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Hend Ghazzai
Mediterranean School of Business at South Mediterranean University
Rim Lahmandi-Ayed (rim.lahmandi.ayed@gmail.com)
Universite de Carthage Ecole Superieure de Statistique et de l'Analyse de l'Information
https://orcid.org/0000-0002-6427-4778

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Ecolabel: Is More Information Better?*

Hend Ghazzai[†a] and Rim Lahmandi-Ayed[‡b]

[a]Mediterranean School of Business, SMU and U.R. MASE-ESSAI,

Université de Carthage

[b]ESSAI and U.R. MASE-ESSAI, Université de Carthage

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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 comparison between the two types of ecolabel in terms of the brown firm's profit, the industry's profit, the consumers surplus and the environment depend in a non-obvious way on the marginal cost of quality and on the environmental sensitivity to quality.

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[†]hend.ghazzai@msb.tn

[‡]rim.lahmandi.ayed@gmail.com (corresponding author) ESSAI, 6, rue des métiers, Charguia 2, BP 675-1080 Tunis, Tunisia.

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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 reduce this information asymmetry between consumers and firms by providing information on the ecological attributes of products. Consumers are more and more aware of the environmental issues and ready to make efforts to contribute to achieve a better environment. To enable consumers to express their concern through well informed purchases may be a good way to exert pressure on firms and get them to be more friendly to the environment. Thus, one may think that the more accurate the information provided the better off are 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 as classified by the International Standards Organization (ISO). ISO Type I ecolabels, such as the "Nordic Swan", "Japanese-Eco Mark" and "Canadian Environmental Choice" 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. ISO Type III Environment Declarations consist of a list of quantitative indicators of the environmental performance of a product that allow objective comparisons between products fulfilling the same function. Thus, The role of a type III ecolabel is to provide consumers with complete information about a product environmental quality without setting *a priori* any environmental criteria. Most Environmental Product Declaration (EPD) are third party verified. Examples are "Eco-Leaf" and "IBU Environmental Product Declaration".[1]

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. Vertical preferences imply that consumers are willing to pay more to acquire a product with better environmental attributes, thus have an intrinsic preference for environmental friendly products. We compare two scenarii corresponding to each type

[1]ISO type 2 Self-declared environmental claims also exist but they are not of interest for our paper as they are claims made by companies describing an environmental attribute of their product but not third-party certified.

of ecolabel considered. 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 or not to conform to 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. The authority is assumed to be able to know the exact quality of the product and to inform consumers about it. Finally firms compete in prices.

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.

The results concerning the social welfare and the green firm's profit are expected by construction. But those concerning the brown firm, the industry profit, consumers and the environmental damage are not obvious. Interestingly, consumers' preferences (between the two types of label) and industry preferences may change twice as the marginal cost of quality increases. Moreover, agents may behave in a surprising way. For high enough marginal costs, the industry as a whole and consumers have divergent interests in terms of the best ecolabel type. If firms cooperate through appropriate transfers, they may campaign for the label's type the most friendly to the environment, going against the consumers' interest. The industry as a whole may thus behave in a way more friendly to the environment than consumers even though firms do not have any intrinsic preferences for the environmental quality contrary to consumers. Many empirical studies show a positive relationship between firms' environmental performance and financial performance using different performance measures and are thus aligned with this result. Among them we may cite: King and Lenox (2001), Freedman and Patten (2004), Nakao et al (2007a) and (2007b) and Guenster et al (2011). It is worth noting that this result is not linked to any greenwashing behavior of firms who are supposed to reveal their real environmental qualities certified by third party organizations [2].

[2] An extensive literature review about greewashing can be found in Lyon and Montgomery (2015), Seele and Gatti (2017) and Gatti et al (2019).

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; Fischer & Lyon, 2014; Fischer & Lyon, 2019 and Poret 2019).

The first scenario of this paper (type I ecolabel) 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. The 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 type III product declarations where the central authority certifies the exact quality of each firm.

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: Fischer & Lyon (2019) 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, considering price-taking firms while we consider strategic firms choosing their prices and having market power as in Amacher & al (2004), Andre & al (2009), Poret (2019)...

In this paper, we compare a type I label (taking the model of Ben Youssef and Lahmandi-Ayed, 2008) and a type III one (consisting simply in giving firms the possibility to choose from a continuous segment and not from a discrete set as in a multi-level ecolabel). What is new in our paper is not the calculation of equilibria (qualities, prices) under each type of ecolabels, but the comparison of these ecolabels on consumers, producers, environmental damage and social welfare. To the best of our knowledge this comparison is done for the first time relative to the existing literature.

Bonroy & Constantatos (2015) compare the level (stringency) of a type I label according to the agency that selects it: the goverment, an NGO or the industry; using a consumers' utility function

similar to ours but incorporating a different environmental damage function. Only the optimal labeling criteria are compared while we compare the effect of type I and Type III labels on welfare, firms, consumers, the industry and the environment.

Fischer & Lyon (2019) and Li & Van't Veld (2015) use different models. The former authors 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). Li & Van't Veld (2015) 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.

The information on environmental quality has extensively been studied in the litterature. 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. Podhorsky (2020) compares information provision through certification with taxation, considering a different model where the demand may be represented by a representative consumer and there is uncertainty on the ability of firms to learn the technology necessary to conform to the certification. Information on environmental quality has been dealt with differently by Sinclair-Degagné and Gozlan (2003). They suppose that a potential polluter informed on the actual risk of its activity deals with a stakeholder holding only prior beliefs. The informed firm delivers a report with a chosen degree of precision (more precision requiring a higher cost), then the stakeholder decides to approve, to boycott or to carefully study the report, which has different consequences on the payoff of each party. The authors determine conditions under which the firm delivers precise information and conditions under which it chooses to deliver hazier information. Finally, Garrido et al (2020) show that regulation requiring mandatory certification can hinder information transmission.

The idea that more information may be detrimental to the informed parties is not new. Sakai (1985) considering a duopoly model with cost functions subject to uncertainty, shows that information may

be detrimental to either firm and to consumers. Schlee (1996) considering a model with consumers and a monopolist both uncertain about the product's quality, proves that consumers may not prefer more public information. Gal-Or (1987) proves that in a Stackelberg quantity competition with a leader benefitting from a private information, the follower may be better off compared to the leader. Gal-Or (1988) proves that a firm in a duopolistic market in which there is incomplete information about cost may benefit from having less precise prior information than its competitor. In all these papers, firms are imperfectly informed about either quality, demand or costs. Information allows the agent to make better decisions but also affects the decisions of the other agents. The overall effect may be negative. Concerning consumers, as explained by Schlee (1996), they "may dislike public information if the firm's response to new information is on average sufficiently detrimental". In our paper only consumers may be imperfectly informed on the product's environmental quality. Therefore their possible preference for less information does not stem from a fear of a detrimental reaction of firms to information. They may prefer to be less informed because complete information allows the green firm to choose the green quality so as to maximize its profit, while partial information means that an authority chooses the green quality so as to maximize the social surplus, thus takes better charge of the interests of consumers. The difference between the two types of ecolabels is not limited to the quantity or the accuracy of the information provided. Finally, we establish our results while ignoring the problem of processability of information as in Scammon (1977) for instance.

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 $[\underline{\theta}, \overline{\theta}]$, with $0 < \underline{\theta} < \overline{\theta}$. We assume that each consumer

buys exactly one unit of the product from the firm which ensures to him/her the highest utility. The market is thus fully covered. As in Mussa & Rosen [32], the indirect utility of a consumer θ buying quality q_i at price p_i, is given by:

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

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, thus supposing that environment friendly processes are more costly.

Before the set-up of an ecolabel, firms produce quality $\underline{q} > 0$ that may be considered as a minimum quality standard. 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 q satisfying $\underline{q} \leq q < \tilde{q}$ 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 $[\underline{q}, \overline{q}]$.

Moving to a quality q greater than $\underline{q}$ means that a firm is becoming greener. This is supposed to involve a fixed cost I increasing with respect to the difference between the initial and the new quality and 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 global environmental 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.[3]

In our model, we consider two types of effects of the environmental quality. First the consumer perceives it in a subjective way through the utility function $U_i = \theta q_i - p_i$ which depends on the quality, the price and his/her individual characteristic (θ). Second there is an objective damage per unit of good (d) which depends physically on the quality produced. We suppose that this damage is not perceived by consumers[4]. Consider simply a consumer purchasing a car. Depending on his/her awareness of the environmental issue (θ), the environmental quality (electrical or not, more or less fuel consuming...) and the price, he/she will make his/her choice. He/she then derives a utility equal to $\theta q_i - p_i$. But the pollution and the other nuisances caused by the production of the car result in an objective and theoretically measurable global damage not taken into account by the consumer. The paper allows the distinction between the subjective utility and an objective environmental damage.

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

Partial Information Label

1. The labeling authority chooses the level of labeling criteria $\tilde{q}$ so as to maximize the social welfare.

[3] Amir et al (2019) offer an alternative modeling of green quality using Spence (1975)'s model.
There is an abundant literature on pollution regulation with a homogenous product: David and Sinclair-Desgagné (2005) and (2010), Benchekroun and Yildiz (2011), Acikgoz and Benchekroun (2017)...among the most recent papers. In our model, we suppose that the environmental quality of the product, which summarizes its environmental impact including direct pollution, determines at the same time the environmental damage and the utility of the consumers differently depending on their awareness of the environment.

[4] we may also suppose that it is equally perceived by each one of them as assumed by Bonroy & Constantatos (2015). Both hypotheses indifferently lead to the same analysis.

2. Firms simultaneously choose their qualities in the pair $\{\underline{q}, \tilde{q}\}$.

3. The labeling authority attributes the ecolabel to the deserving firms (i.e. when $q \geq \tilde{q}$).

4. Firms simultaneously choose their prices.

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:

$$SW = CS + \Pi - D,$$

CS being the consumers' surplus, Π the industry profit and D the (total) environmental damage. The expression of each term depends on the number of active firms on the market (one or two).

The objective function of the labeling authority takes into account the interests of many stakeholders: consumers, firms and the environment. It is thus acting as a social planner. The Blue Angel ecolabel and the EU ecolabel are examples of labels issued by such environmental authorities. Their criteria have been developed and reviewed in cooperation of experts, industry representatives, consumers' organizations and environmental NGOs.[5]

Complete Information Label

1. Firms simultaneously choose their qualities q_i in the segment $[\underline{q}, \overline{q}]$.

2. The labeling authority declares publicly the exact environmental quality of each firm.

3. Firms simultaneously choose their prices.

We suppose that $\overline{q}$ is sufficiently high so that it is never constraining.
The labeling authority role in the case of a complete information label is only informative. Contrary to a labeling authority offering a type I label, it does not set any labeling criteria.

The games described above will keep the same solutions if firms are given the choice to certify their environmental efforts once they choose their qualities. Indeed, it is always in the interest of a firm that

[5] The results would of course differ if the label was proposed by an NGO or by the industry as the labeling authority will maximize a different objective function.

produces a quality higher than $\underline{q}$ to certify it. In the partial information game, the labeling authority attributes the ecolabel to the deserving firms i.e. those that produce an environmental quality higher than or equal $\tilde{q}$. As consumers are not able to recognize by themselves the environmental quality of a product, when a firm meets the labeling criteria it should always apply for the label. Otherwise, consumers will believe that it has the lowest environmental quality. The same reasoning applies for the complete information game. As far as a firm produces a higher quality than $\underline{q}$, it has interest to have it certified by the labeling authority otherwise it will not be recognized by consumers.

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 in case of multiplicity of equilibria. 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 as long as producing a higher quality does not decrease their profits. Firms are supposed to make green choices only when this does not require any effort. This is different from consumers who are willing to pay more to acquire a more friendly product. In this sense consumers are supposed to have intrinsic preferences for environment, while firms are not.

We now state a first result derived from Ben Youssef and Lahmandi-Ayed (2008), about the price equilibrium for any couple of qualities, whether 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 $\alpha \geq 2\overline{\theta} - \underline{\theta}$, only Firm 1 is active and prices and demands are respectively given by:*

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

2. ***Low Marginal Costs:*** *if $\alpha \leq 2\underline{\theta} - \overline{\theta}$, only Firm 2 is active and prices and demands are respectively given by:*

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

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

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

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

The proof of Result 1 can be found in Ben Youssef and Lahmandi-Ayed (2008). Helpfully Lemma 1 provides some interesting properties on firms' demands and margins when the marginal cost is intermediate (Case 3 of Result 1).

Lemma 1 (Demands and margins in the intermediate marginal costs case)**.** *In the intermediate marginal costs case, for any couple of qualities, at price equilibrium,*

1. *The demands of both firms do not depend on qualities.*
2. *The high quality firm's demand is decreasing with α and the low quality firm's demand is increasing in α.*
3. *The margin of the high quality firm is decreasing with α and the margin of the low quality firm is increasing in α.*
4. *The margin of each firm 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 forces the high quality firm to loose 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's. 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 state 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 $\alpha \geq 2\overline{\theta} - \underline{\theta}$ 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 $\alpha < 2\overline{\theta} - \underline{\theta}$.

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 social welfare. 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 [7]. 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:

$\overline{\delta}_L = \frac{(\overline{\theta}-\underline{\theta})(\underline{\theta}-\alpha)}{\beta}$, $\delta^*_L = \frac{(\overline{\theta}-\underline{\theta})(\overline{\theta}+\underline{\theta}-2\alpha+2\mu)}{4\beta}$, $\overline{\delta}_I = \frac{(2\overline{\theta}-\underline{\theta}-\alpha)^2}{9\beta}$ and $\delta^*_I = \frac{(2\overline{\theta}-\underline{\theta}-\alpha)(4\overline{\theta}+\underline{\theta}-5\alpha+6\mu)}{36\beta}$.

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

$\overline{\delta}_L$ and $\overline{\delta}_I$ 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 $\overline{\delta}_L$ and $\overline{\delta}_I$ are not binding, respectively in the low and intermediate marginal costs cases.

Lemma 2 (Partial Information Label, Ben Youssef and Lahmandi-Ayed, 2008)**.** *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*** *($\alpha \leq 2\underline{\theta} - \overline{\theta}$): 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 $\mu \leq \frac{3\underline{\theta}-\overline{\theta}}{2} - \alpha$ then $\tilde{q}^* = \delta^*_L + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \delta^*_L + \underline{q}$.*
   - *if $\mu > \frac{3\underline{\theta}-\overline{\theta}}{2} - \alpha$ then $\tilde{q}^* = \overline{\delta}_L + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \overline{\delta}_L + \underline{q}$.*

2. ***Intermediate marginal costs*** *($2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$): 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 $\mu \leq \frac{5\alpha-4\overline{\theta}-\underline{\theta}}{6}$ then $\tilde{q}^* = \underline{q}$, which amounts to no label and $q_1 = q_2 = \underline{q}$.*
   - *if $\frac{5\alpha-4\overline{\theta}-\underline{\theta}}{6} < \mu \leq \frac{4\overline{\theta}-5\underline{\theta}+\alpha}{6}$ then $\tilde{q}^* = \delta^*_I + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \delta^*_I + \underline{q}$.*
   - *if $\mu > \frac{4\overline{\theta}-5\underline{\theta}+\alpha}{6}$ then $\tilde{q}^* = \overline{\delta}_I + \underline{q}$; $q_1 = \underline{q}$ and $q_2 = \overline{\delta}_I + \underline{q}$.*

When the marginal cost is intermediate and the environmental sensitivity to quality is too low ($2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$ and $\mu \leq \frac{5\alpha-4\overline{\theta}-\underline{\theta}}{6}$), the labeling authority chooses the labeling criteria $\tilde{q} = \underline{q}$, which amounts to the same as the absence of 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 $\mu \leq \frac{5\alpha-4\overline{\theta}-\underline{\theta}}{6}$ is never satisfied when $\alpha < \frac{4\overline{\theta}+\underline{\theta}}{5}$, as we easily check that $2\underline{\theta} - \overline{\theta} < \frac{4\overline{\theta}+\underline{\theta}}{5} < 2\overline{\theta} - \underline{\theta}$. Thus, when $2\underline{\theta} - \overline{\theta} < \alpha < \frac{4\overline{\theta}+\underline{\theta}}{5}$, 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 equilibirum qualities are given as follows:*

1. ***Low marginal costs*** *($\alpha \leq 2\underline{\theta} - \overline{\theta}$): $q_1^* = \underline{q}$ and $q_2^* = \frac{\overline{\delta}_L}{2} + \underline{q}$. Only firm 2 is active.*
2. ***Intermediate marginal costs*** *($2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$): $q_1^* = \underline{q}$ and $q_2^* = \frac{\overline{\delta}_I}{2} + \underline{q}$. 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 quality higher than $\underline{q}$ thus becoming 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 $\tilde{\alpha} = -4\underline{\theta} + 5\overline{\theta} - 3\sqrt{3}(\overline{\theta} - \underline{\theta})$ and by $\overline{\alpha} = 5\underline{\theta} - 4\overline{\theta} + 3\sqrt{2}(\overline{\theta} - \underline{\theta})$. We easily check that $2\underline{\theta} - \overline{\theta} < \tilde{\alpha} < \underline{\theta} < \overline{\alpha} < 2\overline{\theta} - \underline{\theta}$.

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

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

Table 1 – Zones

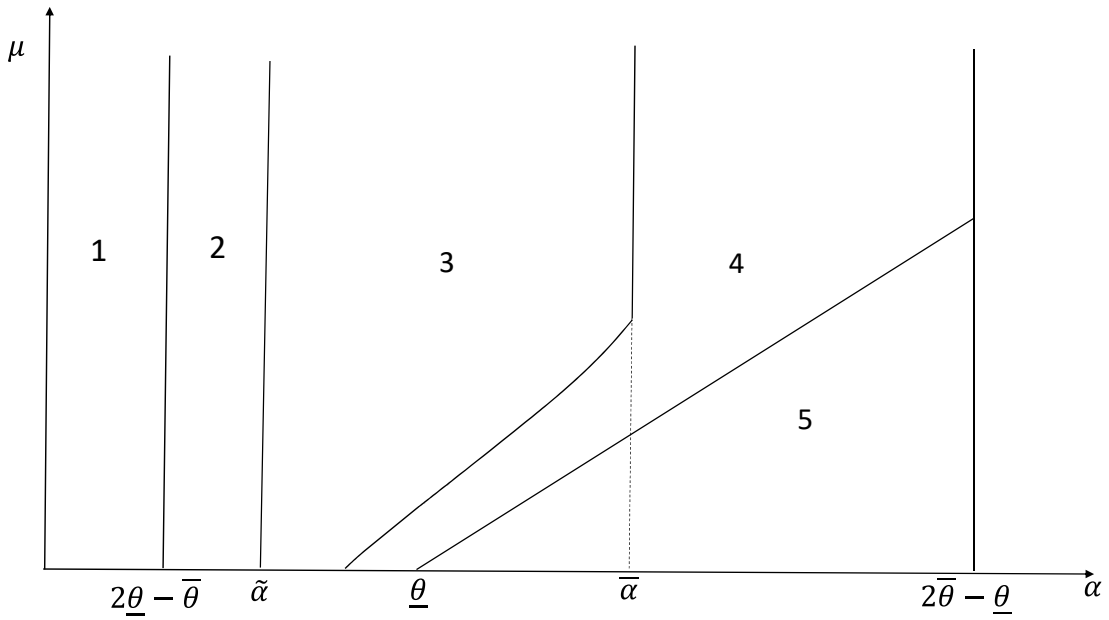

Figure 1 – Zones in the (α, μ)-space of interest for Propositions 1 to 5.

We now give the results of the comparison between the labels in Propositions 1 to 5.

Proposition 1 (The social welfare and the green firm profit)**.** *For all values of* (α, μ)*, such that* $\alpha < 2\overline{\theta} - \underline{\theta}$ *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. This result holds by construction. Indeed 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, 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 $[\underline{q}, \overline{q}]$. To ensure maximal differentiation the brown firm chooses the lowest quality $\underline{q}$. Hence, the green quality corresponds to the best response of the green firm to $\underline{q}$ 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 and environmental damage)**.** *Using the zones defined in Table 1 and depicted in Figure 1, relative to a complete information label, under a partial information label,*

- *In zones 1 to 4 (i.e. when $\mu > \frac{\alpha-\theta}{2}$), the green quality is more stringent and the environmental damage is lower.*
- *In zones 5 (i.e. when $\mu < \frac{\alpha-\theta}{2}$), the green quality is less stringent and the environmental damage is higher.*

The labeling criteria chosen by the authority issuing a partial information label may be more or less stringent than the green quality adopted under a complete information label. A 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 a 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, neither is it always beneficial to green consumers who consume a greener quality but at a higher price permitted by more differentiation. The partial information labeling authority has to take into consideration all these diverging interests. The higher α the

higher are the negative effects of a higher green quality on consumers and the green firm. The higher μ the higher is the benefit on the environment of a higher green quality. When μ is sufficiently high relative to α, the benefit of a higher green quality is high relative to its drawbacks, which urges the labeling authority to choose labeling criteria more stringent relative to a decentralized choice made 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) the authority does not set labeling criteria.

The comparison for the environmental damage follows strictly the comparison between the green qualities: the higher the green quality the lower the environmental damage as demands for both qualities do not depend on qualities as explained in Lemma 1. Thus, as in Takeshi and Mukherjee (2020), we prove that a higher welfare does not necessarily imply a lower environmental damage.

Proposition 3 (The brown firm profit)**.** *Using the zones defined in Table 1 and depicted in Figure 1, relative to the complete information label, under the partial information label,*

- *In zone 1, the profit of the brown firm is null (under both scenarii).*

- *In zones 2, 3 and 4, the profit of the brown firm is higher.*

- *In zone 5, the profit of the brown firm is lower.*

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 (Proposition 2).

Proposition 4 (Consumers' surplus)**.** *Using the zones defined in Table 1 and depicted in Figure 1, relative to the complete information label, under the partial information label:*

- *In zones 1, 2 and 5, consumers' surplus is higher.*
- *In zones 3 and 4, consumers' surplus is lower.*

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:

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

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

The surplus of green consumers is linearly related to the green quality q and 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 ($\alpha \leq 2\underline{\theta} - \overline{\theta}$), 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 4^{th} degree polynomial function (see Appendix).

Proposition 5 (Industry profit)**.** *Using the zones defined in Table 1 and depicted in Figure 1, relative to the complete information label, under the partial information label,*

- *In zones 1, 2, 3 and 5, the industry profit is lower.*
- *In zone 4, the industry profit is higher.*

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 partial information label is more stringent than the green quality of a complete information label. The industry profit is lower with a partial information label in zone 5 as the labeling criteria are less stringent than the green qualtiy of the complete information label case. 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 4^{th} 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). 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" together 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 together 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, contrary to consumers, do not have an intrinsic preference for green products.

Finally, if we observe the interests of the industry, the consumers and the environment, there is never convergence between the three, i.e. they never agree on a type of ecolabels.

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. A partial information label is always socially better than a complete information one, implying that more information is not socially better in this framework. It is socially better to provide information on the category of a product rather than on its exact quality level.

As for agents taken separately, a partial information label always deteriorates the green firm profit compared to a complete information label, but there is no clear advantage of one type of label over the other for the environment, the brown firm, the industry and consumers. The comparison depends in the last cases on the sensitivity of the environment to the quality relative to the quality cost.
Interestingly, we showed that the industry as a whole may prefer the most friendly ecolabel type against the consumers' interests. If firms accept to cooperate through appropriate transfers, they may campaign for the ecolabel type the most friendly to the environment and may therefore seem more friendly to the environment than the consumers.

One of the 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 a priori only be found numerically.

Another possible extension of the adopted model is to examine the effects on equilibrium outcomes of a change in consumers' tastes as in Garcia-Gallegos and Georgantzis (2009). We have first to determine the effect of such changes on the equilibrium under each type of ecolabel, then on the comparison between their outcomes.

Finally, we may explore the endogenous determination of the minimum standard ($\underline{q}$) which is supposed in our model exogenous and the same in the two types of ecolabel. Supposing that this standard may be determined under each regime should lead to different values of the standard and may possibly change the comparisons relative to our findings.

Appendix

Proof of Lemma 1

The proof follows from Result 1. The firms' demands and margins with intermediate marginal costs are given respectively by:

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

■

Proof of Result 2

The proof is based on Result 1. Assuming that $q_1 < q_2$, we have that $\Pi_1 = (\alpha - \overline{\theta})(q_2 - q_1) - \beta(q_1 - \underline{q})^2$ and $\Pi_2 = -\beta(q_2 - \underline{q})^2$. 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 $\underline{\delta}_I = \frac{(\alpha+\overline{\theta}-2\underline{\theta})^2}{9\beta}$.

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:

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

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

$$\underline{SW} = \underline{CS} - (\gamma - \mu\underline{q})(\overline{\theta} - \underline{\theta}) = (\overline{\theta} - \underline{\theta})((\frac{\overline{\theta} + \underline{\theta}}{2} - \alpha + \mu)\underline{q} - \gamma).$$

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

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 $\alpha \leq 2\underline{\theta} - \overline{\theta}$, as proved 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:

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

$$\Pi_1 = 0,$$

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

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

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

$$SW = CS + \Pi_1 + \Pi_2 - (\gamma - \mu q)(\overline{\theta} - \underline{\theta}) = (\overline{\theta} - \underline{\theta})[(\frac{\overline{\theta} + \underline{\theta}}{2} - \alpha - \mu)q - \gamma] - \beta\Delta q^2,$$

$$= \underline{SW} + \beta\Delta q(2\delta_L^* - \Delta q).$$

2. When $2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$ 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:

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

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

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

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

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

$$= \underline{CS} + \Delta q(\frac{(\underline{\theta} - \alpha)(2\overline{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\overline{\theta} - 2\underline{\theta} + \alpha)^2}{9}),$$

$$SW = CS + \Pi_1 + \Pi_2 - (\gamma - \mu q)(\frac{2\overline{\theta} - \underline{\theta} - \alpha}{3}) - (\gamma - \mu\underline{q})\frac{\alpha + \overline{\theta} - 2\underline{\theta}}{3},$$

$$= \underline{SW} + \beta\Delta q(2\delta_I^* - \Delta q).$$

3. When $2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$ 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.*

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

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

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

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

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

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

  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 $q_2^* = \frac{\overline{\delta}_L}{2} + \underline{q}$.

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

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

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

  We check that $\frac{\partial \Pi_1}{\partial q_1} = -\frac{1}{9}(2\underline{\theta} - \overline{\theta} - \alpha)^2 - 2\beta (q_1 - \underline{q}) < 0$. 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 $q_2^* = \frac{\overline{\delta}_I}{2} + \underline{q}$. ■

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.*

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

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

We now move to the comparison of the green firm profits

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

Proof of Proposition 2

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

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

As for the environmental damage, we notice from Table 2 that the environmental damage is linearly and negatively related to the green quality. Denote by D^p and D^c, the environmental damage with a partial and complete information label, respectively, we have:

- If $\alpha \leq 2\underline{\theta} - \overline{\theta}$ 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 $2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$ 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 Π_1^p and Π_1^c, the brown firm profit with a partial and complete information label, respectively. Recall that D^p and D^c denote the environmental damage with a partial and complete information label, respectively.

Proof of Proposition 3

The brown firm profit is null when $\alpha < 2\underline{\theta} - \overline{\theta}$ as consumers only buy the green product whatever the label's type. When $2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$ 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 $\mu > \frac{\alpha - \underline{\theta}}{2}$ then $\Pi_1^p - \Pi_1^c > 0$.
- If $\mu < \frac{\alpha - \underline{\theta}}{2}$ then $\Pi_1^p - \Pi_1^c < 0$.

■

Proof of Proposition 4

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

- If $\alpha \leq 2\underline{\theta} - \overline{\theta}$ 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 $2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$ 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 $\frac{(\underline{\theta} - \alpha)(2\overline{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\overline{\theta} - 2\underline{\theta} + \alpha)^2}{9}$. We show that if $2\underline{\theta} - \overline{\theta} < \alpha < \tilde{\alpha}$ then $\frac{(\underline{\theta} - \alpha)(2\overline{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\overline{\theta} - 2\underline{\theta} + \alpha)^2}{9} > 0$ and if $\tilde{\alpha} < \alpha < 2\overline{\theta} - \underline{\theta}$ then $\frac{(\underline{\theta} - \alpha)(2\overline{\theta} - \underline{\theta} - \alpha)}{6} - \frac{(\overline{\theta} - 2\underline{\theta} + \alpha)^2}{9} < 0$. 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. ■

Proof of Proposition 5

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

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

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

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

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

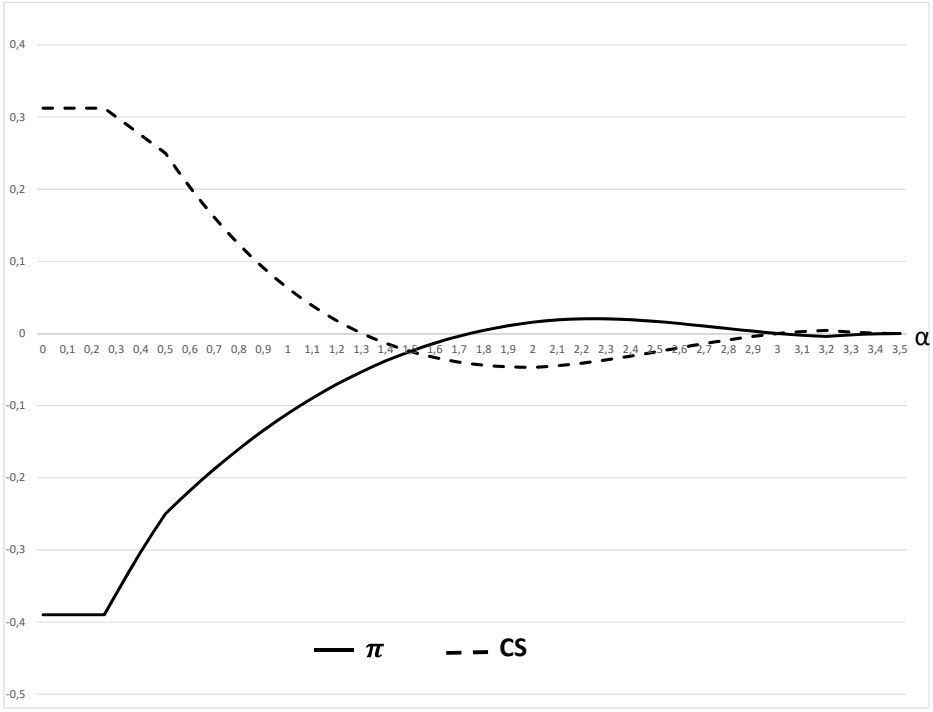

Figure 2 – Difference of consumers' surplus and difference of industry profit curves for $\overline{\theta} = 2.5$, $\underline{\theta} = 1.5$, $\beta = 1$ and $\mu = 0.75$.

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Figures

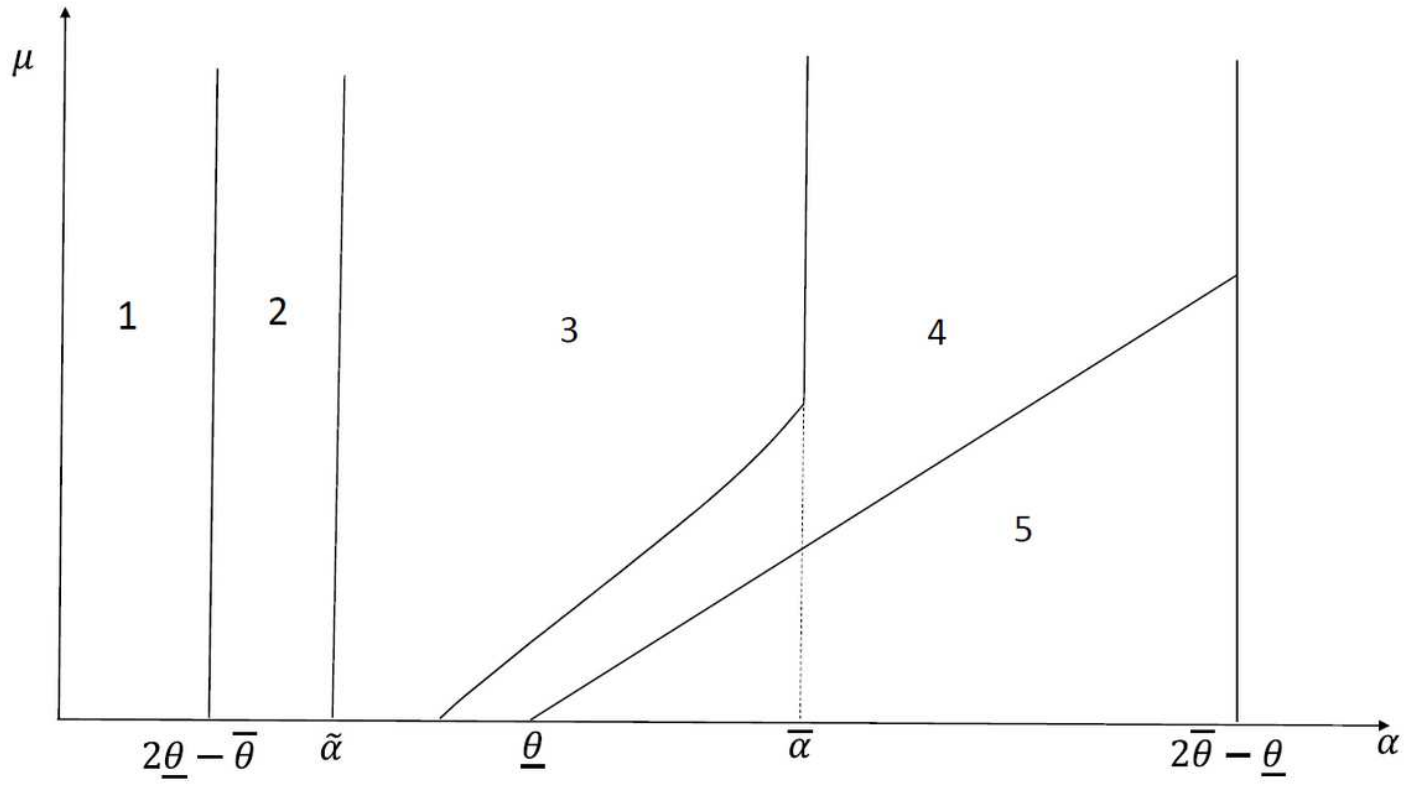

Figure 1

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