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Ecolabels: Is More Information Better?

H. Ghazzai^{*a} and R. Lahmandi-Ayed^{†b}

^aMediterranean School of Business and Unité MASE-ESSAI, Université de Carthage

^bESSAI and Unité MASE-ESSAI, Université de Carthage

Abstract

We study in this paper the effect of the type of information provided by an ecolabel. For this purpose, in the framework of a model of vertical differentiation, we compare the effects of a partial information label (Type I) and a complete information label (Type III) on firms' profits, industry profit, consumers' surplus, environmental damage and social welfare. A partial information label indicates that the environmental quality of a good exceeds some given threshold. The authority issuing a partial information label chooses its labeling criteria while maximizing the social welfare. A complete information label indicates the exact environmental quality chosen by firms. We prove that while a partial information label always improves the social welfare and deteriorates the green firm profit compared to a complete information label, the preferences of the brown firm, the industry, the consumers and the impact on the environment depend on the marginal cost of quality and on the environmental sensitivity to quality.

Keywords: Ecolabel, Complete Information, Partial Information, Environmental Quality, Vertical Differentiation.

JEL Classification L11, Q58.

1 Introduction

The ecological quality of a product is a credence attribute difficult or impossible to be identified by a simple consumer. Ecolabels are precisely intended to minimize this information asymmetry between consumers and firms by providing information on the ecological quality of the product. One may think that the more accurate the information provided the better off are consumers, the environment and perhaps even the social welfare. In other terms, we would expect that more information should be desirable, at least from the viewpoint of consumers and the environment.

Ecolabels have proliferated over the last forty years and different types have been created. We are interested in two types of ecolabels. Type I ecolabels, such as the "Blue Angel" label,

*hend.ghazzai@msb.tn

†rim.lahmandi.ayed@gmail.com

the "EU Ecolabel" and "Nordic Swan" among others, are awarded by a third party authority to products fulfilling some minimal criteria in terms of respect of the environment. As such they deliver partial information on the environmental attributes of a product as they only allow consumers to know whether a product satisfies the label criteria and not to know its exact environmental quality. Type III ecolabels also called Environmental Product Declarations consist of a set of quantified data describing different environmental aspects of a product and are awarded by a third party organization. They give consumers complete information about a product environmental quality (Examples are "Eco-Leaf" and "IBU Environmental Product Declaration").

The objective of this paper is to compare the impact of type I (partial information) and type III (complete information) ecolabels on social welfare, consumers, firms and the environment.

To answer our research question, we consider a vertical differentiation model with two firms each offering a good characterized by its environmental quality. We compare two scenarios. In the first scenario, a labeling authority maximizing the social welfare offers a partial information label (type I) then firms decide whether to adopt the label i.e. firms choose whether to offer an environmental quality that satisfies the labeling criteria and finally compete in prices. In a second scenario, firms choose their environmental qualities among all the possible values and then apply for a complete information label (type III) awarded by an independent labeling authority (assumed to be able to know the exact quality of the product and to inform consumers about it), prior to price competition.

We prove that the social welfare is always higher with a partial information label and that the profit of the green firm is always higher with a complete information label. When comparing the equilibrium qualities chosen by firms in both cases, we prove that a partial information label is more stringent than the high quality certified by the complete information label authority for low marginal costs and high environmental sensitivity to quality. Finally, depending on the environmental sensitivity to quality and the marginal cost of quality, the low quality firm profit, the industry profit, the environmental damage and consumers' surplus may be higher or lower with a partial information label. Interestingly, consumers' preferences and industry preferences may change twice as the marginal cost of quality increases. Some interesting agents' behavior also appear. We show that the industry and the consumers may have divergent preferences for the label's type. For high enough marginal costs, even though firms, contrary to consumers, do not have any intrinsic preferences for the environmental quality, they can cooperate (through appropriate transfers between them) and campaign for the label's type the more friendly to the environment going against consumers' interests.

The Literature Review: The theoretical literature on ecolabels has mainly focused on type I ecolabels by studying different issues: (1) Firms' incentives to adopt environmentally friendly products (Amacher et al., 2004; Ben Youssef & Lahmandi-Ayed, 2008; Andre et al., 2009) (2) Effects of ecolabels on international trade (Nimon & Beghin, 1999; Greaker, 2006) (3) Implication of imperfect monitoring of ecolabels (Ibanez & Grolleau, 2008 and Hamilton & Zilberman, 2006) (4) Perverse and undesirable effects of ecolabels (Mattoo & Singh, 1994 and Dosi & Moretto, 2001) and (5) Competition between ecolabels (Harbaugh et al., 2011; Ben Youssef & Abderrazak, 2009; and Fischer & Lyon, 2014).

The first scenario of this paper corresponds to the game studied in Ben Youssef & Lahmandi-Ayed (2008). They use a vertical differentiation model with a central authority and two identical firms. A central authority chooses first the level of labeling criteria so as to maximize

the social surplus, then firms compete in environmental qualities and prices. We compare the results of their paper to the case where the central authority certifies the exact quality of a firm i.e. the central authority issues a type III ecolabel.

Little attention has been given to the market implications of type III labels and to the comparison of different labels' types. To our knowledge, only two papers compare labels' types: Fisher & Lyon (2016) and Li & Van't Veld (2015). They both compare multi-level labels which establish graded levels of certification and type I labels. More precisely, they compare a two-level ecolabel and a type I ecolabel (which may be considered as a multi-level ecolabel with only one level). In this paper, we compare a type I label and a type III one which consists in giving firms the possibility to choose from a continuous segment and not from a discrete set as in a multi-level ecolabel. Besides, they both consider price-taking firms while we consider strategic firms choosing their prices and having market power.

Fisher & Lyon (2016) and Li & Van't Veld (2015) use different models. The former consider a finite number of firms divided into two types based on their unit-costs of reducing the environmental damage of their product and a continuum of consumers characterized by their intensity of preference for the label's stringency (defined as the minimum effort of a firm to reduce its environmental damage). The latter consider a finite number of firms differing by their unit-costs and a finite number of consumers differing by their preference for the environmental quality of a good. Both papers consider labeling authorities managed by different sponsors (NGO, Industry, Government...). For each type of schemes, the labeling authority choice between a single level (Type I) and a multi-level label depends on the model's parameters.

Leire & Thidell (2005) and Van Amstel et Al (2008) study the type of information provided by ecolabels and examine the role of ecolabels in reducing the information gap between consumers and producers. They mainly focus on consumers' perception and use of ecolabels and not on the market implication of different types of labels as we do in our paper.

The remainder of the paper is organized as follows. Section 2 describes the model and presents some preliminary results. Section 3 provides the results. We conclude in Section 4. All proofs are provided in Appendix.

2 The Model and Preliminary Results

We consider a model of vertical differentiation with two firms ($i = 1, 2$) each producing a good of environmental quality q_i .

We assume that consumers are aware of the need to preserve the environment for current and future generations. This consciousness is tackled through their preference for the most environment friendly product if they have the choice between several environmental qualities offered at the same price. Consumers are characterized by their intensity of preference for the environmental quality, denoted by θ , and are uniformly distributed over the interval $[\underline{\theta}, \bar{\theta}]$, with $0 < \underline{\theta} < \bar{\theta}$. We assume that each consumer buys exactly one unit of the product from the firm which ensures to him/her the highest utility. As in Mussa & Rosen (1978), the indirect utility of a consumer θ buying quality q_i at price p_i , is given by:

$$u_i(\theta) = \theta q_i - p_i.$$

The highest price consumers are willing to pay for the product (denoted by y) is supposed to be sufficiently high so as it is never constraining.

Production of some quality q is characterized by a constant marginal cost $c(q) = \alpha q$ with $\alpha \geq 0$. The marginal cost $c(q)$ is then assumed to be an increasing function with respect to q as environment friendly processes are supposed to be more costly.

Before the set-up of an ecolabel, firms produce quality \underline{q} . In fact, they have no incentive to produce a quality better than \underline{q} as it is more costly and not recognized by consumers. As the environmental quality is not observable by consumers, the set-up of an ecolabel aims at providing consumers with information about the environmental quality of a product. We consider two types of ecolabels:

1. *Partial information ecolabels* (type I) indicate that the environmental quality of the good exceeds some given threshold \tilde{q} , called in the following "labeling criteria". Hence, as far as consumers are concerned, a labeled firm has a priori a quality $q_i \geq \tilde{q}$ and a non-labeled one has a quality $q_i < \tilde{q}$. The preceding assumptions about consumers' beliefs imply that Firm i will choose its quality q_i from the pair $\{\underline{q}, \tilde{q}\}$. Indeed as consumers are not able to make the difference between \underline{q} and a quality \bar{q} satisfying $\underline{q} \leq \bar{q} < \tilde{q}$ and between \tilde{q} and a better quality, producers set the product in "some category" (labeled or not labeled) at the least cost.
2. *Complete information ecolabels* (type III) indicate the exact environmental quality of the good and therefore give complete information to consumers about the environmental quality of a firm's product. In this framework, Firm i chooses its quality q_i from all the quality segment $[\underline{q}, \bar{q}]$, then the labeling authority certifies the exact environmental quality of the product giving consumers complete information about the exact quality of the product.

Moving to a quality q greater than \underline{q} means that a firm is becoming greener. This involves a fixed cost I increasing with respect to the difference between the initial and the new quality assumed to be given by:

$$I(\Delta q) = \beta(\Delta q)^2,$$

with $\beta > 0$ and $\Delta q = q - \underline{q}$.

We assume that each unit consumed involves a damage d . The unit damage is supposed to be decreasing with environmental quality at a constant rate $\mu > 0$. Formally, we assume that:

$$d = \gamma - \mu q,$$

with $\gamma > 0$.

Parameter μ reflects the environmental sensitivity to quality. The higher μ , the higher the impact of the environmental quality on the environment. Parameter γ refers to the maximal environmental damage occurring in the case of a null quality.

We consider two games corresponding respectively to the two types of labels: the partial information label and the complete information one.

Partial Information Label

The game is organized as follows:

1. The labeling authority chooses the level of labeling criteria \tilde{q} so as to maximize the social welfare.
2. Firms simultaneously choose their qualities in the pair $\{q, \tilde{q}\}$.
3. The labeling authority attributes the ecolabel to the deserving firms (i.e. when $q \geq \tilde{q}$).
4. Firms simultaneously choose their prices in $[0, y]$.

The social welfare to be maximized in the first step is equal to the sum of consumers' and producers' surpluses minus the environmental damage caused by the consumption of goods.

Complete Information Label

The game is organized as follows:

1. Firms simultaneously choose their qualities q_i in the segment $[q, \bar{q}]$.
2. The labeling authority indicates the exact environmental quality of each firm.
3. Firms simultaneously choose their prices in $[0, y]$.

Multiple equilibria may exist at the quality stage of the partial information label game. When needed we adopt the following selection assumption:

(SA): If multiple equilibria exist at the quality stage of the game, we choose the equilibrium where firms produce the highest qualities.

The selection assumption (SA) ensures that the resulting environmental damage is the lowest possible. Indeed, for some values of the labeling criteria, a firm has the same profit with the labeled product and the non-labeled one. With assumption (SA), it chooses to produce the labeled one. This is the way firms are supposed to have an ecological consciousness. In other words, firms are environment friendly when producing a higher quality does not decrease their profits.

We now enounce a first result about the price equilibrium under a partial or complete information label.

Result 1. *Denote by q_1 and q_2 the qualities sold respectively by Firms 1 and 2 and suppose without loss of generality that $q_1 \leq q_2$, at price equilibrium:*

- *If $q_1 = q_2 = q$. Firms share equitably the market and set prices $p_1 = p_2 = \alpha q$.*
- *If $q_1 < q_2$ then,*
 1. **High Marginal Costs:** *if $\alpha \geq 2\bar{\theta} - \underline{\theta}$, only Firm 1 is active and prices and demands are given by:*

$$\begin{cases} p_1 = \alpha q_2 - \bar{\theta}(q_2 - q_1), \\ p_2 = \alpha q_2. \end{cases} \quad \text{and} \quad \begin{cases} D_1 = \bar{\theta} - \underline{\theta}, \\ D_2 = 0. \end{cases}$$
 2. **Low Marginal Costs:** *if $\alpha \leq 2\underline{\theta} - \bar{\theta}$, only Firm 2 is active and prices and demands are given by:*

$$\begin{cases} p_1 = \alpha q_1, \\ p_2 = \alpha q_1 + \underline{\theta}(q_2 - q_1). \end{cases} \quad \text{and} \quad \begin{cases} D_1 = 0, \\ D_2 = \bar{\theta} - \underline{\theta}. \end{cases}$$

3. **Intermediate Marginal Costs:** if $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$, both firms are active and prices and demands are given by:

$$\begin{cases} p_1 = \frac{1}{3}[(\bar{\theta} - 2\underline{\theta})(q_2 - q_1) + \alpha q_2 + 2\alpha q_1], \\ p_2 = \frac{1}{3}[(2\bar{\theta} - \underline{\theta})(q_2 - q_1) + 2\alpha q_2 + \alpha q_1]. \end{cases} \quad \text{and} \quad \begin{cases} D_1 = \frac{\bar{\theta} - 2\underline{\theta} + \alpha}{3}, \\ D_2 = \frac{2\bar{\theta} - \underline{\theta} - \alpha}{3}. \end{cases}$$

The consumer indifferent between q_1 and q_2 is characterized by $\hat{\theta} = \frac{\bar{\theta} + \underline{\theta} + \alpha}{3}$.

The proof of Result 1 can be found in Ben Youssef and Lahmandi-Ayed (2008). Result 1 leads to some properties on the demands and firms' margins when the marginal cost is intermediate given by Lemma 1.

Lemma 1 (Demands and firms' margins in the intermediate marginal costs case). *In the intermediate marginal costs case, at equilibrium,*

1. *The demands of both firms do not depend on qualities.*
2. *The high quality firm demand is decreasing with α and the low quality firm demand is increasing with α .*
3. *The margin of the high quality firm is decreasing with α and the margin of the low quality firm is increasing with α .*
4. *The margin of both firms is increasing with respect to the difference between firms' qualities.*

Lemma 1 follows immediately from Result 1. The variation of the demands with α may be explained as follows: the marginal cost, being given by $c(q) = \alpha q$, increases more quickly for the high quality firm than for the low quality one, which makes both prices increase but more the high quality product's one and thus makes the high quality firm lose some of its market share to the benefit of the low quality one.

As for the variation of the firms' margins with α , as α increases, the cost differentiation between firms increases as well. The increase in the high quality firm's costs can be only partially compensated by a price increase, which reduces the margin of the high quality firm. Indeed, the temptation of the high quality firm to increase its price is restricted by the competition with its competitor. The low quality firm, however, can afford increasing its market share as the increase in its costs is less important than its rival. Finally, the variation of firms' margins with respect to the difference between firms' qualities is due to the relaxed competition between firms when products are more differentiated.

We finally enounce a second result about the firms' qualities under both types of labels when the marginal cost of quality is high. The proof of Result 2 is given in Appendix.

Result 2 (High Marginal Costs). *If $\alpha \geq 2\bar{\theta} - \underline{\theta}$ then both firms keep producing \underline{q} whatever the label's type.*

When the marginal cost α is too high, whether under a partial information label or a complete information one, firms completely ignore it and keep producing \underline{q} , as moving to any higher quality is too costly. The case of high marginal costs is thus obvious as no change occurs under both types of ecolabels. We assume in the rest of the paper that $\alpha < 2\bar{\theta} - \underline{\theta}$.

3 Is More Information Better?

We aim in this section to compare the two types of ecolabels; partial information and complete information labels, from the viewpoint of each type of agent, the environment and the planner. We first present the results of the partial information label game then those of the complete information label one. Then, we compare the effects of both labels on global welfare, qualities, environmental damage, firms' profits, industry profit and consumers' surplus.

The partial information label game was completely solved by BenYoussef & Lahmandi-Ayed (2008). The equilibrium labeling criteria with a partial information label as well as the qualities produced by firms are recalled (but formatted differently) in Lemma 2. The equilibrium qualities chosen by firms with a complete information label are provided in Lemma 3. Propositions 1 to 5 give the results of the comparison. Denote by:

$$\begin{aligned}\bar{\delta}_L &= \frac{(\bar{\theta}-\underline{\theta})(\bar{\theta}-\alpha)}{\beta}, \\ \delta_L^* &= \frac{(\bar{\theta}-\underline{\theta})(\bar{\theta}+\underline{\theta}-2\alpha+2\mu)}{4\beta}, \\ \bar{\delta}_I &= \frac{(2\bar{\theta}-\underline{\theta}-\alpha)^2}{9\beta}, \\ \delta_I^* &= \frac{(2\bar{\theta}-\underline{\theta}-\alpha)(4\bar{\theta}+\underline{\theta}-5\alpha+6\mu)}{36\beta}.\end{aligned}$$

The subscript "L" refers to the case where the marginal cost is low ($\alpha \leq 2\bar{\theta} - \bar{\theta}$), while "I" refers to the case where the marginal cost is intermediate ($2\bar{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$).

$\bar{\delta}_L$ and $\bar{\delta}_I$ are defined to be the maximal Δq allowing the adoption of the partial information label by one firm, i.e. allowing a nonnegative profit for the labeled firm, respectively in the low and intermediate marginal costs cases.

δ_L^* and δ_I^* correspond to the differential of quality Δq that maximizes the social welfare with a positive green demand without constraint i.e. when $\bar{\delta}_L$ and $\bar{\delta}_I$ are not binding, respectively in the low and intermediate marginal costs cases.

Lemma 2 (Partial Information Label). *In the partial information label case, assuming without loss of generality that $q_1 \leq q_2$, depending on the marginal cost α , two cases are distinguished:*

1. **Low marginal costs** ($\alpha \leq 2\bar{\theta} - \bar{\theta}$): *at equilibrium one firm is labeled and the other firm is non-labeled but only the labeled firm is active. Depending on the environmental sensitivity rate μ , the optimal labeling criteria and the equilibrium qualities are given as follows:*

- if $\mu \leq \frac{3\bar{\theta}-\bar{\theta}}{2} - \alpha$ then $\tilde{q}^* = \delta_L^* + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \delta_L^* + \underline{q}$.
- if $\mu > \frac{3\bar{\theta}-\bar{\theta}}{2} - \alpha$ then $\tilde{q}^* = \bar{\delta}_L + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \bar{\delta}_L + \underline{q}$.

2. **Intermediate marginal costs** ($2\bar{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$): *at equilibrium both firms are active. Depending on the environmental sensitivity rate μ , the optimal labeling criteria and the equilibrium qualities are given as follows:*

- if $\mu \leq \frac{5\alpha-4\bar{\theta}-\underline{\theta}}{6}$ then $\tilde{q}^* = \underline{q}$, which amounts to no label and $q_1 = q_2 = \underline{q}$.
- if $\frac{5\alpha-4\bar{\theta}-\underline{\theta}}{6} < \mu \leq \frac{4\bar{\theta}-5\underline{\theta}+\alpha}{6}$ then $\tilde{q}^* = \delta_I^* + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \delta_I^* + \underline{q}$.
- if $\mu > \frac{4\bar{\theta}-5\underline{\theta}+\alpha}{6}$ then $\tilde{q}^* = \bar{\delta}_I + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \bar{\delta}_I + \underline{q}$.

When the marginal cost is intermediate and the environmental sensitivity to quality is too low ($2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ and $\mu \leq \frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6}$), the labeling authority chooses the labeling criteria $\tilde{q} = \underline{q}$ which amounts to the same as the absence of the label. Both firms produce \underline{q} and no environmental improvement is observed. This is because the impact of the environmental quality is too small, while it costs too much. It is worth noting that the inequality $\mu \leq \frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6}$ is never satisfied when $\alpha < \frac{4\bar{\theta} + \underline{\theta}}{5}$, as we easily check that $2\underline{\theta} - \bar{\theta} < \frac{4\bar{\theta} + \underline{\theta}}{5} < 2\bar{\theta} - \underline{\theta}$. Thus, when $2\underline{\theta} - \bar{\theta} < \alpha < \frac{4\bar{\theta} + \underline{\theta}}{5}$, this sub-case is not relevant.

In all other cases, one firm which will be referred to as the brown firm keeps producing \underline{q} , and the label is adopted by the other firm which will be referred to as the green firm. The choice of the stringency of the label depends on the marginal cost of quality and the environmental sensitivity to quality. Result 4 in the appendix gives the expressions of the social welfare, firms' profits, environmental damage, consumers' surplus and industry profits at equilibrium with a partial information label. We now move to the results of the complete information label case.

Lemma 3 (Complete Information Label). *In the complete information label case, assuming without loss of generality that $q_1 \leq q_2$, depending on the marginal cost α , the equilibrium qualities are given as follows:*

1. **Low marginal costs** ($\alpha \leq 2\underline{\theta} - \bar{\theta}$): $q_1^* = \underline{q}$ and $q_2^* = \frac{\bar{\delta}_L}{2} + \underline{q}$. Only firm 2 is active.
2. **Intermediate marginal costs** ($2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$): $q_1^* = \underline{q}$ and $q_2^* = \frac{\bar{\delta}_L}{2} + \underline{q}$. Both firms are active.

With a complete information label firms choose their qualities which are then certified by the labeling authority giving consumers the exact information on the firms' quality. One firm keeps producing \underline{q} and remains brown. The other firm offers a higher quality than \underline{q} and becomes greener. The choice of the green quality depends on the marginal cost of quality. The existence of a complete information label has thus an impact on the economic agents and on the environment. Result 5 in Appendix gives the expressions of the social welfare, firms' profits, environmental damage, consumers' surplus and industry profits at equilibrium with a complete information label.

Denote by $\tilde{\alpha} = -4\underline{\theta} + 5\bar{\theta} - 3\sqrt{3}(\bar{\theta} - \underline{\theta})$ and by $\bar{\alpha} = 5\underline{\theta} - 4\bar{\theta} + 3\sqrt{2}(\bar{\theta} - \underline{\theta})$. We easily check that $2\underline{\theta} - \bar{\theta} < \tilde{\alpha} < \underline{\theta} < \bar{\alpha} < 2\bar{\theta} - \underline{\theta}$.

Table 1 provides the different zones of interest for in Propositions 1 to 5. These zones are depicted in Figure 1 in the (α, μ) -space.

Zones	α	μ
1	$\alpha \leq 2\underline{\theta} - \bar{\theta}$	Any $\mu > 0$
2	$2\underline{\theta} - \bar{\theta} < \alpha \leq \tilde{\alpha}$	Any $\mu > 0$
3	$\tilde{\alpha} < \alpha \leq \bar{\alpha}$	$\mu > \frac{2}{3} \frac{(\alpha + \bar{\theta} - 2\underline{\theta})^2}{2\bar{\theta} - \underline{\theta} - \alpha} + \frac{\alpha - \underline{\theta}}{2}$
4	$\tilde{\alpha} < \alpha \leq \bar{\alpha}$	$\frac{\alpha - \underline{\theta}}{2} < \mu < \frac{2}{3} \frac{(\alpha + \bar{\theta} - 2\underline{\theta})^2}{2\bar{\theta} - \underline{\theta} - \alpha} + \frac{\alpha - \underline{\theta}}{2}$
	$\bar{\alpha} < \alpha < 2\bar{\theta} - \underline{\theta}$	$\mu > \frac{\alpha - \underline{\theta}}{2}$
5	$\underline{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$	$\mu < \frac{\alpha - \underline{\theta}}{2}$

Table 1 – Zones

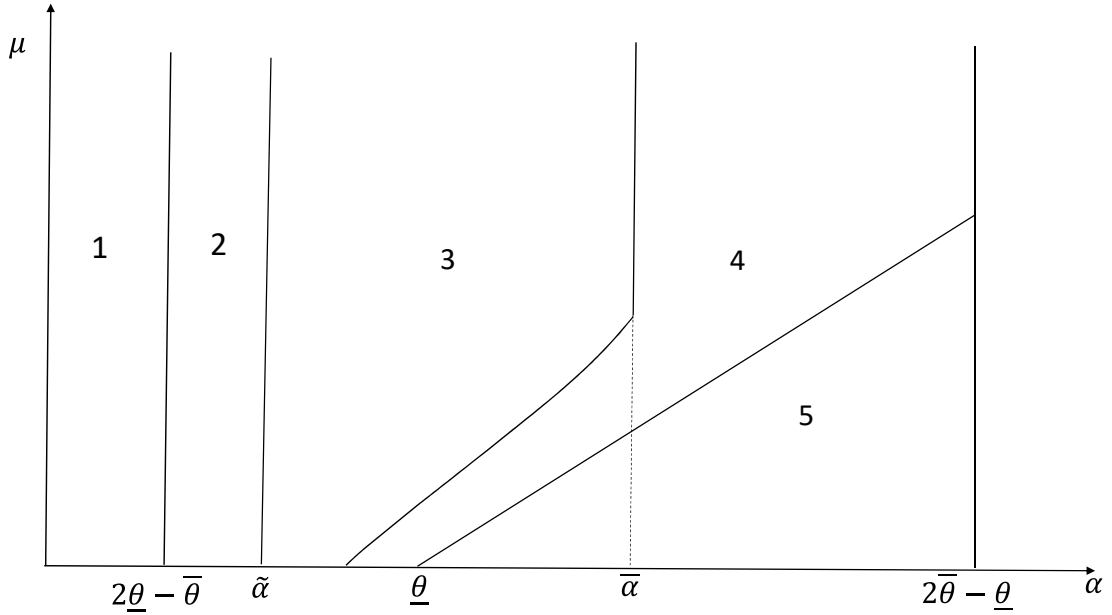


Figure 1 – Zones in the (α, μ) -space of interest for Propositions 1 to 5.

We now give the results of the labels' comparison through Propositions 1 to 5.

Proposition 1 (The social welfare and the green firm profit). *For all values of (α, μ) , such that $\alpha < 2\bar{\theta} - \underline{\theta}$ and $\mu \geq 0$, the social welfare is higher and the profit of the green firm lower with a partial information label than with a complete information one.*

A partial information label always leads to a higher social welfare compared to a complete information label. With a partial information label, the labeling authority chooses the labeling

criteria \tilde{q} so as to maximize the social welfare anticipating the fact that one firm is green and one firm remains brown. With a complete information label, only one firm is green as well but the determination of the green quality corresponds to a decentralized choice by firms at the subgame perfect equilibrium. It does not result from a maximization of social welfare, the role of the labeling authority being limited to observe the qualities and inform consumers on their exact values.

A complete information label gives more power to firms and more precisely to the green firm which always prefers this type of label. Indeed, with a complete information label, firms choose their qualities from all the segment $[q, \bar{q}]$. To ensure maximal differentiation the brown firm chooses the lowest quality q . Hence, the green quality corresponds to the best response of the green firm to q i.e. the one that maximizes its profit given its rival's quality. Whereas with a partial information label, the choice of the green firm reduces to only one possibility: the label quality chosen by the authority so as to maximize the social welfare taking into account the interests of all parties and not only the green firm's one.

Proposition 2 (The green qualities). *The green quality is more stringent under a partial information label than under a complete information label in zones 1 to 4 of Figure 1 (i.e. when $\mu > \frac{\alpha-\theta}{2}$) and less stringent in zone 5 (i.e. when $\mu < \frac{\alpha-\theta}{2}$).*

The labeling criteria chosen by the authority issuing a partial information label may be more or less stringent than the green quality certified by the authority issuing a complete information label. Higher labeled quality is beneficial to the environment and to the brown firm which is better off with more differentiation allowing it higher prices and higher profits. But higher labeled quality hurts the consumers of the brown quality because of higher prices induced by more differentiation; and is not always beneficial to the green firm which has to bear higher investment costs. The partial information labeling authority has to take into consideration all these diverging interests. When μ is sufficiently high relative to the marginal cost parameter, the environmental damage has an important weight in the social welfare and the production cost is not too high for the green firm, which urges the labeling authority to choose more stringent labeling criteria relative to a decentralized choice by firms (complete information).

When μ is sufficiently low relative to the marginal cost parameter, the opposite occurs: the green quality in the complete information label case is greener than in the partial information label one. This is so even if with type III ecolabels (complete information) there is no authority to set labeling criteria. It occurs when the weight of the environmental damage in the social welfare maximized by a type I labeling authority is too low compared to the weight of other agents that are better off with less stringent labeling criteria, namely the green firm and the consumers of the brown quality.

Proposition 3 (The environmental damage and the brown firm profit). *Using the zones defined in Table 1 and depicted in Figure 1, we have the following:*

- *In zone 1, the profit of the brown firm is null whether with a partial or a complete information label and the environmental damage is lower with a partial information label.*

- In zones 2, 3 and 4, the profit of the brown firm is higher; and the environmental damage is lower with a partial information label than with complete information label.
- In zone 5, the profit of the brown firm is lower and the environmental damage is higher with a partial information label than with complete information label.

In Zone 1, when the marginal cost is low, there is no room for a brown firm. The green firm, under both types of labels, takes all the market. The brown firm is thus indifferent between the two types of labels. In the rest of the zones, as we explained above, the brown firm benefits from a higher green quality. The comparison for the brown firm's profit follows from the comparison of the green qualities.

The same reasoning applies for the environmental damage as the higher the green quality the lower the environmental damage (demands for both qualities being constant with respect to qualities as explained in Lemma 1). As the green quality is higher under a partial information label in zones 1 to 4 than under a complete information label, then the environmental damage is lower in these zones. The opposite occurs in zone 5.

Proposition 4 (Comparison of Consumers' surplus). *Using the zones defined in Table 1 and depicted in Figure 1, we have the following:*

- In zones 1, 2 and 5, consumers' surplus is higher with a partial information label than with a complete information one.
- In zones 3 and 4, consumers' surplus is lower with a partial information label than with a complete information one.

Consumers' population is composed of consumers of the brown product and consumers of the green one. Buying a green quality procures consumers a higher gross utility but at a higher price. The positive quality effect outweighs the negative price effect for small enough α as the price of the green quality remains sufficiently low. This is confirmed by the expression of the surplus of green consumers when both firms are active (i.e. for intermediate α) given by:

$$CS(q) = \int_{\hat{\theta}}^{\bar{\theta}} (\theta q - \frac{1}{3}(\alpha \underline{q} + 2\alpha q + (2\bar{\theta} - \theta)\Delta q)) d\theta = \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{9} \underline{q} + \frac{(2\bar{\theta} - \underline{\theta} - \alpha)(\underline{\theta} - \alpha)}{6} q,$$

with $\hat{\theta} = \frac{\bar{\theta} + \underline{\theta} + \alpha}{3}$.

The surplus of green consumers is thus linearly related to the green quality q and is positively related to q if $\alpha < \underline{\theta}$. Green consumers are thus positively affected by the green quality for small α and negatively affected by the green quality for high α . Brown consumers are always better off with a lower green quality. Indeed, a high green quality corresponds to higher differentiation allowing higher prices. Thus, brown consumers are always negatively affected by the green quality. Hence, brown consumers' preferences and green consumers' preferences diverge for small α and converge for high α .

When α is low ($\alpha \leq 2\underline{\theta} - \bar{\theta}$), the brown product has no market share. Beyond this threshold, as α increases the brown demand increases and the green demand decreases as explained in Lemma 1. Consumers' preferences are determined by the green consumers for low values of

α (zones 1 and 2) and by brown consumers for high values of α (zones 3, 4 and 5), following the relative weight of each type of consumers in the whole population.

In zones 1 and 2, partial information labeling which leads to a higher green quality (Proposition 2) is preferred by green consumers, thus by the whole population. Both brown and green consumers prefer the lowest green quality in zones 3, 4 and 5, thus complete information in zones 3 and 4 and partial information in zone 5.

Interestingly, the preference of consumers may change twice as α varies. The set of parameters in which partial information is preferred is not a connected set. Mathematically, this occurs because the function corresponding to the difference between consumers' surplus under the two types of labels is a piece-wise defined 4th degree polynomial function (see Appendix).

Proposition 5. *Using the zones defined in Table 1 and depicted in Figure 1, we have the following:*

- *In zones 1, 2, 3 and 5, the industry profit is lower with a partial information label than with a complete information one.*
- *In zone 4, the industry profit is higher with a partial information label than with a complete information one.*

The industry profit is the sum of the brown firm and the green firm profits. The comparison for the industry between both types of labels is determined by the relative weight of demands of both types of product, the profit margin of each firm and the difference between the green qualities with a partial information label and a complete information one. When the marginal cost is low the profit of the green firm has more weight as this firm has a higher demand and a more important margin. As previously proved, the green firm is better off with a complete information label (Proposition 1). Hence, the industry profit is higher with a complete information label in zones 1, 2, and 3. When the marginal cost keeps increasing, the market share of the brown firm becomes more important as well as its margin and the industry profit is more affected by the brown firm profit and therefore the brown firm preferences. The brown firm prefers more differentiation between firms' products allowing it to set higher prices. Thus, it prefers a higher green quality. Consequently, the industry profit is higher with a partial information label in zone 4 as the the partial information label is more stringent than the green quality of a complete information label and the industry profit is lower with a partial information label in zone 5. As observed with consumers' preferences, mathematically, the function corresponding to the difference of industry profits under the two types of labels is a piece-wise defined 4th degree polynomial function (see Appendix).

Interestingly, the industry, as a whole, may prefer a centralized choice of ecolabels (partial information label) to a decentralized one (complete information label). If we observe the interests of the industry as a whole, the consumers and the environment, there is never convergence between the three. They never agree on a type of ecolabels. Now, more precisely, in zone 4, the two firms together make more profit under a partial information label and it is possible for the brown firm to convince the green firm through an appropriate compensation to "campaign" for the set-up of a partial information label, which is also more friendly for the environment (Proposition 3) but goes against the interest of consumers (Proposition 4).

In zone 5, the two firms together make more profit under complete information label. In this case, it is possible for the green firm to convince the brown firm, through an appropriate transfer, to campaign for the set-up of a complete information label more friendly to the environment but going against the consumers' interests.

To sum up, in zones 4 and 5, if firms agree on appropriate transfers, the industry may seem more friendly to the environment than consumers, while firms do not have an intrinsic preference for green products, contrary to consumers.

4 Conclusion

We compared in this paper the effects of a partial information label and a complete information one on the social welfare, the economic agents and the environment. While a partial information label always improves the social welfare and deteriorates the green firm profit compared to a complete information label, there is no clear advantage of one type of label over the other for the environment, the brown firm, the industry and consumers. We showed that the preferences of environmentalists and the brown firm depend on how stringent are the labeling criteria of a type I authority compared to the green quality of a complete information label. We also proved that consumers and industry preferences are complex as they may change twice as the marginal cost of quality increases.

One of the main limitations of this paper is the assumption that the market is fully covered. Relaxing this assumption will lead to demands that depend on firms' qualities. However, the maximization of the social welfare is not obvious in this case and the equilibria of the partial information case can only be found numerically. This may be done in a future work. Another way to extend our work is to consider a different composition of the participants in the type I labeling process. Indeed, in our paper, we consider a labeling authority that gives equal weights to firms, consumers and the environment. We may study the situation where the participants in the standardization process of the labeling authority do not have equal powers. The objective function of the labeling authority will thus depend on the weight of each category of participants.

References

- Amacher F. S., Koskela, E. and Ollikainen, M. (2004). Environmental quality competition and eco-labeling. *Journal of Environmental Economics and Management*, 47(2), 284-306.
- Andre F. J., Gonzalez, P. and Porteiro, N. (2009). Strategic quality competition and the Porter Hypothesis. *Journal of Environmental Economics and Management*, 57(2), 182-194.
- Bagnoli M. and Watts, S. (2003). Selling to socially responsible consumers: Competition and the private provision of public goods. *Journal of Economics and Management Strategy*, 12(3), 419-445.
- BenYoussef A. and Lahmandi-Ayed, R. (2008). Eco-labeling, competition and environment: Endogenization of labeling criteria. *Environmental and Resource Economics*, 41(2), 133-154.
- BenYoussef A. and Abderrazak, C. (2009). Multiplicity of eco-labels, competition, and the environment. *Journal of Agricultural and Food Industrial Organization*, 7(2), 1-22.
- Dosi C. and Moretto, M. (2001). Is ecolabeling a reliable environmental policy measure? *Environmental and Resource Economics*, 18(1), 113-127.
- Fischer C. and Lyon, T., P. (2014). Competing environmental labels. *Journal of economics and management strategy*, 23(3), 692-716.
- Fischer C. and Lyon, T., P. (2016). A Theory of Multi-Tier Ecolabel Competition . *Ross School of Business Paper No. 1319*. Available at SSRN: <https://ssrn.com/abstract=2797256> or <http://dx.doi.org/10.2139/ssrn.2797256>
- Galarraga Gallastegui, I. (2002). The use of eco-labels: a review of the literature. *European Environment*, 12(6), 316-331.
- Greaker, M. (2006). Eco-labels, Trade and Protectionism. *Environmental and Resource Economics*, 33, 1-37.
- Hamilton S. F. and Zilberman, D. (2006). Green markets, eco-certification, and equilibrium fraud. *Journal of environmental economics and management*, 52(3), 627-644.
- Harbaugh R., Maxwell, J. and Roussillon, B. (2011). Label confusion: The Groucho effect of uncertain standards. *Management Science*, 57(9), 1512-1527.
- Ibanez L. and Grolleau, G. (2008). Can eco-labeling schemes preserve the environment? *Environmental and resource economics*, 40(2), 233-249.
- Leire C. and Thidell, A. (2005). Product-Related Environmental Information to Guide Consumer Purchases- A Review and Analysis of Research and Perceptions, Understanding and Use among Nordic Consumers. *Journal of Cleaner Production*, 13(10-11), 1061-1070.
- Li Y. and Van't Veld, K. (2015). Green, greener, greenest: Eco-label degradation and competition. *Journal of environmental economics and management*, 72, 164-176.
- Mattoo A. and Singh, H. V. (1994). Eco-labeling: Policy considerations. *Journal of economic theory*, 41(1), 53-65.

- Mussa M. and Rosen, S. (1978). Monopoly and product quality. *Kyklos*, 18(2), 301-317.
- Nimon W. and Beghin, J. (1999). Ecolabels and International Trade in the Textile and Apparel Market. *American Journal of Agricultural Economics*, 81(5), 1078-1083.
- Van Amstel M., Driessen, P. and Glasbergen, P.(2008). Eco-labeling and Information Asymmetry: A Comparison of Five Ecolabels in the Netherlands. *Journal of Cleaner Production*, 16(3). 263-276.

Appendix

Proof of Lemma 1

The proof is based on Result 1. The firms' demands and margins with intermediate marginal costs are given respectively by:

$$\begin{cases} D_1 = \frac{\bar{\theta} - 2\underline{\theta} + \alpha}{3}, \\ D_2 = \frac{2\bar{\theta} - \underline{\theta} - \alpha}{3}. \end{cases} \quad \text{and} \quad \begin{cases} p_1 - \alpha q_1 = \frac{\bar{\theta} - 2\underline{\theta} + \alpha}{3}(q_2 - q_1), \\ p_2 - \alpha q_2 = \frac{2\bar{\theta} - \underline{\theta} - \alpha}{3}(q_2 - q_1). \end{cases}$$

■

Proof of Result 2

The proof is based on Result 1. Assuming that $q_1 < q_2$, we have that $\Pi_1 = (\alpha - \bar{\theta})(q_2 - q_1) - \beta(q_1 - q)^2$ and $\Pi_2 = -\beta(q_2 - q)^2$. We easily check that Π_1 is decreasing with respect to q_1 and Π_2 is decreasing with respect to q_2 . Thus, both firms produce \underline{q} . When $q_1 = q_2 = q$ then $\Pi_1 = \Pi_2 = -\beta(\Delta q)^2$ and both firms produce \underline{q} . ■

Denote by $\delta_I = \frac{(\alpha + \bar{\theta} - 2\underline{\theta})^2}{9\beta}$.

Denote by \underline{D} , \underline{CS} and \underline{SW} the environmental damage, consumers' surplus and the social welfare, respectively, when both firms produce \underline{q} . They are given as follows:

$$\begin{aligned} \underline{D} &= (\gamma - \mu\underline{q})(\bar{\theta} - \underline{\theta}), \\ \underline{CS} &= \int_{\underline{\theta}}^{\bar{\theta}} (\underline{\theta}q - \alpha\underline{q})d\theta = (\bar{\theta} - \underline{\theta})\left(\frac{\bar{\theta} + \underline{\theta}}{2} - \alpha\right)\underline{q}, \\ \underline{SW} &= \underline{CS} - (\gamma - \mu\underline{q})(\bar{\theta} - \underline{\theta}) = (\bar{\theta} - \underline{\theta})\left(\left(\frac{\bar{\theta} + \underline{\theta}}{2} - \alpha + \mu\right)\underline{q} - \gamma\right). \end{aligned}$$

Denote by Π_1 , Π_2 , Π , D , CS and SW , respectively the brown firm's profit, the green firm's profit, the industry profit, the environmental damage, consumers' surplus and the social welfare. Result 3 gives their general expressions. Whether in the partial information label case or in the complete information one, Lemmas 2 and 3 show that either both firms produce \underline{q} or one firm remains brown and the other firm becomes green.

Result 3. *The general expression of firms' profits, Industry profit, environmental damage, consumers' surplus and the social welfare at price equilibrium when one firm produces \underline{q} and the other firm produces $q \geq \underline{q}$ are given in Table 2.*

Low α : $\alpha \leq 2\underline{\theta} - \bar{\theta}$	Intermediate α : $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$
$\Pi_1 = 0$	$\Pi_1 = \beta\delta_I\Delta q$
$\Pi_2 = \beta(\bar{\delta}_L - \Delta q)\Delta q$	$\Pi_2 = \beta(\bar{\delta}_I - \Delta q)\Delta q$
$\Pi = \beta(\bar{\delta}_L - \Delta q)\Delta q$	$\Pi = \beta(\bar{\delta}_I + \delta_I - \Delta q)\Delta q$
$D = \underline{D} - \mu\Delta q(\bar{\theta} - \underline{\theta})$	$D = \underline{D} - \mu\Delta q\frac{2\bar{\theta} - \underline{\theta} - \alpha}{3}$
$CS = \underline{CS} + \frac{(\bar{\theta} - \underline{\theta})^2}{2}\Delta q$	$CS = \underline{CS} + \Delta q\left(\frac{(\bar{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9}\right)$
$SW = \underline{SW} + \beta\Delta q(2\delta_L^* - \Delta q)$	$SW = \underline{SW} + \beta\Delta q(2\delta_I^* - \Delta q)$

Table 2 – The firms' profits, the industry profit, the environmental damage, the consumers' surplus and the social welfare when one firm produces \underline{q} and the other q .

Proof of Result 3

We distinguish three cases:

1. When $\alpha \leq 2\bar{\theta} - \underline{\theta}$, as proven in Result 1, only the green firm is active. The expressions of firms' profits, industry profit, environmental damage, consumers' surplus and the social welfare, for a given q produced by the green firm, are as follows:

$$\Pi_2 = (\underline{\theta} - \alpha)(\bar{\theta} - \underline{\theta})\Delta q - \beta\Delta q^2 = \beta(\bar{\delta}_L - \Delta q)\Delta q,$$

$$\Pi_1 = 0,$$

$$\Pi = \Pi_1 + \Pi_2 = \beta(\bar{\delta}_L - \Delta q)\Delta q,$$

$$D = (\gamma - \mu q)(\bar{\theta} - \underline{\theta}) = \underline{D} - \mu\Delta q(\bar{\theta} - \underline{\theta}),$$

$$CS = \int_{\underline{\theta}}^{\bar{\theta}} (\theta q - \alpha \underline{q} - \underline{\theta}\Delta q) d\theta = \frac{(\bar{\theta} - \underline{\theta})^2}{2} q - (\alpha - \underline{\theta})(\bar{\theta} - \underline{\theta}) \underline{q} = \underline{CS} + \frac{(\bar{\theta} - \underline{\theta})^2}{2} \Delta q,$$

$$\begin{aligned} SW &= CS + \Pi_1 + \Pi_2 - (\gamma - \mu q)(\bar{\theta} - \underline{\theta}) = (\bar{\theta} - \underline{\theta}) \left[\left(\frac{\bar{\theta} + \underline{\theta}}{2} - \alpha - \mu \right) q - \gamma \right] - \beta\Delta q^2, \\ &= \underline{SW} + \beta\Delta q(2\delta_L^* - \Delta q). \end{aligned}$$

2. When $2\bar{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ and one firm is green i.e. $q > \underline{q}$, the expressions of firms' profits, industry profit, environmental damage, consumers' surplus and the social welfare for a given q are as follows:

$$\Pi_2 = \frac{1}{9}(2\bar{\theta} - \underline{\theta} - \alpha)^2 \Delta q - \beta\Delta q^2 = \beta(\bar{\delta}_I - \Delta q)\Delta q,$$

$$\Pi_1 = \frac{1}{9}(\alpha + \bar{\theta} - 2\underline{\theta})^2 \Delta q = \beta\underline{\delta}_I \Delta q,$$

$$\Pi = \Pi_1 + \Pi_2 = \beta(\bar{\delta}_I + \underline{\delta}_I - \Delta q)\Delta q,$$

$$D = (\gamma - \mu \tilde{q}) \frac{2\bar{\theta} - \underline{\theta} - \alpha}{3} + (\gamma - \mu \underline{q}) \frac{\alpha + \bar{\theta} - 2\underline{\theta}}{3} = \underline{D} - \mu\Delta q \frac{2\bar{\theta} - \underline{\theta} - \alpha}{3},$$

$$\begin{aligned} CS &= \int_{\underline{\theta}}^{\bar{\theta}} \left(\theta \underline{q} - \frac{1}{3}(2\alpha \underline{q} + \alpha q + (\bar{\theta} - 2\underline{\theta})\Delta q) \right) d\theta + \int_{\bar{\theta}}^{\hat{\theta}} \left(\theta q - \frac{1}{3}(\alpha \underline{q} + 2\alpha q + (2\bar{\theta} - \underline{\theta})\Delta q) \right) d\theta, \\ &= \underline{CS} + \Delta q \left(\frac{(\underline{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9} \right), \end{aligned}$$

$$\begin{aligned} SW &= CS + \Pi_1 + \Pi_2 - (\gamma - \mu q) \left(\frac{2\bar{\theta} - \underline{\theta} - \alpha}{3} \right) - (\gamma - \mu \underline{q}) \frac{\alpha + \bar{\theta} - 2\underline{\theta}}{3}, \\ &= \underline{SW} + \beta\Delta q(2\delta_I^* - \Delta q). \end{aligned}$$

3. When $2\bar{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ and both firms are brown then $\Pi_1 = \Pi_2 = \Pi = 0$; $D = \underline{D}$, $CS = \underline{CS}$ and $SW = \underline{SW}$. The general expression established in the previous case are still valid in this case with $\Delta q = 0$. ■

Result 4. In the partial information label case, depending on the marginal cost α and the environmental sensitivity to quality μ , at the SPNE, the firms' profits, the industry profit, the environmental damage, consumers' surplus and the social welfare are given in Table 3 for low α and Table 4 for intermediate α .

$\alpha \leq 2\underline{\theta} - \bar{\theta}$ and $\mu \leq \frac{3\underline{\theta} - \bar{\theta}}{2} - \alpha$	$\alpha \leq 2\underline{\theta} - \bar{\theta}$ and $\mu > \frac{3\underline{\theta} - \bar{\theta}}{2} - \alpha$
$\Pi_1 = 0$	$\Pi_1 = 0$
$\Pi_2 = \beta\delta_L^*(\bar{\delta}_L - \delta_L^*)$	$\Pi_2 = 0$
$\Pi = \beta\delta_L^*(\bar{\delta}_L - \delta_L^*)$	$\Pi = 0$
$D = \underline{D} - \mu\delta_L^*(\bar{\theta} - \underline{\theta})$	$D = \underline{D} - \mu\bar{\delta}_L(\bar{\theta} - \underline{\theta})$
$CS = \underline{CS} + \frac{(\bar{\theta} - \underline{\theta})^2}{2}\delta_L^*$	$CS = \underline{CS} + \frac{(\bar{\theta} - \underline{\theta})^2}{2}\bar{\delta}_L$
$SW = \underline{SW} + \beta\delta_L^{*2}$	$SW = \underline{SW} + \beta\bar{\delta}_L(2\delta_L^* - \bar{\delta}_L)$

Table 3 – The SPNE outcome for low α with a partial information label.

$2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ and $\mu \leq \frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6}$	$2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ and $\frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6} < \mu \leq \frac{4\bar{\theta} - 5\underline{\theta} + \alpha}{6}$	$2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ and $\mu > \frac{4\bar{\theta} - 5\underline{\theta} + \alpha}{6}$
$\Pi_1 = 0$	$\Pi_1 = \beta\underline{\delta}_I\delta_I^*$	$\Pi_1 = \beta\underline{\delta}_I\bar{\delta}_I$
$\Pi_2 = 0$	$\Pi_2 = \beta\delta_I^*(\bar{\delta}_I - \delta_I^*)$	$\Pi_2 = 0$
$\Pi = 0$	$\Pi = \beta\delta_I^*(\bar{\delta}_I - \delta_I^*) + \beta\underline{\delta}_I\delta_I^*$	$\Pi = \beta\underline{\delta}_I\bar{\delta}_I$
$D = \underline{D}$	$D = \underline{D} - \mu\delta_I^*\frac{2\bar{\theta} - \underline{\theta} - \alpha}{3}$	$D = \underline{D} - \mu\underline{\delta}_I\frac{2\bar{\theta} - \underline{\theta} - \alpha}{3}$
$CS = \underline{CS}$	$CS = \underline{CS} + \delta_I^*\left(\frac{(\underline{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9}\right)$	$CS = \underline{CS} + \bar{\delta}_I\left(\frac{(\underline{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9}\right)$
$SW = \underline{SW}$	$SW = \underline{SW} + \beta\delta_I^{*2}$	$SW = \underline{SW} + \beta\underline{\delta}_I(2\delta_I^* - \bar{\delta}_I)$

Table 4 – The SPNE outcome for intermediate α with a partial information label.

Proof of Result 4

We substitute Δq in the general expressions given in Table 2 by the values provided in Lemma 2. ■

Proof of Lemma 3

Using Result 1, we distinguish two cases:

- If $\alpha \leq 2\underline{\theta} - \bar{\theta}$, firms' profits are given by:

$$\Pi_1 = -\beta(q_1 - \underline{q})^2,$$

$$\Pi_2 = (\underline{\theta} - \alpha)(\bar{\theta} - \underline{\theta})(q_2 - q_1) - \beta(q_2 - \underline{q})^2.$$

We check that $\frac{\partial \Pi_1}{\partial q_1} = -2\beta(q_1 - \underline{q}) < 0$. Thus, Firm 1 chooses $q_1^* = \underline{q}$.

We check that Π_2 is concave down with respect to q_2 and that it is maximized at $q_2^* = \frac{\bar{\delta}_L}{2} + \underline{q}$.

- If $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$, firms' profits are given by:

$$\Pi_1 = \frac{1}{9}(2\underline{\theta} - \bar{\theta} - \alpha)^2(q_2 - q_1) - \beta(q_1 - \underline{q})^2,$$

$$\Pi_2 = \frac{1}{9}(2\bar{\theta} - \underline{\theta} - \alpha)^2(q_2 - q_1) - \beta(q_2 - \underline{q})^2.$$

We check that $\frac{\partial \Pi_1}{\partial q_1} = -\frac{1}{9}(2\underline{\theta} - \bar{\theta} - \alpha)^2 - 2\beta(q_1 - \underline{q}) < 0$. Thus, Firm 1 chooses $q_1^* = \underline{q}$. We check that Π_2 is concave down with respect to q_2 and that it is maximized at $q_2^* = \frac{\bar{\delta}_I}{2} + \underline{q}$. ■

Result 5. *In the complete information label case, depending on the marginal cost α , at the SPNE, the firms' profits, the industry profit, the environmental damage, consumers' surplus and the social welfare are given in Table 5.*

$\alpha \leq 2\underline{\theta} - \bar{\theta}$	$2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$
$\Pi_1 = 0$	$\Pi_1 = \beta \bar{\delta}_I \frac{\bar{\delta}_I}{2}$
$\Pi_2 = \beta \frac{\bar{\delta}_I^2}{4}$	$\Pi_2 = \beta \frac{\bar{\delta}_I^2}{4}$
$\Pi = \beta \frac{\bar{\delta}_I^2}{4}$	$\Pi = \beta \frac{\bar{\delta}_I}{2} (\frac{\bar{\delta}_I}{2} + \underline{\delta}_I)$
$D = \underline{D} - \mu \frac{\bar{\delta}_I}{2} (\bar{\theta} - \underline{\theta})$	$D = \underline{D} - \mu \frac{\bar{\delta}_I}{2} \frac{2\bar{\theta} - \underline{\theta} - \alpha}{3}$
$CS = \underline{CS} + \frac{(\bar{\theta} - \underline{\theta})^2}{2} \frac{\bar{\delta}_I}{2}$	$CS = \underline{CS} + \frac{\bar{\delta}_I}{2} \left(\frac{(\bar{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9} \right)$
$SW = \underline{SW} + \beta \bar{\delta}_L (\delta_L^* - \frac{\bar{\delta}_I}{4})$	$SW = \underline{SW} + \beta \bar{\delta}_I (\delta_I^* - \frac{\bar{\delta}_I}{4})$

Table 5 – The SPNE outcome with a complete information label.

Proof of Result 5

We substitute Δq in the general expressions given by Table 2 by the values provided in Lemma 3. ■

Denote by SW^p , SW^c , the social welfare with a partial and complete information label, respectively. Denote by Π_2^p and Π_2^c , the green firm profit with a partial and complete information label, respectively.

Proof of Proposition 1

We start by comparing the social welfare in both cases:

- If $\alpha \leq 2\underline{\theta} - \bar{\theta}$ then

– if $\mu < \frac{3\underline{\theta} - \bar{\theta}}{2} - \alpha$ then $SW^p - SW^c = \beta(\delta_L^* - \frac{\bar{\delta}_I}{2})^2 > 0$.

– if $\mu > \frac{3\underline{\theta} - \bar{\theta}}{2} - \alpha$ then $SW^p - SW^c = \beta \bar{\delta}_L (\delta_L^* - \frac{3}{4} \bar{\delta}_L) > 0$ as $\delta_L^* > \bar{\delta}_L$.

- If $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$

– if $\mu < \frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6}$ then $SW^p - SW^c = -\beta \bar{\delta}_I (\delta_I^* - \frac{\bar{\delta}_I}{4}) > 0$ as $\delta_I^* < 0$ when $\mu < \frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6}$.

- if $\frac{5\alpha-4\bar{\theta}-\theta}{6} < \mu < \frac{4\bar{\theta}-5\theta+\alpha}{6}$ then $SW^p - SW^c = \beta(\delta_I^* - \frac{\bar{\delta}_I}{2})^2 > 0$.
- if $\mu > \frac{4\bar{\theta}-5\theta+\alpha}{6}$ then $SW^p - SW^c = \beta\bar{\delta}_I(\delta_I^* - \frac{3}{4}\bar{\delta}_I) > 0$ as $\delta_I^* > \bar{\delta}_I$.

We now move to the comparison of the green firm profits

- If $\alpha \leq 2\underline{\theta} - \bar{\theta}$ then
 - if $\mu < \frac{3\theta-\bar{\theta}}{2} - \alpha$ then $\Pi_2^p - \Pi_2^c = -\beta(\delta_L^* - \frac{\bar{\delta}_L}{2})^2 < 0$.
 - if $\mu > \frac{3\theta-\bar{\theta}}{2} - \alpha$ then $\Pi_2^p - \Pi_2^c = -\beta\frac{(\bar{\delta}_L)^2}{4} < 0$.
- If $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ then
 - if $\mu < \frac{5\alpha-4\bar{\theta}-\theta}{6}$ then $\Pi_2^p - \Pi_2^c = -\beta\frac{(\bar{\delta}_I)^2}{4} < 0$.
 - if $\frac{5\alpha-4\bar{\theta}-\theta}{6} < \mu < \frac{4\bar{\theta}-5\theta+\alpha}{6}$ then $\Pi_2^p - \Pi_2^c = -\beta(\delta_I^* - \frac{\bar{\delta}_I}{2})^2 < 0$.
 - if $\mu > \frac{4\bar{\theta}-5\theta+\alpha}{6}$ then $\Pi_2^p - \Pi_2^c = -\beta\frac{(\bar{\delta}_I)^2}{4} < 0$. ■

Proof of Proposition 2

The cases that appeared when the label is a partial information label have to be distinguished here:

- If $\alpha \leq 2\underline{\theta} - \bar{\theta}$ then
 - if $\mu < \frac{3\theta-\bar{\theta}}{2} - \alpha$ then we easily prove that $\delta_L^* > \frac{\bar{\delta}_L}{2}$. Indeed, $\delta_L^* - \frac{\bar{\delta}_L}{2} = \frac{(\bar{\theta}-\theta)(\bar{\theta}-\theta+2\mu)}{4\beta} > 0$.
 - if $\mu > \frac{3\theta-\bar{\theta}}{2} - \alpha$ then obviously $\bar{\delta}_L > \frac{\bar{\delta}_L}{2}$.
- If $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ then
 - if $\mu < \frac{5\alpha-4\bar{\theta}-\theta}{6}$ then a partial information labeling authority does not offer any label i.e. $\Delta\tilde{q} = 0$. Thus, $\Delta\tilde{q} = 0 < \frac{\bar{\delta}_I}{2}$.
 - if $\frac{5\alpha-4\bar{\theta}-\theta}{6} < \mu < \frac{4\bar{\theta}-5\theta+\alpha}{6}$ then $\delta_I^* > \frac{\bar{\delta}_I}{2}$ if and only if $\mu > \frac{\alpha-\theta}{2}$.
 - if $\mu > \frac{4\bar{\theta}-5\theta+\alpha}{6}$ then obviously $\bar{\delta}_I > \frac{\bar{\delta}_I}{2}$. ■

Denote by Π_1^p and Π_1^c , the brown firm profit with a partial and complete information label, respectively. Denote by D^p and D^c , the environmental damage with a partial and complete information label, respectively.

Proof of Proposition 3

The brown firm profit is null when $\alpha < 2\underline{\theta} - \bar{\theta}$ as consumers only buy the green product whatever the label's type. When $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ then the profit of the brown firm is positively and linearly related to Δq . Thus, the brown firm prefers that the green firm offers the highest possible quality. Using the results of Proposition 2, we have:

- If $\mu > \frac{\alpha-\theta}{2}$ then $\Pi_1^p - \Pi_1^c > 0$.
- If $\mu < \frac{\alpha-\theta}{2}$ then $\Pi_1^p - \Pi_1^c < 0$.

The same results hold when considering the environmental damage. We first notice from Table 2 that the environmental damage is linearly and negatively related to the green quality. Thus,

- If $\alpha \leq 2\underline{\theta} - \bar{\theta}$ then the partial information labeling criteria are more stringent than the green quality of the complete information label and consequently $D^p - D^c < 0$.
- If $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ then the partial information labeling criteria are more stringent than the green quality of the complete information label if and only if $\mu > \frac{\alpha - \underline{\theta}}{2}$ in which case, we have $D^p - D^c > 0$. ■

Denote by CS^p and CS^c , consumers' surplus with a partial and complete information label, respectively.

Proof of Proposition 4

We now examine consumers' surplus:

- If $\alpha \leq 2\underline{\theta} - \bar{\theta}$ then consumers' surplus is positively and linearly related to Δq as shown in Table 2. As the labeling criteria with a partial information label are more stringent than the green quality of the complete information label then $CS^p - CS^c > 0$
- If $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ then consumers' surplus is linearly related to Δq as shown in Table 2. However, the relationship can be positive or negative depending on the sign of $\frac{(\underline{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9}$. We show that if $2\underline{\theta} - \bar{\theta} < \alpha < \tilde{\alpha}$ then $\frac{(\underline{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9} > 0$ and if $\tilde{\alpha} < \alpha < 2\bar{\theta} - \underline{\theta}$ then $\frac{(\underline{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9} < 0$. Thus,
 - If $\mu < \frac{\alpha - \underline{\theta}}{2}$ then $\alpha > \tilde{\alpha}$. Thus, $CS^p - CS^c > 0$ as the partial information label is less stringent than the green quality of the complete information label and as consumers' surplus is negatively related to Δq .
 - If $\mu > \frac{\alpha - \underline{\theta}}{2}$ and $\alpha < \tilde{\alpha}$ then $CS^p - CS^c > 0$ as the partial information label is more stringent than the green quality of the complete information label and as consumers' surplus is positively related to Δq .
 - If $\mu > \frac{\alpha - \underline{\theta}}{2}$ and $\alpha > \tilde{\alpha}$ then $CS^p - CS^c < 0$ as the partial information label is more stringent than the green quality of the complete information label and as consumers' surplus is negatively related to Δq . ■

Denote by Π^p and Π^c , the industry profit with a partial and complete information label, respectively.

Proof of Proposition 5

We now examine the industry profit.

- If $\alpha \leq 2\underline{\theta} - \bar{\theta}$, then the industry profit is equal to the green firm profit and is higher with a complete information label as shown in Proposition 1.
- If $2\underline{\theta} - \bar{\theta} < \alpha < 2\bar{\theta} - \underline{\theta}$ then
 - if $\mu < \frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6}$ then $\Pi^p - \Pi^c = -\beta(\underline{\delta}_I + \frac{\bar{\delta}_I}{2})\frac{\bar{\delta}_I}{2} < 0$.

- if $\frac{5\alpha - 4\bar{\theta} - \underline{\theta}}{6} < \mu < \frac{4\bar{\theta} - 5\underline{\theta} + \alpha}{6}$ then $\Pi^p - \Pi^c = \beta(\delta_I^* - \frac{\bar{\delta}_I}{2})(\frac{\bar{\delta}_I}{2} + \underline{\delta}_I - \delta_I^*)$. We have that $\Pi^p - \Pi^c > 0$ if and only if $\frac{\bar{\delta}_I}{2} < \delta_I^* < \frac{\bar{\delta}_I}{2} + \underline{\delta}_I$ which is equivalent to $\frac{\alpha - \underline{\theta}}{2} < \mu < \frac{2}{3} \frac{(\alpha + \bar{\theta} - 2\underline{\theta})^2}{2\bar{\theta} - \underline{\theta} - \alpha} + \frac{\alpha - \underline{\theta}}{2}$.
- if $\mu > \frac{4\bar{\theta} - 5\underline{\theta} + \alpha}{6}$ then $\Pi^p - \Pi^c = \beta \frac{\bar{\delta}_I}{2} (\underline{\delta}_I - \frac{\bar{\delta}_I}{2})$. We have that $\Pi^p - \Pi^c > 0$ if and only if $\underline{\delta}_I > \frac{\bar{\delta}_I}{2}$ which is equivalent to $\alpha^2 - 2\alpha(5\underline{\theta} - 4\bar{\theta}) - 2\bar{\theta}^2 + 7\underline{\theta}^2 - 4\bar{\theta}\underline{\theta} > 0$. The quadratic expression is positive if $\alpha > \bar{\alpha}$ and negative if $\alpha < \bar{\alpha}$. Thus,
 - * if $\alpha < \bar{\alpha}$ then $\underline{\delta}_I < \frac{\bar{\delta}_I}{2}$ and $\Pi^p - \Pi^c < 0$.
 - * if $\alpha > \bar{\alpha}$ then $\underline{\delta}_I > \frac{\bar{\delta}_I}{2}$ and $\Pi^p - \Pi^c > 0$. ■

Difference of consumers' surplus and difference of industry profits under the two types of labels

Denote by $\Delta CS(\alpha) = CS^p(\alpha) - CS^c(\alpha)$ the difference between consumers' surpluses with a partial information label and a complete information label at equilibrium and denote by $\Delta \Pi(\alpha) = \Pi^p(\alpha) - \Pi^c(\alpha)$ the difference between industry profits with a partial information label and a complete information label at equilibrium. Using Results 4 and 5, the expressions of $\Delta CS(\alpha)$ and $\Delta \Pi(\alpha)$ for $\frac{\bar{\theta} - \underline{\theta}}{2} < \mu < \frac{3\bar{\theta} - \underline{\theta}}{2}$ are respectively given by:

$$\Delta CS(\alpha) = \begin{cases} \frac{(\bar{\theta} - \underline{\theta})^3}{8\beta} (\bar{\theta} - \underline{\theta} + 2\mu) & \text{if } \alpha < \frac{3\bar{\theta} - \underline{\theta}}{2} - \mu, \\ \frac{(\bar{\theta} - \underline{\theta})^3}{4\beta} (\underline{\theta} - \alpha) & \text{if } \frac{3\bar{\theta} - \underline{\theta}}{2} - \mu < \alpha < 2\underline{\theta} - \bar{\theta}, \\ \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18\beta} \left(\frac{(\bar{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9} \right) & \text{if } 2\underline{\theta} - \bar{\theta} < \alpha < 6\mu - 4\bar{\theta} + 5\underline{\theta}, \\ \left(\frac{(2\bar{\theta} - \underline{\theta} - \alpha)(4\bar{\theta} + \underline{\theta} - 5\alpha + 6\mu)}{36\beta} - \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18\beta} \right) \left(\frac{(\bar{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9} \right) & \text{if } 6\mu - 4\bar{\theta} + 5\underline{\theta} < \alpha < \frac{6\mu + 4\bar{\theta} + \underline{\theta}}{5}, \\ -\frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18\beta} \left(\frac{(\bar{\theta} - \alpha)(2\bar{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9} \right) & \text{if } \alpha > \frac{6\mu + 4\bar{\theta} + \underline{\theta}}{5}. \end{cases}$$

$$\Delta \Pi(\alpha) = \begin{cases} -\frac{(\bar{\theta} - \underline{\theta})^2}{16\beta} (\bar{\theta} - \underline{\theta} + 2\mu)^2 & \text{if } \alpha < \frac{3\bar{\theta} - \underline{\theta}}{2} - \mu, \\ -\frac{(\bar{\theta} - \underline{\theta})^2}{4\beta} (\underline{\theta} - \alpha)^2 & \text{if } \frac{3\bar{\theta} - \underline{\theta}}{2} - \mu < \alpha < 2\underline{\theta} - \bar{\theta}, \\ \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18\beta} \left(\frac{(\alpha + \bar{\theta} - 2\underline{\theta})^2}{9} - \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18} \right) & \text{if } 2\underline{\theta} - \bar{\theta} < \alpha < 6\mu - 4\bar{\theta} + 5\underline{\theta}, \\ \left(\frac{(2\bar{\theta} - \underline{\theta} - \alpha)(4\bar{\theta} + \underline{\theta} - 5\alpha + 6\mu)}{36} - \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18} \right) \left(-\frac{(2\bar{\theta} - \underline{\theta} - \alpha)(4\bar{\theta} + \underline{\theta} - 5\alpha + 6\mu)}{36\beta} + \frac{(\bar{\theta} - 2\underline{\theta} + \alpha)^2}{9\beta} + \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18\beta} \right) & \text{if } 6\mu - 4\bar{\theta} + 5\underline{\theta} < \alpha < \frac{6\mu + 4\bar{\theta} + \underline{\theta}}{5}, \\ -\frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18\beta} \left(\frac{(\alpha + \bar{\theta} - 2\underline{\theta})^2}{9} + \frac{(2\bar{\theta} - \underline{\theta} - \alpha)^2}{18} \right) & \text{if } \alpha > \frac{6\mu + 4\bar{\theta} + \underline{\theta}}{5}. \end{cases}$$

Figure 2 gives the curves of $\Delta CS(\alpha)$ and $\Delta \Pi(\alpha)$ in the particular case where $\bar{\theta} = 2.5$, $\underline{\theta} = 1.5$, $\beta = 1$ and $\mu = 0.75$.

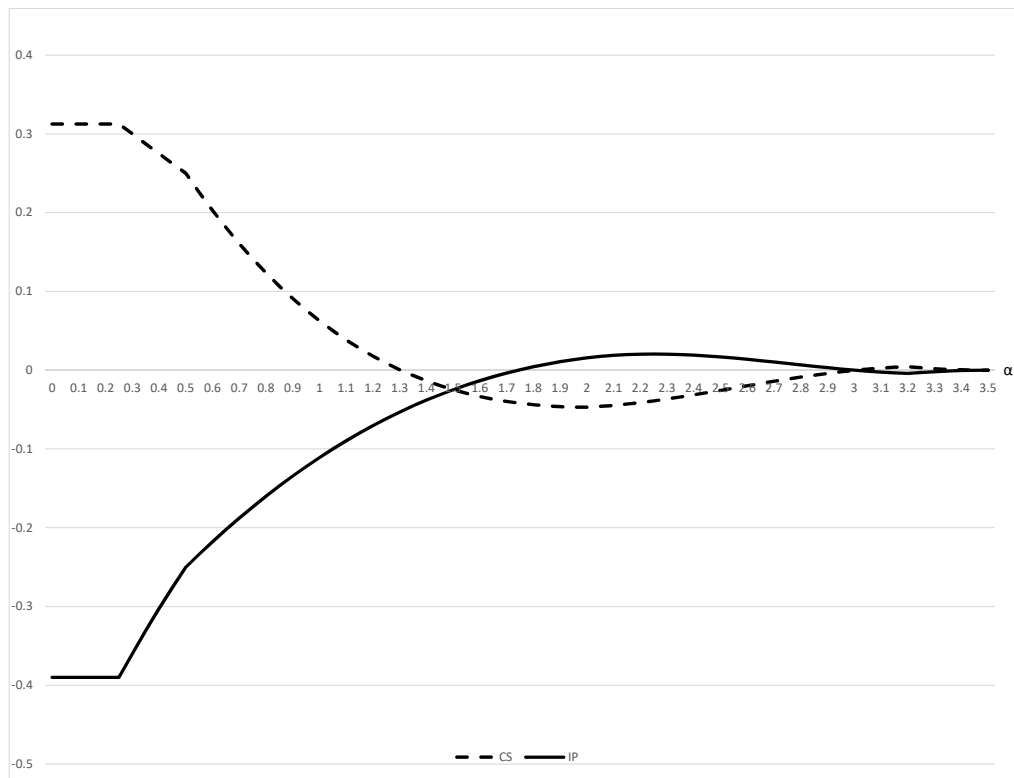


Figure 2 – Difference of consumers' surplus and difference of industry profit curves for $\bar{\theta} = 2.5$, $\underline{\theta} = 1.5$, $\beta = 1$ and $\mu = 0.75$.