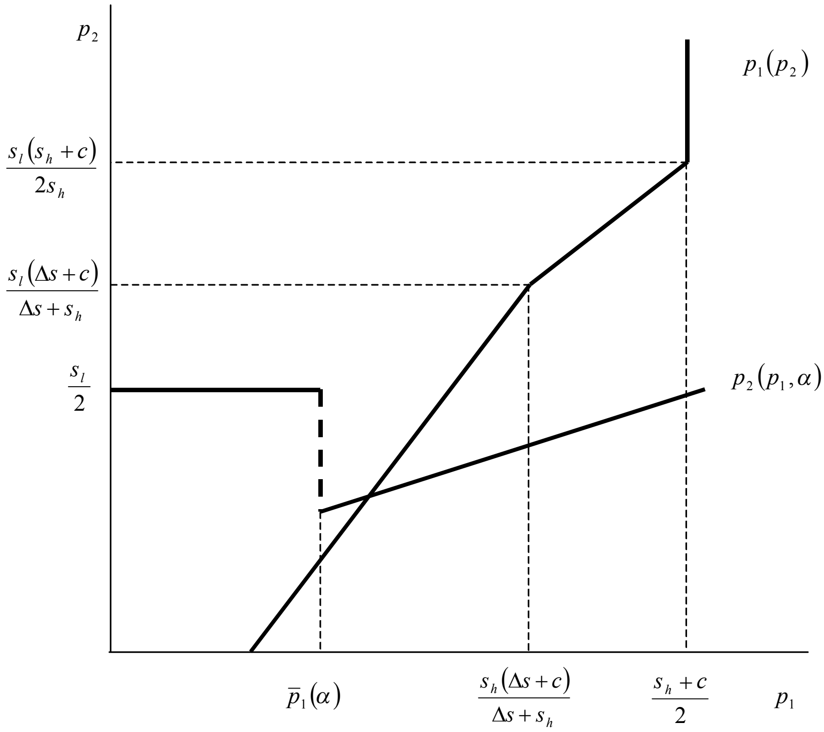

Fig. 1: The equilibrium when $2c \geq s_l$.

From the expressions for the equilibrium prices, it follows that $p_1^*(\alpha) > p_2^*(\alpha)$. In equilibrium:

$$\hat{\theta}(\alpha) = \frac{(\Delta s + c)(2\Delta s + \alpha s_l) - s_l \Delta s (1-\alpha)}{\Delta s(4\Delta s + 3\alpha s_l)} \tag{4.a}$$

$$\underline{\theta}(\alpha) = \frac{\alpha(\Delta s + c) + 2\Delta s(1-\alpha)}{4\Delta s + 3\alpha s_l} \tag{4.b}$$

Note that $\hat{\theta} \in (0,1)$ and $\hat{\theta} > \underline{\theta}$. Although the ecological consumers value environmental quality, $p_1^*(\alpha)$ is too high, and some ecological consumers prefer to buy from firm 2. It can be shown that $\hat{\theta}(\alpha)$ increases with α and $\underline{\theta}(\alpha)$ decreases with α:

$$\frac{d\hat{\theta}(\alpha)}{d\alpha} = \frac{s_l\ [2(\Delta s - c) + 3s_l]}{(4\Delta s + 3\alpha s_l)^2} \tag{5.a}$$

$$\frac{d\underline{\theta}(\alpha)}{d\alpha} = -\frac{2\Delta s\ [2(\Delta s - c) + 3s_l]}{(4\Delta s + 3\alpha s_l)^2} \tag{5.b}$$

As environmental awareness grows, the marginal valuation of the indifferent ecological consumer increases. The proportion of ecological consumers gets larger but $\left(1-\hat{\theta}(\alpha)\right)$ is reduced. Alternatively, both equilibrium prices decrease with α. The more environmental awareness, the less competition between the firms. The difference between the equilibrium prices is larger as α increases. An increase in the proportion of ecological consumers mitigates competition as product differentiation becomes more important. The value of the ecolabel as a mechanism to differentiate both goods increases as more consumers become ecological. However, less competition does not lead to increases in equilibrium prices as in the standard models of product differentiation due to the existence of two types of consumers. Note also that agregate sales are bigger as α increases.

We have assumed in Proposition 1 that $2c \geq s_l$. Let us now assume that $2c < s_l$. The marginal cost of producing environmental quality is relatively small. The pair of prices given in Proposition 1 is no longer the equilibrium of the game $\forall\alpha$. When $2c < s_l$, it follows that $\frac{s_l}{2} > \frac{s_l(\Delta s + c)}{\Delta s + s_h}$. Let $\hat{\alpha} = \frac{\Delta s(s_l - 2c)}{\Delta s(s_l - 2c) + s_h(\Delta s + c)}$. Note that the equilibrium prices in Proposition 1 when they are evaluated at $\hat{\alpha}$ are $p_1^*(\hat{\alpha}) = \frac{s_h(\Delta s + c)}{\Delta s + s_h}$ and $p_2^*(\hat{\alpha}) = \frac{s_l(\Delta s + c)}{\Delta s + s_h}$. As both prices decrease with α, we have that they are the equilibrium of the game for $\alpha \geq \hat{\alpha}$. When $\alpha < \hat{\alpha}$, the equilibrium of the game is given by the solution to:

$$\begin{aligned} p_1 &= \frac{p_2 s_h}{s_l} \\ p_2 &= \frac{s_l\left[(1-\alpha)\Delta s + \alpha p_1\right]}{2(\Delta s + \alpha s_l)} \end{aligned}$$

After solving these equations, we have that the equilibrium of the game for $\alpha < \hat{\alpha}$ is $\left(\frac{s_h(1-\alpha)\Delta s}{2(\Delta s + \alpha s_l) - \alpha s_h}, \frac{s_l(1-\alpha)\Delta s}{2(\Delta s + \alpha s_l) - \alpha s_h}\right)$. Figure 3 below depicts this equilibrium.

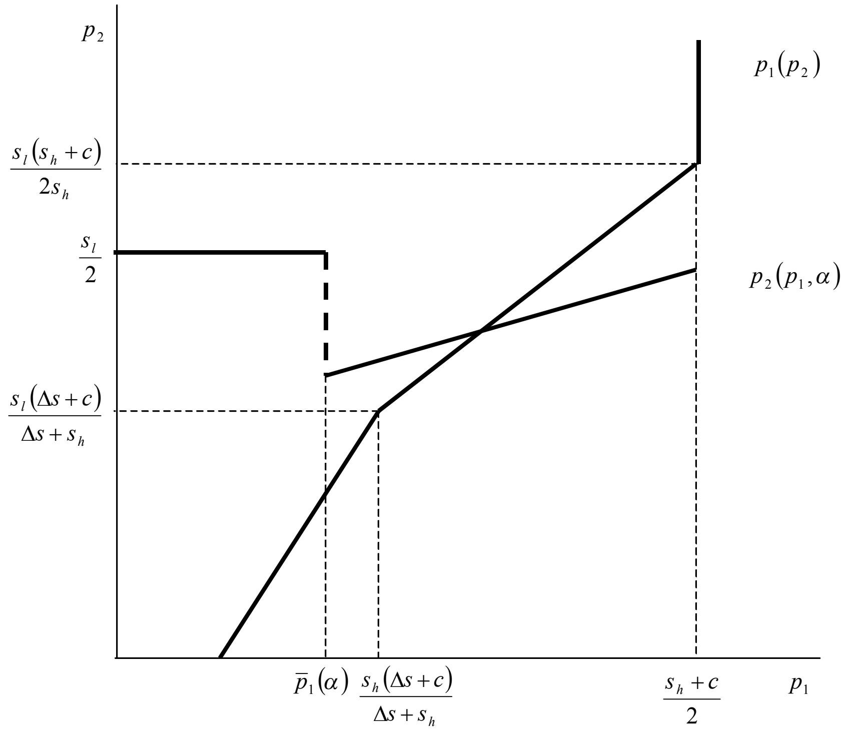

Fig. 2. The equilibrium for $\alpha < \hat{\alpha}$ when $s_l > 2c$.

When $\alpha < \hat{\alpha}$, firm 2's best response crosses firm 1's best response at $p_1 \in \left(\frac{s_h(\Delta s + c)}{\Delta s + s_h}, \frac{s_h + c}{2}\right)$. This drastically differs from the situation in Proposition 1, where firm 2's best response crossed firm 1's best response at $p_1 < \frac{s_h(\Delta s + c)}{\Delta s + s_h}$ $\forall\alpha$. Note that for $\alpha < \hat{\alpha}$, $\hat{\theta}(\alpha) = \underline{\theta}(\alpha) = \frac{(1-\alpha)\Delta s}{2(\Delta s + \alpha s_l) - \alpha s_h}$. Ecological consumers buy from firm 1 and non-ecological consumers buy from firm 2.

4 Environmental awareness and pollution

We are interested in analyzing the effect of an increase in α in the pollution level. Let us start with the case $2c \geq s_l$. In our model, pollution is equivalent to firm 2's equilibrium demand:

$$q_2^*(\alpha) = D_2(p_1^*(\alpha), p_2^*(\alpha), \alpha) = \left(1 - \hat{\theta}(\alpha)\right)(1-\alpha) + \left(\hat{\theta}(\alpha) - \underline{\theta}(\alpha)\right) \quad (6)$$

There are two effects. On the one hand, as α increases, $\hat{\theta}(\alpha) - \underline{\theta}(\alpha)$ is bigger. Some ecological consumers switch from firm 1 to firm 2. Besides these, there are some consumers (ecological and non ecological) who now buy from firm 2. On the other hand, firm 2 sells to fewer no ecological consumers with high marginal valuation for the good as $\left(1 - \hat{\theta}(\alpha)\right)(1-\alpha)$ is smaller. It is not clear which effect dominates. In order to see how pollution level changes with α we need some preliminary results that are presented in the next lemmas.

Lemma 3 *Firm 2's equilibrium demand is a concave function of α.*

Proof. From (6), it follows:

$$\frac{d^2 q_2^*(\alpha)}{d\alpha^2} = -\frac{d^2\underline{\theta}(\alpha)}{d\alpha^2} + 2\frac{d\hat{\theta}(\alpha)}{d\alpha} + \alpha\frac{d^2\hat{\theta}(\alpha)}{d\alpha^2}$$

By differentiating $(5.a)$ and $(5.b)$ we get:

$$\begin{aligned}
\frac{d^2\underline{\theta}(\alpha)}{d\alpha^2} &= \frac{12 s_l \Delta s\left[3s_l + 2(\Delta s - c)\right]}{(4\Delta s + 3\alpha s_l)^3} > 0 \\
\frac{d^2\hat{\theta}(\alpha)}{d\alpha^2} &= -\frac{6 s_l^2\left[3s_l + 2(\Delta s - c)\right]}{(4\Delta s + 3\alpha s_l)^3} < 0 \\
2\frac{d\hat{\theta}(\alpha)}{d\alpha} + \alpha\frac{d^2\hat{\theta}(\alpha)}{d\alpha^2} &= \frac{8 s_l \Delta s\left[3s_l + 2(\Delta s - c)\right]}{(4\Delta s + 3\alpha s_l)^3} > 0
\end{aligned}$$

It follows that $\dfrac{d^2 q_2^*(\alpha)}{d\alpha^2} = -\dfrac{4 s_l \Delta s\left[3s_l + 2(\Delta s - c)\right]}{(4\Delta s + 3\alpha s_l)^3} < 0$ ■

Lemma 4 $\left.\dfrac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} = \dfrac{s_l - 2(\Delta s - c)}{8\Delta s}$

Proof. From (6), we have:

$$\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} = -\left.\frac{d\underline{\theta}(\alpha)}{d\alpha}\right|_{\alpha=0} - \left(1 - \hat{\theta}(0)\right)$$

From $(4.a)$ we have $\hat{\theta}(0) = \dfrac{2(\Delta s + c) - s_l}{4\Delta s}$ and from $(5.b)$ $\left.\dfrac{d\underline{\theta}(\alpha)}{d\alpha}\right|_{\alpha=0} = -\dfrac{2(\Delta s - c) + 3s_l}{8\Delta s}$. The result easily follows. ■

Lemma 5 $\left.\dfrac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=1} < 0$

Proof. *Differentiating* (6) *with respect to* α *yields:*

$$\frac{dq_2^*(\alpha)}{d\alpha} = -1 - \frac{d\underline{\theta}(\alpha)}{d\alpha} + \alpha\frac{d\hat{\theta}(\alpha)}{d\alpha} + \hat{\theta}(\alpha)$$

By taking into account (4.a), (5.a) *and* (5.b) *and after some algebra, we obtain:*

$$\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=1} = \frac{c\ \left[4s_h^2 - s_l^2\right] - \Delta s\ \left[4s_h^2 - s_l\ (2s_h - s_l)\right]}{\Delta s\ (4s_h - s_l)^2}$$

The result follows by noticing that the numerator is negative for $s_h = s_l$ *and becomes smaller as* s_h *increases.* ■

Lemma 6 $\lim_{\alpha\to 0} q_2^*(\alpha) = \frac{1}{2}$ *and* $q_2^*(1) = \dfrac{s_h(\Delta s + c)}{\Delta s(4\Delta s + 3s_l)}$.

Proof. From (6), we have:

$$\lim_{\alpha\to 0} q_2^*(\alpha) = 1 - \underline{\theta}(0) = 1 - \frac{1}{2} = \frac{1}{2}$$

When all the consumers care for environmental quality, the equilibrium level of pollution is given by:

$$q_2^*(1) = \hat{\theta}(1) - \underline{\theta}(1) = \frac{(2\Delta s + s_l)(\Delta s + c)}{\Delta s(4\Delta s + 3s_l)} - \frac{(\Delta s + c)}{(4\Delta s + 3s_l)} = \frac{s_h(\Delta s + c)}{\Delta s(4\Delta s + 3s_l)}$$

■

It follows from Lemma 6 that $q_2^*(1) \leq \lim_{\alpha\to 0} q_2^*(\alpha)$ if $s_l(2c - \Delta s) \leq 2\Delta s(\Delta s - c)$. Let us assume that $2c - \Delta s \leq 0$. This amounts to assume that the increase in quality perceived by the ecological consumers is relatively large when compared to its cost. It follows that the level of pollution as α goes to zero is higher than that when $\alpha = 1$. Besides, we must have that $s_l \leq 2(\Delta s - c)$ as $2c \geq s_l$. Therefore, from Lemma 4 $\left.\dfrac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} \leq 0$. As $q_2^*(\alpha)$ is concave, it follows that pollution decreases as the proportion of ecological consumer grows.

Let us assume that $2c - \Delta s > 0$ but $s_l (2c - \Delta s) < 2\Delta s (\Delta s - c)$. We can write this condition as $\frac{s_h}{s_l} > \frac{\Delta s}{2(\Delta s - c)}$. We can interpret the left hand side as a measure of the product differentiation and the right hand side as a measure of the cost of achieving that product differentiation. In this case, although the increase in quality perceived by the ecological consumers is relatively small when compare to its cost, it is still big enough to have that the level of pollution when α goes to zero is higher than that when $\alpha = 1$. Let $s_l > 2(\Delta s - c)$. Thus, $\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} > 0$. Given the concavity of $q_2^*(\alpha)$, there must exist a α^* such that for $\alpha < \alpha^*$ pollution grows with α and for $\alpha > \alpha^*$pollution is reduced as α becomes larger.[11] Although environmental awareness increases, the level of pollution in equilibrium is larger. Therefore, it may not be adequate to try to increase the population of ecological consumers if we care for the level of pollution. Let $s_l \leq 2(\Delta s - c)$. In this case, the intuitive result that pollution is reduced as the population of ecological consumer increases holds.

Let us assume that $2c - \Delta s > 0$ and $s_l (2c - \Delta s) \geq 2\Delta s (\Delta s - c)$. In this case, the level of pollution as α goes to zero is lower than that when $\alpha = 1$. Given the parameters constraints, it follows that $s_l > 2(\Delta s - c)$ and $\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} > 0$. From the above lemmas, we have that pollution level follows a $\frown$ pattern. We summarize next.

Proposition 2

Let $2c \geq s_l$ and $s_l (2c - \Delta s) < 2\Delta s (\Delta s - c)$. If $s_l > 2(\Delta s - c)$, there exists $\alpha^* \in (0, 1)$ such that for $\alpha < \alpha^*$ pollution grows with α and for $\alpha > \alpha^*$pollution decreases as α increases. If $s_l \leq 2(\Delta s - c)$, the equilibrium pollution level decreases with α. Let $2c \geq s_l$ and $s_l (2c - \Delta s) \geq 2\Delta s (\Delta s - c)$. Then, pollution level follows a $\frown$ pattern.

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[11] If, for example, $s_l = 1$, $s_h = 2$ and $c = 0.6$, we have $\alpha^* = 0.12$.

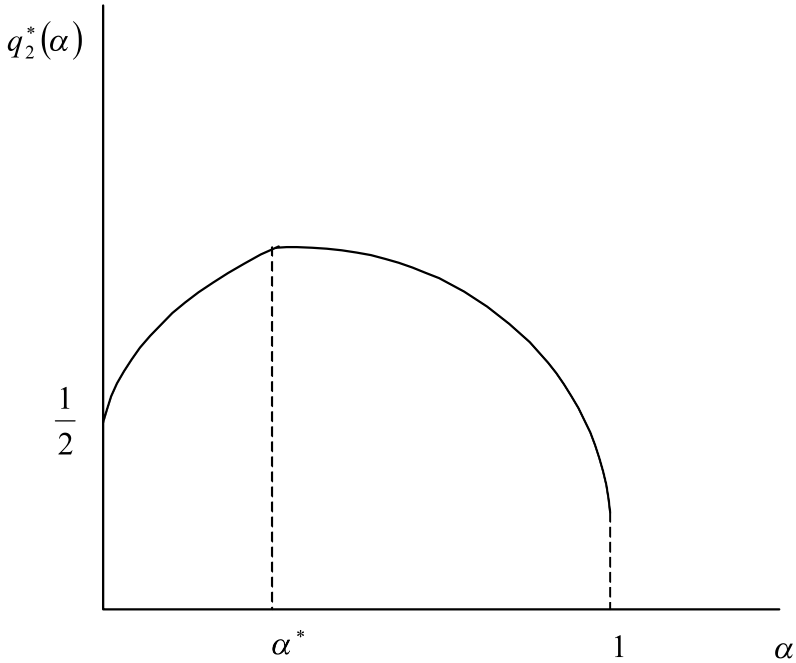

Fig. 3. Pollution when $s_l\,(2c - \Delta s) < 2\Delta s\,(\Delta s - c)$ and $s_l > 2\,(\Delta s - c)$.

Let us now assume that $2c < s_l$. From the analysis in section 3 we can write the equilibrium pollution level as:

$$q_2^*(\alpha) = \begin{cases} (1-\alpha)\left(1 - \dfrac{(1-\alpha)\,\Delta s}{2\,(\Delta s + \alpha s_l) - \alpha s_h}\right) & if\ \alpha < \hat{\alpha} \\ (1-\alpha)\left(1 - \hat{\theta}(\alpha)\right) + \left(\hat{\theta}(\alpha) - \underline{\theta}(\alpha)\right) & if\ \alpha \geq \hat{\alpha} \end{cases}$$

where $\hat{\theta}(\alpha)$ and $\underline{\theta}(\alpha)$ are given in $(4.a)$ $(4.b)$. Note that Lemma 3, Lemma 5 and Lemma 6 keep being true. It can be easily ckecked that

$$\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} = \frac{2s_l - s_h}{4\Delta s}$$

By taking all the previous results into account, we have the next proposition.

Proposition 3

Let $s_l > 2c$. If $s_h \geq 2s_l$, pollution level decreases as α increases. Let $s_h < 2s_l$. Then, there exists $\bar{\alpha} \in (0,1)$ such that for $\alpha < \bar{\alpha}$ pollution increases with α and for *$\alpha > \bar{\alpha}$ pollution diminishes with α.*

Proof. *If* $s_h \geq 2s_l$, *we must have* $\Delta s \geq 2c$. *Assume that this is not true. Then,* $s_l + 2c > s_h \geq 2s_l$. *But this implies that* $2c > s_l$, *what it is a contradiction. Therefore,* $s_l (2c - \Delta s) < 2\Delta s (\Delta s - c)$ *and pollution level when* α *goes to zero is higher than that when* $\alpha = 1$. *As* $\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} < 0$, *it follows from concavity that pollution level decreases as* α *increases. Let* $s_h < 2s_l$. When $s_l (2c - \Delta s) < 2\Delta s (\Delta s - c)$, *pollution level when* α *goes to zero is higher than that when* $\alpha = 1$. *As* $\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} > 0$, *there must exists* $\bar{\alpha} \in (0, 1)$ *such that for* $\alpha < \bar{\alpha}$ *pollution increases with* α and for $\alpha > \bar{\alpha}$. *pollution diminishes with* α. When $s_l (2c - \Delta s) \geq 2\Delta s (\Delta s - c)$, *pollution level when* α *goes to zero is lower than that when* $\alpha = 1$. *The result follows by concavity as* $\left.\frac{dq_2^*(\alpha)}{d\alpha}\right|_{\alpha=0} > 0$. ■

5 Conclusions

In this paper, we have considered a duopolistic model of environmental product differentiation to analyze how pollution changes when environmental awareness increases. The model captures in a simple way the following stylized facts: 1) some consumers are willing to pay a premium for enviromental quality; 2) enviromental quality is a "credence" good, and therefore, it can not be directly observed by consumers, even after purchase and 3) consumers rely on eco-labeling to assess environmental quality. In the model, eco-labeling is good for the environment as the level of pollution falls below the level it would result without it. We find that, in equilibrium, one firm only adopts the eco-label. Ecological consumers have a higher valuation for its product and they are willing to pay a higher price. As a result, in equilibrium, the firm that adopts the eco-label charges a higher price and it only sells to ecological consumers. The other firm sells to ecological and non ecological consumers unless the marginal cost of producing environmental quality and the proportion of ecological consumers are relatively small.

Regarding the impact of environmental awarenss on pollution, we have distinguished two cases. Let the marginal cost of producing environmental quality be relatively large. When the difference in quality is large in relation to its cost, we find that the higher the proportion of ecological consumers, the less pollution is generated. When the difference in quality is small in relation to its cost, we find that, for some range, we have more pollution in equilibrium.when environmental awareness increases. This counterintuitive result arises if the valuation of the good by the non-ecological consumers is high enough. Otherwise, the intuitive result that pollution is reduced as the population of ecological consumer increases holds.

Let the marginal cost of producing environmental quality be relatively small. In this case, educating consumers on environmental values to increase the segment of the population that cares for the environment can be counterproductive as the equilibrium level of pollution may be higher. When the degree of product differentation is not large enough, sales by the non ecological firm increases and so does the level of pollution. If the valuation of enviromental quality by concerned consumers is relative large compared to that by the non ecological consumer, then all the measures taken to increase the population of ecological consumers will be welcome.

The paper shows that we must be very careful with the implications for the environment derived from increases in environmental awareness as non desirable effects may happen. Further research must consider more than two firms as we should expect the number of ecological firms to increase as environmental awareness grows. This could mitigate the counterintuitive results found here and restore the intuitive negative relationship between pollution and environmental awareness.

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