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ORIGINAL ARTICLE

Consumer misperception of eco-labels, green market structure and welfare

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Abstract Eco-labels are essential for informing consumers about products' environmental characteristics. However, the many different labels consumers encounter can be confusing, which makes assessing environmental quality associated with each label difficult. How does consumer misperception of competing eco-labels affect market structure and welfare? This article provides theoretical insight into this issue by using a double-differentiation model in which three products compete: an unlabeled product and two distinctly eco-labeled products, one with a medium and one with a high level of environmental quality. The study investigates the effects of consumers' imperfect information when they perceive all eco-labels as a sign of the same high environmental quality and consider each label as a unique product. This misperception can weaken the firm that provides the greenest product, though paradoxically this situation is not always detrimental to social welfare. However, depending on the certifying organizations, consumer misperception can induce firms to use a greenwashing strategy and encourage nongovernmental organizations and regulators to introduce less stringent standards.

Keywords Eco-label · Environmental quality · Green consumer · Product differentiation

JEL Classification D11 · D62 · D83 · L15 · Q58

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1 Introduction

A product's environmental impact is part of its life cycle, from cradle to grave, and thus serves as a credence attribute of goods. Eco-labels enable consumers to 'identify products and services that have a reduced environmental impact throughout their life cycle, from the extraction of raw material through to production, use and disposal'.[1] However, most consumers have difficulties navigating 'the increasingly important and complex world of greener products'.[2] Accordingly, 91% of Europeans believe that current product labels do not provide enough information (59%) or provide unclear information (32%) about their environmental impact (European Commission [EC] 2013).

Consumer misperception of eco-labels arises mainly from eco-label proliferation. The Eco-Label Index[3] currently identifies 465 eco-labels in 199 countries and 25 industry sectors. Gruère (2013) notes that the proliferation of environmental labeling and information schemes since the 1990s could be contributing to consumer misperception. Harbaugh et al. (2011) show that when consumers are unsure of labeling requirements, the proliferation of eco-labels decreases the informativeness of labels and thereby increases consumer confusion. How does misperception of competing eco-labels affect consumers' demand for green products and firms' strategies? What are the ensuing impacts on welfare, through profits, consumer surplus and the quality of the environment? This paper addresses these issues using a model of two-dimensional product differentiation.

A wealth of theoretical literature investigates optimal policies and corporate strategies for eco-labeling when a labeled and an unlabeled product compete (Bonroy and Constantatos 2015).[4] However, these models assume a single eco-label; they do not address consumers' difficulties in comprehending competing eco-labels. An exception is Fischer and Lyon (2014), who analyze competition between two perfect eco-labels that deliver full information to consumers: a non-governmental organization (NGO) label and an industry label. They show that such a competition may be more damaging for the environment than an NGO label alone. Only a few studies investigate competing imperfect eco-labels that fail to disclose full information to consumers, thereby causing consumer misperception of labels (Ben Youssef and Abderrazak 2009; Harbaugh et al. 2011; Brécard 2014).[5] Ben Youssef and Abderrazak (2009) consider a situation

[1] European Commission's definition of 'eco-label' (see http://ec.europa.eu/environment/ecolabel/index_en.htm (accessed 2014/05/09).

[2] See the Environmental Protection Agency web page on 'Greener Products', http://www.epa.gov/greenerproducts/index.html (accessed 2016/12/15).

[3] www.ecolabelindex.com (accessed 2015/11/17).

[4] Studies most often adopt a vertical (Arora and Gangopadhyay 1995; Amacher et al. 2004; Ben Youssef and Lahmandi-Ayed 2008; Bottega and de Freitas 2009; Bottega et al. 2009) or horizontal (Eriksson 2004; Boyer et al. 2006; Clemenz 2010) differentiation model framework. They emphasize the conditions under which eco-labeling may be an efficient policy, depending on cost structure and abatement method of firms and on environmental consciousness, information and altruism of consumers.

[5] Note that a single eco-label may also be imperfect, as when the label imperfectly informs consumers on the environmental quality of the high-quality product. Bonroy and Constantatos (2008) show that when consumers have heterogeneous beliefs that a firm provides a high-quality product (and that its competitor

in which consumers face two eco-labeled products and use product prices to assess the probability that an eco-label will guarantee high environmental quality. They conclude that firms are incentivized to provide products of lower environmental quality than in the perfect information case and that consumers make their purchasing decision by ignoring eco-labels, which then renders the labels useless. By only considering labeled products, Ben Youssef and Abderrazak neglect the crucial role of eco-labels in helping consumers distinguish green products from 'brown' products (those that make no environmental claims). Brécard (2014) introduces an unlabeled product in addition to two imperfectly eco-labeled products. She assumes that consumers view eco-labels as signs of environmental quality but do not perceive the difference in the environmental quality they certify. Moreover, they exhibit heterogeneous willingness to pay (WTP) for environmental quality and, according to their moral and social values, heterogeneous tastes toward the eco-labels. Comparing uniform and non-uniform labeling standards, she shows that this consumer confusion weakens the unlabeled and the greenest firms, to the benefit of the firm that provides the eco-labeled product of medium quality. Furthermore, NGOs and regulators have an interest in harmonizing labeling criteria and in adopting an exact standard; in contrast, although firms also have an interest in harmonizing labeling criteria, they prefer an undemanding standard. Brécard (2014) leaves one issue partly unresolved: How does consumer misperception of competing eco-labels change green market structure and welfare from the case of perfect eco-labels, which disclose full information on environmental quality? [6]

The current study investigates this issue using a model similar to, but more tractable than, Brécard's (2014).[7] The uniqueness of this model stems from the assumption that consumers are homogeneous in their WTP for environmental quality but heterogeneous in their perception of an ideal eco-label, depending on their concern with various ethical issues (e.g., health, pollution, working conditions). Therefore, all else being equal, consumer choices crucially depend on the interplay between WTP for the perceived environmental quality and WTP for a specific eco-label, which is contingent on their ideal label. With this framework, the study compares the case of imperfect eco-labels, in terms of consumer misperception of environmental quality, with the textbook case of perfect eco-labels, in which consumers accurately know the environmental impacts of all available eco-labeled products.

Footnote 5 continued
provides a low-quality product), introducing a perfect label enhances welfare; however, they note that sometimes such a label should be made mandatory and an imperfect label may be damaging.

[6] Baksi et al. (2016) investigate a related issue in a vertical differentiation model with three competing products. However, rather than assuming consumer misperception of eco-labels, they assume that consumers overestimate intermediate environmental quality and perfectly assess the low and high quality. Moreover, they assume that qualities only result from firm strategies and that firms know that consumers overestimate the intermediate-quality product. Finally, they assume that environmental externalities do not affect social welfare. In such a specific framework, Baksi et al. show that overestimation benefits the intermediate-quality firm and enhances social welfare when firms compete on price but harms social welfare when they compete on quantity.

[7] Brécard's (2014) model cannot be analytically solved, except in the specific case of uniform standard, and does not allow comparison between perfect and imperfect information cases.

Imperfect eco-labeling is related to imperfect quality disclosure, a concept widely examined since Akerlof's (1970) seminal work. In the absence of a certification process enabling sellers to disclose the quality of their product, consumers face Akerlof's 'lemons' problem: the 'bad' products tend to drive out the 'good'. Such an adverse selection effect leads to multiple equilibria, which depend on buyer expectations of the relationship between price and quality (Wilson 1980). Firms can use prices as signals of product quality. Daughety and Reinganum (2008) show that when firms encounter Bayesian consumers, a unique symmetric separating equilibrium occurs in which the representative consumer accurately assesses the quality of each product from its price.[8] The current model differs from this literature by proposing that prices do not influence consumers' beliefs, because consumers face two types of product attributes: environmental quality (disclosed by the absence or presence of an eco-label) and the nature of the eco-label (which may be more or less specific). They do not necessarily interpret high price as a signal of high environmental quality, insofar as they may deem the difference in prices simply as reflecting the difference in eco-label types (i.e., horizontal attributes of labeled products). The role of price is then ambiguous.[9] The purpose of quality certification is to help firms communicate product quality to consumers by helping them avoid adverse selection, but imperfect certification can result from upstream imperfect disclosure of information or from downstream imperfect understanding of information conveyed by a label. In the first case, the certifier or the firm has an interest in not revealing or manipulating quality information.[10] A wealth of literature (for a review, see Dranove and Jin 2010) focuses on the reasons for the failure of full information disclosure. The current study's model differs from that literature by restricting analysis to upstream perfect certification, assuming that eco-labels are delivered by honest certifiers using effective product testing. In the second case, downstream quality signaling is imperfect because consumers do not perfectly assess the quality, despite the reliable certification. The current study's model falls into this category, along with those of Ben Youssef and Abderrazak (2009), Harbaugh et al. (2011) and Brécard (2014). Note that imperfect eco-labeling is likely to arise from both upstream and downstream imperfect processes of information disclosure, as in Marette's (2010) model, in which firms can select a credible or a non-credible certification and a portion of consumers are confused, mistaking the credible for non-credible certification. Consumer confusion leads to multiple equilibria in which high-quality products are signaled with credible certification and low-quality products are signaled with non-credible certification. The current framework differs

[8] In Daughety and Reinganum's (2008) model, product quality is private information of each firm and therefore is unknown to both the consumer and the firm's competitors. However, consumers know that the quality may be either high or low.

[9] In Ben Youssef and Abderrazak's (2009) model, the prices do reveal information on environmental quality because consumers face two eco-labels and know that the eco-labeled products are vertically differentiated. This departs from the assumptions in the current study that consumers do not know differences in environmental quality of (imperfect) eco-labeled products and that these products are horizontally differentiated.

[10] In particular, imperfect disclosure can come from 'noisy certification', due to the limited reliability of product testing (De and Nabar 1991; Mason and Sterbenz 1994; Mason 2011), or from the incentive of certification intermediaries with market power to manipulate information to capture the informational surplus in the market (Lizzeri 1999).

from Marette's (2010) in that consumer confusion does not lead them to reduce the significance of both (credible) eco-labels but rather to wrongly believe that both labeled products are of the same environmental quality and better than the unlabeled one.

The current model's original assumptions[11] fit well with empirical findings on the green consumer profile. Empirical studies reveal that most consumers prefer environmentally friendly products to standard ones (Organization for Economic Co-operation and Development [OECD] 2005; EC 2013, 2014). However, several factors affect preferences and consumers' WTP for eco-labeled products. For example, in their systematic review of the relevant literature, Taufique et al. (2014) identify 10 constructs that influence consumers' understanding and perception of eco-labels, including environmental awareness, knowledge, involvement and trust, in addition to sociodemographic features (e.g., education, gender, age). These constructs imply some heterogeneity in preferences for eco-labeled products, which can then be viewed as vertically and horizontally differentiated. Furthermore, according to OECD (2015), double-differentiation of eco-labeled products is particularly widespread in the agricultural and apparel sectors, which display many competing environmental labeling and information schemes. For example, coffees are labeled with many differed descriptors (e.g., organic, bird-friendly, fair trade, shade grown, biodiversity) and varying levels of stringency.

The current study provides new insights into consumer misperception effects on firms' pricing strategies and market structure, social welfare and eco-labeling strategies of various certifying organizations. The main results are fourfold. First, consumer misperception can affect market structure by weakening the green firm (the firm that provides the greenest product), to the benefit of not only the 'blue' firm (the firm that offers intermediate environmental quality) but also, in some cases, the brown firm, even though consumers know that the green product is of better quality than the brown one. Second, paradoxically, consumer misperception is not always detrimental to social welfare when consumers view eco-labels as a sign of high environmental quality. Third, although firms would likely adopt the same demanding eco-labeling criteria if they faced fully informed consumers, they might resort to greenwashing if they know how consumers form their beliefs about environmental quality. Fourth, NGOs and regulators faced with consumer misperception implement a less stringent standard than in the perfect information case.

The rest of the paper proceeds as follows: Section 2 presents the demand side of the model. Section 3 analyzes the price equilibrium in cases of perfect and imperfect eco-labels and compares market structures in both cases. Section 4 infers the consequences of imperfect information on welfare and analyzes eco-labeling strategies of the various instigators of the eco-labels (firms, an NGO and/or the regulator). Section 5 concludes.

[11] The current research's assumptions differ from those of Brécard (2014), who considers heterogeneous WTP for environmental quality and assumes no interplay between WTP for the perceived environmental quality and WTP for a specific eco-label.

2 Consumer information and demand

Consider a market in which three products are potentially in competition: a brown unlabeled product of low environmental quality, a blue eco-labeled product of medium environmental quality and a green eco-labeled product of high environmental quality. Two distinct eco-labels are used to inform consumers about both eco-labeled products' higher qualities. The green label's standard is more stringent than the blue label's one.

Furthermore, consider two polar cases. In the perfect information case, eco-labels play their full role in informing consumers about the minimal environmental quality of a labeled product. In the imperfect information case, assume that consumers believe that the environmental quality is the same regardless of the label stamped on the product. In both cases, consumers view each label as a unique variety of a product.

2.1 Perfect eco-labels

A fully informed consumer decides whether he or she consumes the unlabeled product of quality q_{NL}, the blue product of medium quality q_{LM} (labeled l_M) or the green product of high quality q_{LH} (labeled l_H), with $q_i \in \left[\underline{q}, \bar{q}\right]$ and $l_i \in [0, 1]$. All consumers have the same marginal WTP for quality, θ ($\theta > 0$),[12] However, each consumer has an ideal label λ, depending on his or her concern for various ethical issues, such as health, biodiversity, air pollution, climate change and working conditions, which in turn depend on the consumer's moral and social values and sociodemographic characteristics. Accordingly, when the consumer chooses an eco-labeled product, he or she selects not only its environmental quality but also its associated horizontal characteristic, label l_M or l_H. Hotelling space [0, 1] represents the scale of ethical concerns, associated with potential eco-labels, from the most specific one (e.g., organic agriculture) to the most general one (e.g., carbon footprint). Assume that ideal labels λ are uniformly distributed over the Hotelling space and, for simplicity, that $l_M = 0$ and $l_H = 1$.

The indirect utility that consumer λ derives from the consumption of one unit of the product of quality q_i, at price p_i, is defined as follows ($i = NL, LM, LH$):

$$u_\lambda(q_{NL}, p_{NL}) = r + \theta q_{NL} - p_{NL} \tag{1}$$

$$u_\lambda(q_{LM}, p_{LM}) = r + \theta q_{LM} + (1 - \lambda)\theta q_{LM} - p_{LM} \tag{2}$$

$$u_\lambda(q_{LH}, p_{LH}) = r + \theta q_{LH} + \lambda\theta q_{LH} - p_{LH}, \tag{3}$$

where r is the consumer's gross utility from consuming one unit of the product[13] and θq_i is his or her basic WTP for quality q_i. When he or she consumes the brown product, his or her indirect utility is the usual function à la Mussa and Rosen (1978).

[12] Assuming that θ is identical for all consumers allows analytical resolution of the game, which would not be achievable with a more conventional assumption of uniform distribution of parameters θ as in Brécard (2014).

[13] Assume that r is large enough to ensure that the market is covered.

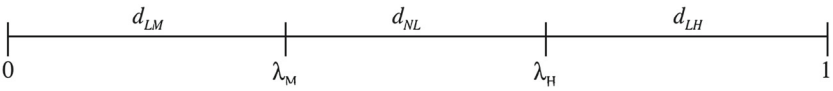


Fig. 1 Consumer demand in the perfect information case

When he or she consumes a blue (or a green) product, his or her gross surplus also depends on the proximity between the blue (or green) label and his or her ideal label λ. Measure gross surplus by the interaction between the proximity to the ideal label and the basic WTP for labeled qualities q_{LM} and q_{LH}: $(1-\lambda)\,\theta q_{LM}$ and $\lambda\theta q_{LH}$.[14]

To define consumer demand, denote consumer λ_M as indifferent between the unlabeled and the blue product and consumer λ_H as indifferent between the unlabeled and the green product, characterized as follows (see Fig. 1):

$$\lambda_M = \frac{2\theta q_{LM} - \theta q_{NL} - p_{LM} + p_{NL}}{\theta q_{LM}}, \tag{4}$$

$$\lambda_H = \frac{\theta q_{NL} - \theta q_H + p_{LH} - p_{NL}}{\theta q_H}. \tag{5}$$

The market is covered and demand is defined by $d_{LM} = \lambda_M$, $d_{NL} = \lambda_H - \lambda_M$ and $d_{LH} = 1 - \lambda_H$.

2.2 Imperfect eco-labels

A misinformed consumer believes that the environmental quality is the same regardless of the label and that both labeled products are of better environmental quality than the unlabeled one. In other words, the *perceived* quality of the blue and the green products, denoted $\tilde{q}_L$, is higher than quality q_{NL} of the unlabeled product. Meanwhile, he or she still perceives blue and green eco-labels as distinct varieties of the good. Assume, without loss of generality, that $\tilde{q}_L \in [q_{LM}, q_{LH}]$.[15]

The indirect utility derived from the consumption of the unlabeled product is still defined by Eq. (1). However, rewrite the indirect utility from the consumption of the labeled products, at price $\tilde{p}_{Lj}$ as follows ($j = M, H$):

$$u_\lambda(\tilde{q}_L, \tilde{p}_{LM}) = r + \theta\tilde{q}_L + (1-\lambda)\,\theta\tilde{q}_L - \tilde{p}_{LM} \tag{6}$$

$$u_\lambda(\tilde{q}_L, \tilde{p}_{LH}) = r + \theta\tilde{q}_L + \lambda\theta\tilde{q}_L - \tilde{p}_{LH}. \tag{7}$$

[14] This assumption differs from Brécard (2014), who assumes additivity of WTP for environmental quality and WTP for a given label. It is close to Degryse and Irmen's (2001) assumption, which states that the indirect utility depends on the product quality not only through the quality level itself but also through the transportation cost towards the product, proportional to the quality level: $u_i(\lambda) = r + q_i - (1+\delta q_i)\,\lambda - p_i$, with δ the interaction parameter.

[15] The main results are not affected by this assumption: The brown product would be favored by undervaluation of eco-labeled products when $\tilde{q}_L \in [q_{NL}, q_{LM}]$ and penalized by overvaluation of eco-labeled products when $\tilde{q}_L \in [q_{LH}, \bar{q}]$. In both cases, the blue product would benefit from a competitive advantage over the green product, as in the case in which $\tilde{q}_L \in [q_{LM}, q_{LH}]$.

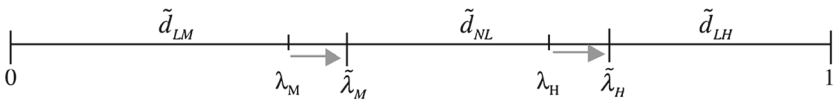


Fig. 2 Consumer demand in the imperfect information case

Therefore, if all products were sold at the same price, half the consumers would buy the blue product and the other half would purchase the green product. Moreover, all else being equal, because utility is an increasing function of perceived environmental quality, consumer misperception leads to utility loss from consuming the green product and utility gain from consuming the blue product. For different prices, indifferent consumers are characterized by

$$\tilde{\lambda}_M = \frac{2\theta\tilde{q}_L - \theta q_{NL} - \tilde{p}_{LM} + \tilde{p}_{NL}}{\theta\tilde{q}_L} \tag{8}$$

$$\tilde{\lambda}_H = \frac{\theta q_{NL} - \theta\tilde{q}_L + \tilde{p}_{LH} - \tilde{p}_{NL}}{\theta\tilde{q}_L}. \tag{9}$$

Demands are defined by $\tilde{d}_{LM} = \tilde{\lambda}_M$, $\tilde{d}_{NL} = \tilde{\lambda}_H - \tilde{\lambda}_M$ and $\tilde{d}_{LH} = 1 - \tilde{\lambda}_H$.

Figure 2 illustrates consumers' demand for given prices and qualities of the three products. It highlights that, all else being equal, consumer misperception weakens the greenest product of undervalued quality, to the benefit of the blue product of overvalued quality.

Note that in a vertical differentiation framework with three firms, Scarpa (1998, p.667) shows that 'the demand level of a firm depends on the quality and price of the firm itself and of its neighbouring rivals only, while it does not depend on products that are farther away in the product space'. In the current model, because of interactions between variety and quality in consumer preferences, the demand for a labeled product does not depend on the quality and price of the other labeled product, but it does depend on the quality and price of the unlabeled product, which is therefore the neighboring rival of both eco-labeled products.

3 Price equilibrium and market structure

The competition between firms takes place in a two-stage game. In the first stage, firms decide on (real) quality q_i to be produced, with $q_i \in \left[\underline{q}, \bar{q}\right]$. In the second stage, prices p_i are chosen. Assume that only one firm produces one variant of a product. A firm has an interest in selecting a variety that differs from that of its competitors, to avoid a price war, which would lead to a dramatic fall in profits. It also chooses from among the three possible variants: unlabeled, blue labeled or green labeled.[16] The blue and the green variants require that the firms provide a quality higher than q_{LM} and q_{LH}, with $q_{LH} \geq q_{LM}$.

[16] Moreover, firms choosing the medium and the high environmental quality always want to disclose quality though an eco-label, according to the 'unraveling result' (Dranove and Jin 2010).

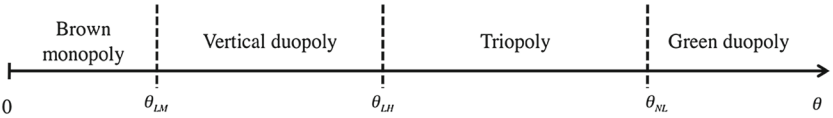


Fig. 3 Marginal WTP and market structures

Firm profits are defined by

$$\pi_i = (p_i - c(q_i))\, d_i^- k_i \quad i = NL, LM, LH, \tag{10}$$

where $c(q_i)$ is the unit production cost (with $c'(q_i) > 0$, $c'(q_i) \geq 0$ and $c(0) = 0$) and k_i is the certifying cost ($k_i \geq 0$). To ensure profitability of the three firms, assume that the unit production cost of each firm is lower than the maximum WTP for its product: $c\left(q_{Lj}\right) \leq 2\theta q_{Lj}$ $(j = H, M)$ and $c(q_{NL}) \leq \theta q_{NL}$.

3.1 Perfect eco-labels

In the first stage of the game, because quality is costly, a firm chooses either the worst quality $\underline{q}$ or the minimum standard required to label its product, q_{LM} or q_{LH}. In the second stage, firms compete on price. Maximization of profit (Equation (10)) with respect to price leads to the following Nash equilibrium:

$$p_{NL}^* = \frac{2c\left(\underline{q}\right) + \theta\underline{q}}{3} + \frac{c(q_{LM})\, q_{LH} + c(q_{LH})\, q_{LM} - 2\theta q_{LM} q_{LH}}{3(q_{LM} + q_{LH})} \tag{11}$$

$$p_{LM}^* = \frac{c\left(\underline{q}\right) - \theta\underline{q}}{3} + \frac{c(q_{LM})(4q_{LH} + 3q_{LM}) + c(q_{LH})\, q_{LM} + 2\theta q_{LM}(2q_{LH} + 3q_{LM})}{6(q_{LM} + q_{LH})} \tag{12}$$

$$p_{LH}^* = \frac{c\left(\underline{q}\right) - \theta\underline{q}}{3} + \frac{c(q_{LH})(3q_{LH} + 4q_{LM}) + c(q_{LM})\, q_{LH} + 2\theta q_{LH}(3q_{LH} + 2q_{LM})}{6(q_{LM} + q_{LH})}. \tag{13}$$

Profits of the three firms are then defined by $\pi_{NL}^* = \frac{\theta q_{LM} q_{LH}}{q_{LM} + q_{LH}} d_{NL}^{*2}$, $\pi_{LM}^* = \theta q_{LM} d_{LM}^{*2} - k_{LM}$ and $\pi_{LH}^* = \theta q_{LH} d_{LH}^{*2} - k_{LH}$, with d_{NL}^*, d_{LM}^* and d_{LH}^* the market shares (specified in "Appendix 1").

Figure 3[17] illustrates how the market structure depends on marginal WTP for environmental quality, θ, for given qualities: The higher the marginal WTP, the more likely the market structure evolves from a brown monopoly (supplying the unlabeled products) to a vertical duopoly (producing the unlabeled and the blue products), to a triopoly (providing the three products) or a green duopoly (supplying both labeled products). Therefore, the triopoly is only viable when $\theta \in [\theta_{LH}, \theta_{NL}]$.

[17] " Appendix 1" details the marginal WTP θ_{NL}, θ_{LM} and θ_{LH}. Assuming a quadratic production-cost function $c(q_i) = q_i^2/2$, it is straightforward to show that $\theta_{LM} \leq \theta_{LH} \leq \theta_{NL}$.

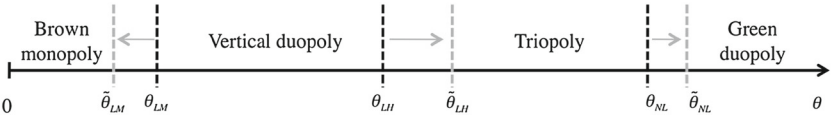


Fig. 4 Effects of imperfect information on market structures

3.2 Imperfect eco-labels

Assume now that consumers perceive environmental quality of eco-labeled products as $\tilde{q}_L$. However, they still regard eco-labeled products as different varieties of the environmentally friendly goods.

The game equilibrium can be deduced from the previous section, by replacing q_{LM} and q_{LH} by $\tilde{q}_L$, while keeping $c\,(q_{LH})$ and $c(q_{LM})$, in Eqs. (11) to (13). Accordingly, prices are characterized by

$$\tilde{p}^*_{NL} = \frac{1}{6}\left[4c\left(\underline{q}\right) + c\,(q_{LM}) + c\,(q_{LH}) - 2\theta\left(q_L - \underline{q}\right)\right] \tag{14}$$

$$\tilde{p}^*_{LM} = \frac{1}{12}\left[4c\left(\underline{q}\right) + 7c\,(q_{LM}) + c\,(q_{LH}) + 2\theta\left(5q_L - 2\underline{q}\right)\right] \tag{15}$$

$$\tilde{p}^*_{LH} = \frac{1}{12}\left[4c\left(\underline{q}\right) + c\,(q_{LM}) + 7c\,(q_{LH}) + 2\theta\left(5q_L - 2\underline{q}\right)\right]. \tag{16}$$

Profits are then defined as $\tilde{\pi}^*_{NL} = \theta q_L \tilde{d}^{*2}_{NL}/2$ and $\tilde{\pi}^*_{Lj} = \theta q_L \tilde{d}^{*2}_{Lj} - k_{Lj}$, with $\tilde{d}^*_{NL}$ and $\tilde{d}^*_{Lj}$ being the market shares typified in "Appendix 1" ($j = M, H$).

Figure 4[18] shows that for medium values of marginal WTP θ, such as $\theta \in \left[\theta_{LH}, \tilde{\theta}_{LH}\right]$, although the greenest product is produced and consumed in the case of perfect labels, it is removed from the market in the case of imperfect labels. For high marginal WTP, such as $\theta \in \left[\theta_{NL}, \tilde{\theta}_{NL}\right]$, although the brown product disappears in the case of perfect labels, it benefits from positive market share in the case of imperfect labels. Therefore, triopoly existence requires higher threshold WTP than in the perfect label case, such as $\theta \in \left[\tilde{\theta}_{LH}, \tilde{\theta}_{NL}\right]$.

Consumer misperception of environmental quality tends to favor the firm that supplies the blue product (hereinafter, the blue firm) to the detriment of the firm that sells the green product (hereinafter, the green firm), because it benefits from higher demand and profit than in the perfect information case.[19] Indeed, the blue firm has a competitive advantage that results from the overstatement of the environmental quality of its product. This competitive advantage is reinforced by its cost advantage (as $c\prime\,(q) > 0$), leading to a *perceived* hedonic price, $\tilde{p}_{LM}/\tilde{q}_L$, that is always lower than that of the green product, $\tilde{p}_{LH}/\tilde{q}_L$. Therefore, the blue firm can increase its price

[18] "Appendix 1" defines the marginal WTP $\tilde{\theta}_{NL}$, $\tilde{\theta}_{LM}$ and $\tilde{\theta}_{LH}$. Assuming a quadratic production cost function$c\,(q_i) = q_i^2/2$, the model shows that $\tilde{\theta}_{LM} \leq \tilde{\theta}_{LH} \leq \tilde{\theta}_{NL}$, $\tilde{\theta}_{NL} \geq \theta_{NL}$, $\tilde{\theta}_{LM} \leq \theta_{LM}$ and $\tilde{\theta}_{LH} \geq \theta_{LH}$ for all values of q_{LM}, q_{LH} and $\tilde{q}_L$.

[19] "Appendix 2" provides demonstrations.

above the perfect information price ($\tilde{p}_{LM} > p_{LM}$), whereas the green firm must lower its price ($\tilde{p}_{LH} < p_{LH}$). Because the three products are strategic complements, these price variations can prompt the brown firm to raise its price (if perceived quality $\tilde{q}_L$ is lower than a given threshold) or reduce it (otherwise). Moreover, imperfect information tends to divert consumers from the greenest, undervalued product to the benefit of the unlabeled product and from the unlabeled product to the benefit of the overvalued blue product ($\tilde{d}_{LH} < d_{LH}$,$\tilde{d}_{LM} > d_{LM}$). The net effect on demand for the brown product is positive when the perceived quality of the labeled products is low and negative otherwise. In summary, imperfect information raises profits of the blue firm, reduces profits of the green firm and increases or decreases profits of the brown firm, according to perceived quality $\tilde{q}_L$.

Proposition 1 *When the perceived quality of eco-labeled products is in the range of real environmental qualities, $\tilde{q}_L \in [q_{LM}, q_{LH}]$, consumer misperception of eco-labels:*

(i) Reduces the price, the market share and the profit of the green firm, which may thus be excluded from the market if the perceived quality is in the lower part of the real quality range and/or if consumers have an insufficient WTP for environmental quality, namely $\theta \in \left[\theta_{LH}, \tilde{\theta}_{LH}\right]$;

(ii) Increases the price, the market share and the profit of the blue firm regardless of the perceived quality and the WTP for environmental quality of consumers; and

(iii) Increases (decreases) the price, the market share and the profit of the brown firm if the perceived quality is in the lower (higher) part of the real quality range and/or, paradoxically, consumers have a high (low) WTP for environmental quality, namely $\theta \in \left[\theta_{NL}, \tilde{\theta}_{NL}\right]$.

Proposition 1 completes the results of Brécard (2014), who stresses the competitive advantage of the blue firm over the green firm in the case of non-uniform standards and misinformed consumers, with regard to the case of uniform standards. It is also in line with Baksi et al. (2016), who show that consumers' overestimation of the medium quality decreases profits of firms that provide the lowest and highest qualities. Finally, this proposition is consistent with Akerlof's (1970) lemons problem, in that consumer misperception of eco-labels weakens the green firm to the benefit of the blue firm. However, in contrast with the lemons problem, the 'worst' product may also benefit from the weakening of the 'best' one, even though consumers know that the green product is of better quality than the brown one.

4 Eco-labeling and welfare

Welfare usually refers to the sum of consumer surplus, firm profits and social benefit of the quality of the environment. Because of consumer misperception of eco-labels, definitions of consumer surplus can differ according to regulator type (Salanié and Treich 2009): A paternalistic regulator should base decisions on real environmental qualities of the good, while a populist regulator should consider perceived environmental qualities. In the first case, real surplus derives from $u_\lambda\left(q_{Lj}, \tilde{p}_{Lj}\right)$ and is only

indirectly affected by quality misperception through prices and demands. In the second case, perceived surplus is based on utility $u_\lambda\left(\tilde{q}_L, \tilde{p}_{Lj}\right)$ and is directly affected by perceived quality $\tilde{q}_L$. In addition, in both cases, the regulator internalizes the environmental externality by including the global environmental quality of products Q, defined by $Q \equiv q_{NL}d_{NL} + q_{LM}d_{LM} + q_{LH}d_{LH}$, in the social environmental benefit. This is simply assumed to be δQ, with $\delta \geq 0$. The term δ can be interpreted as the usual marginal environmental damage, that is, the monetary valuation of marginal degradation (or improvement) of quality of the environment Q. By internalizing the externality, the regulator behaves paternalistically. Finally, the current model adopts the typical normative approach to social welfare by assuming that the regulator behaves paternalistically toward consumers—in other words, it defines social welfare as the sum of actual surplus of consumers, firm profits and social benefit of the environment.[20]

4.1 Welfare implications of consumer misperception

Figure 5 illustrates the effects of consumer misperception on welfare components according to their assessment of the quality of labeled products in the triopoly case.[21]

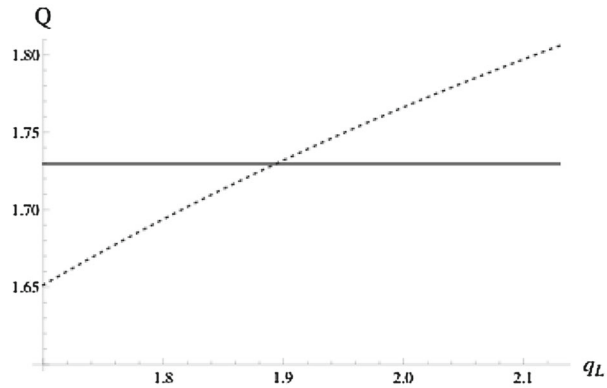
According to Fig. 5a, imperfect information tends to improve the quality of the environment when perceived quality $\tilde{q}_L$ is high, but it has a detrimental effect otherwise (see "Appendix 3"). Indeed, when consumers believe that both labels signal high environmental quality, they are motivated to purchase more blue products and fewer unlabeled products than in the perfect information case. The ensuing beneficial effect on the quality of the environment outweighs the damaging effect of the lower consumption of green product—the reverse is true when consumers are skeptical about the environmental quality of eco-labeled products. This finding highlights the crucial role of consumer views of eco-labels on the quality of the environment and, through this channel, on social welfare.

Consumer misperception has two opposite effects on consumer surplus. On the one hand, the *price effect* is favorable for the consumption of the green product, which is cheaper, whereas the effect is unfavorable for the blue product, which is more expensive. On the other hand, the *volume effect* harms consumers of the green product and favors consumers of the blue product. The global effect is negative for consumers of the green product and positive for consumers of the blue product.[22] In addition, price and volume effects move in the same direction for the unlabeled product: positively when the perceived quality is relatively low and negatively otherwise. Finally, as Fig. 5b shows, the global surplus can be enhanced by imperfect information when consumers

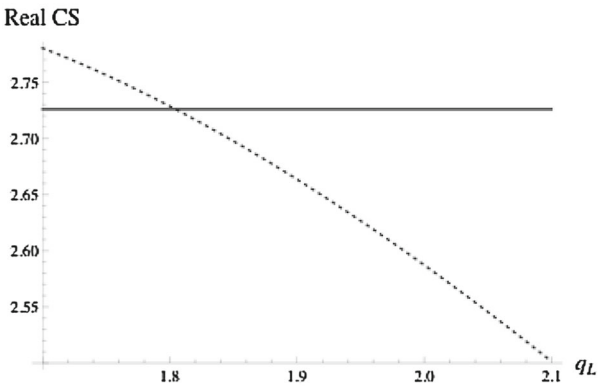
[20] See footnotes 22, 23 and 28 for some results of welfare analysis with a populist regulator.

[21] In Fig. 5, $\theta = 1$, $\underline{q} = 1$, $q_{LM} = 1.7$, $q_{LH} = 2$, fixed costs are equal to 0, and a quadratic cost function is assumed. Because the large number of involved parameters prevents an analytical demonstration of the effects of perceived quality $\tilde{q}_L$ on consumer surplus and profits, it was necessary to perform numerical simulations with a large set of relevant values of parameters to check the robustness of the results.

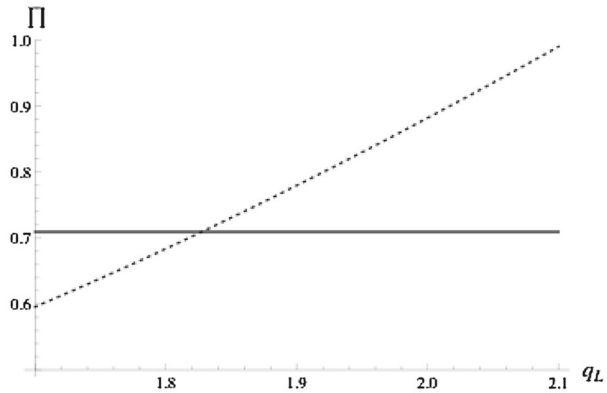
[22] Variations in perceived consumer surplus are greater than changes in the real consumer surplus because consumers directly benefit from higher perceived quality of eco-labeled products.



(a) Quality of the Environment



(b) Consumer Surplus



(c) Profits

Fig. 5 Effects of perceived quality q_L on welfare components

attach a low environmental quality to both labeled products.[23] From previous analyses, it is possible to infer that profit gains of the blue firm can compensate profit losses of other firms, especially when the perceived quality is high (Fig. 5c).

Proposition 2 *Consumer misperception of eco-labels can enhance welfare through its positive effect on the profits of the blue firm and its potential beneficial effect on the quality of the environment. The higher the marginal environmental benefit* δ *and the perceived quality* $\tilde{q}_L$*, the greater is welfare.*

Thus, paradoxically, although consumer misperception represents a market failure, it can improve welfare. Accordingly, for given eco-labeling standards, it is not necessarily, in the regulator's interest to foster eco-label transparency and better information for consumers; it may be more effective to promote eco-labels to improve consumers' opinions of environmentally friendly products.

4.2 Eco-labeling strategies with fully-informed consumers

Eco-labeling objectives differ depending on the certifying organization: The regulator aims to improve welfare, an NGO attempts to improve the quality of the environment and firms want to maximize their profits. To investigate eco-labeling strategies, assume henceforth a quadratic cost function $c\,(q_i) = q_i^2/2$. Numerical resolutions are performed with θ, $\underline{q}$ and δ normalized to 1.[24]

Figure 6 illustrates the reaction functions of each potential certifier, assuming zero certifying costs. It shows that certifiers have upward-sloping reaction functions, which are typical of strategic complementarity in eco-labels, and that four types of eco-labeling strategies can be implemented at the equilibrium. Consider first the equilibrium with corporate eco-labeling (symbolized by the leftmost point in Fig. 6). Maximization of profits with respect to qualities yields a unique equilibrium q_L^*, where both firms adopt the same standard.[25] Because consumers have heterogeneous preferences for eco-labels, firms have an interest in harmonizing their standards to share the market efficiently ($q_{LH}^c = q_{LM}^c = 1.65$).

When an NGO implements eco-label q_{LH}, although only one firm (the blue one) sets up its own eco-label, the best response of the NGO to quality q_{LM} is higher than

[23] However, the global real surplus is always damaged by imperfect information when the differentiation between the brown and the blue products is too low (for a given quality of the green product). Conversely, the global perceived consumer surplus is favored by imperfect information when consumers attach a high environmental quality to both labeled products because increasing perceived quality directly improves perceived surplus.

[24] Unfortunately, no analytical solution exists for any case using first-order conditions. With regard to a numerical solution, the system of equations has many candidates for the equilibrium, but only one solution fulfills the existence condition for triopoly, namely, $q_{Lj} \leq 4\theta$ (j = H, M), the second-order conditions and the non-deviation conditions. Numerical simulations using various suitable values of θ,$\underline{q}$ and δ are used to test the robustness of the results. First-order conditions and simulations are available upon request from the author.

[25] Replacing q_{LM} and q_{LH} by q_L in one of the first-order conditions, the symmetric standard can be defined as $q_L^* = \frac{1}{4}\left(3\theta + \sqrt{9\theta^2 + 8\theta - 4}\right)$.

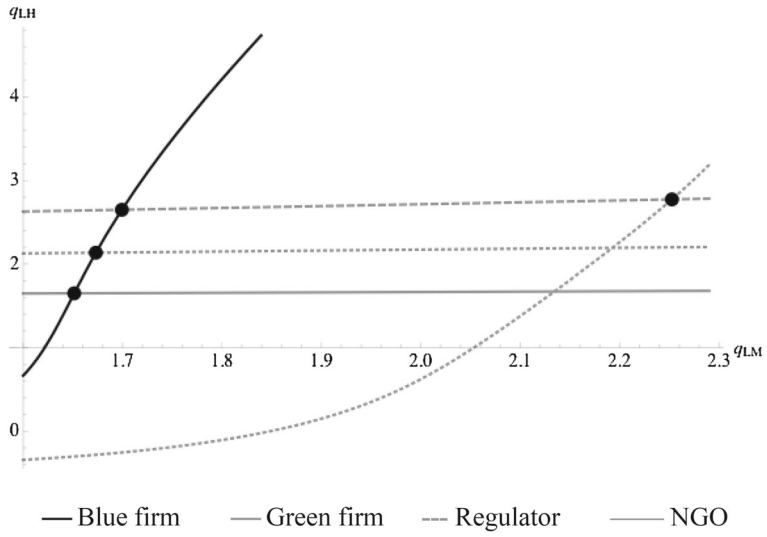


Fig. 6 Reaction functions in quality space (perfect information case)

that of the green firm. At the same time, the blue firm's reaction function exhibits a low level of sensitivity to changes in quality q_{LH}. Therefore, the only consistent equilibrium (represented by the third point from the left in Fig. 6) is such that the NGO implements a more stringent certification criteria than the green firm ($q_{LH}^{nc} = 2.65$), though the blue firm sets a standard that is slightly higher than in the previous case ($q_{LM}^{nc} = 1.70$).

When the regulator is in charge of eco-label q_{LH}, the equilibrium (represented by the second point from the left in Fig. 6) is intermediate between those emerging from corporate labels and from coexistence of an NGO label and a private label ($q_{LM}^{pc} = 1.67$ and $q_{LH}^{pc} = 2.13$).[26] Accordingly, the regulator takes into account the penalizing effect of a rise in q_{LH} on consumer surplus, due to ensuing price increase, and its damaging impact on the green firm's profit. At the same time, the regulator internalizes its enhancing outcome on the quality of the environment.

Finally, consider the case in which the NGO chooses q_{LH} but the regulator choosesq_{LM}. Figure 6 shows that the regulator's best response to q_{LH} is a much better quality than that of the blue firm, though the NGO has a low level of sensitivity to changes in quality q_{LM}. Therefore, at the equilibrium (symbolized by the rightmost point), the resulting standards are the most stringent of all cases ($q_{LM}^{np} = 2.25$ and $q_{LH}^{np} = 2.77$).

Proposition 3 *When consumers are perfectly informed of environmental quality of eco-labeled products, eco-labeling criteria differ depending on the certifying organizations: A corporate eco-label would be less demanding than a public eco-label,*

[26] The greater the δ, the more stringent the public label, but q_{LH}^{pc} is lower than q_{LH}^{nc} of the NGO regardless of the value of δ,

which in turn would be less exacting than an NGO eco-label. Certification by the regulator and the NGO guarantees the highest environmental quality of eco-labeled products.

Table 1 synthesizes the effects of eco-labeling strategies on market performances and on welfare components. While the blue and the green firms share almost all the market in the case of corporate eco-labeling, the blue firm benefits from the highest demand and profit when the NGO and/or the regulator sets one or both eco-labels. Accordingly, complying with stricter labeling criteria weakens the green firm, which is burdened by high production costs, forcing it to noticeably increase its price and lose market share and profit. Note that the green firm has no choice but to comply with this strict standard to signal the best environmental quality of its product and, in this way, differentiates its products from those of its competitors. Paradoxically, the brown firm is better off in the situation of NGO and public eco-labels, because it attracts the consumers who are not able to pay high prices for high environmental qualities, especially for the green product.

From a welfare perspective, NGO and regulator certification leads to the highest global profit and the greatest environmental quality. However, this situation is harmful to consumers because prices are high. Conversely, consumers enjoy the highest surplus but the lowest (non-internalized) quality of the environment in the case of corporate eco-labels.

4.3 Eco-labeling strategies with consumer misperception of quality

In the case of imperfect information, eco-labeling strategies depend on the certifying organizations' information on consumer belief. This situation raises the challenging issue of endogenization of perceived quality, which would require an in-depth analysis of what certifiers know about the way consumers form their beliefs about environmental quality. This section provides only an illustration of eco-labeling strategies in the specific case of fully informed certifying organizations when consumers assess the quality of eco-labeled products as their average quality.[27]

In the case of corporate eco-labeling, the best strategy for firms is greenwashing: supplying the worst quality, $\underline{q}$, and marking their products with homemade green labels. Indeed, consumer demand for an eco-labeled product is a decreasing function of its environmental quality because the production cost of such a product rises faster than the minimal WTP for the product, θq_L. Because loss in market share cannot be offset by higher prices, the maximum profit is reached for $\tilde{q}^c_{LH} = \tilde{q}^c_{LM} = \underline{q}$. Furthermore, greenwashing leads to the disappearance of the unlabeled product and to Hotelling competition between both blue and green firms.

[27] Brécard (2014) assumes that $q_L = \mu q_{LH} + (1-\mu)\, q_{LM}$, with $\mu \in [0, 1]$. The term $\mu\ (1-\mu)$ can be interpreted as the degree of influence of the green (blue) firm on consumers' beliefs. Setting μ to 1/2 avoids the situation in which a firm benefits more than its rival from the way consumers form their beliefs.

Table 1 Implications of eco-labeling strategies in the perfect information case

	Corporate labels			NGO and corporate labels			Public and corporate labels			NGO and public labels		
	NL	LM	LH	NL	LM	LH	NL	LM	LH	NL	LM	LH
q_i	1	1.65	1.65	1	1.70	2.65	1	1.67	2.13	1	2.25	2.77
p_i	0.57	2.12	2.12	0.72	2.28	4.27	0.64	2.19	3.09	0.88	3.46	4.63
d_i	0.09	0.46	0.46	0.22	0.49	0.29	0.15	0.47	0.38	0.30	0.41	0.28
π_i	0.01	0.35	0.35	0.05	0.42	0.22	0.02	0.37	0.31	0.12	0.38	0.23
$\prod$	0.70			0.68			0.70			0.71		
CS	$r + 0.77$			$r + 0.59$			$r + 0.71$			$r + 0.42$		
Q	1.60			1.82			1.75			2.02		

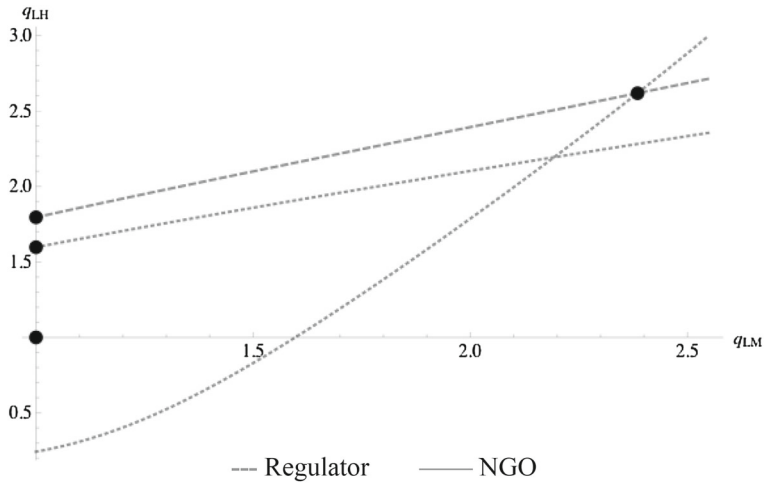


Fig. 7 Reaction functions in quality space (imperfect information case)

What are the best responses of the NGO and the regulator to $\tilde{q}_{LM} = \underline{q}$? Figure 7 shows that the best labeling criteria are $\tilde{q}_{LH}^{nc} = 1.80$ for the NGO and $\tilde{q}_{LH}^{pc} = 1.59$ for the regulator.[28] Both are less demanding than in the perfect information case.

When the NGO and the regulator both implement eco-labels, standards are more stringent than in the previous cases ($\tilde{q}_{LM}^{np} = 2.39$ and $\tilde{q}_{LH}^{np} = 2.62$). Of note, whereas the NGO's label is less exacting than in the perfect information case, the public label is slightly more demanding.

Proposition 4 *When certifying organizations know consumers' beliefs about environmental quality, consumer misperception of eco-labels incentivizes firms to greenwash and forces the NGO and the regulator to adopt less demanding criteria than in the case of perfect information.*

Table 2 synthesizes the effects of eco-labeling strategies on prices, demands, profits and welfare components.

Corporate eco-labeling strategies lead the blue and the green firms to equally share the market and to earn a profit $\left(\theta \underline{q}/2\right) - k_{Lj}$ higher than in the perfect information case (if $k_j \leq \theta \underline{q}/2$). In line with Brécard (2014), the current model shows that in the case of corporate labels, the green and the blue firms choose to harmonize the standards; however, it also shows that because consumers are supposed to be homogeneous in their marginal WTP for environmental quality, firms have no interest in providing high environmental quality to oust their competitors. By greenwashing, they succeed in excluding the brown firm and in gaining substantial profits. In the end, both remaining products bear an eco-label that is not green (or even blue). This profitable situation is

[28] In the case of a populist regulator, accounting for perceived surplus of consumers, the standard would be equal to $\overline{q}$, though such a standard is likely to trigger the disappearance of the green product (for q_{LH} higher than 2.55). Such a puzzling result arises from the positive effect of q_{LH} on perceived quality of the blue product, which artificially increases perceived surplus of consumers.

Table 2 Implications of eco-labeling strategies in the imperfect information case

	Corporate labels			NGO and corporate labels			Public and corporate labels			NGO and public labels		
	NL	LM	LH	NL	LM	LH	NL	LM	LH	NL	LM	LH
q_i	1	1	1	1	1	1.80	1	1	1.60	1	2.39	2.62
p_i	–	1.5	1.5	0.55	1.42	1.98	0.53	1.31	1.70	0.88	3.86	4.15
d_i	–	0.5	0.5	0.08	0.66	0.26	0.05	0.63	0.33	0.30	0.41	0.29
π_i	–	0.5	0.5	0	0.61	0.10	0	0.51	0.14	0.11	0.41	0.21
$\prod$	1			0.71			0.65			0.74		
CS	$r + 0.25$			$r + 0.56$			$r + 0.60$			$r + 0.41$		
Q	1			1.21			1.20			2.03		

damaging for the environment and for the consumers, and it justifies implementation of a system of verification of environmental allegation to prevent firms from untruthfully declaring their products as 'environmentally friendly'.

Although the NGO or the regulator implements the greenest eco-label, welfare remains lower than in the case of perfect eco-labels because of poorer quality of the environment and consumer surplus. Therefore, eco-labeling strategies should be coupled with information policies, such as eco-label guidelines, to avoid consumer misperception of eco-labels.

5 Conclusion

Too much of a good thing? The proliferation of eco-labels tends to counter their primary objective, which is to inform consumers of the environmental quality of credence goods. Consumers have trouble identifying the best eco-labels (those rigorously certified by a third-party) among all the varying green claims. Therefore, competition between green products leads to consumers' imperfect information and could have detrimental effects on economic efficiency and environmental benefits of eco-labels.

The aim of this article was to provide theoretical insight into this issue by using a double-differentiation model, in which an unlabeled product and two eco-labeled products of medium and high environmental quality are in competition. It compared the case of perfect eco-labels, which disclose full information to consumers, with the case of imperfect eco-labels, in which consumers perceive all eco-labels as a sign of the same high environmental quality. In both cases, consumers consider each label as a unique variety of the good.

In this original framework, the model shows that consumer misperceptions can affect the market structure: The greenest firm is weakened by consumer misperception, to the benefit of the firm supplying the eco-labeled product of medium environmental quality and even sometimes to the benefit of the firm providing the unlabeled product. For medium values of marginal WTP, the greenest product can be eliminated from the market in the imperfect information case but not in the perfect information case.

This research also demonstrated that consumer misperception is not always detrimental to social welfare: When consumers believe that both eco-labels signal high environmental quality, it is beneficial for the environment, for global profits, and, thereby, for social welfare. Finally, the study showed that eco-labeling strategies differ depending on the identity of the certifying organizations and the nature of consumer information. In the case of perfect corporate labels, firms will harmonize their eco-labeling criteria and demand high standards of their eco-labeled products. However, in the case of consumer misperception, when firms know how consumers form their beliefs about environmental quality, they will likely turn to greenwashing, thus stamping an eco-label on their lowest-environmental-quality products. In the case of eco-labels certified by a third party, certifying criteria will be more exacting, particularly when an NGO oversees the eco-label. However, when eco-labels are imperfect, the NGO and the regulator will require a less stringent standard than in the perfect label case.

In conclusion, implementation of policies that help consumers correctly assess environmental quality of eco-labeled products, such as publication of eco-label guidelines, does not necessarily improve welfare. In general, promoting green products, which favor consumer opinion that environmentally friendly products are a good value for the money, may be more effective. At the same time, greenwashing should be denounced with communication tools such as the 'Pinocchio awards' of the Friends of the Earth in France.[29] However, public eco-labeling policies are still a prerequisite for driving consumers toward greener products.

To generalize the results, it would be worthwhile to extend the model to more than three firms, thereby assuming higher proliferation of eco-labels and even greater consumer misperception. Entry of a new eco-labeled product may intensify competition, without compromising the existence of price equilibrium (see Gabszewicz and Thisse 1980; Shaked and Sutton 1987; Brenner 2005)[30] and is also likely to reinforce the difficulties encountered by the green firm in the case of imperfect eco-labels. However, this situation is also likely to reduce the competitive advantage of the blue firm and to weaken the brown firm. Although the effects on environmental quality and welfare are not obvious, the conclusions reached herein regarding the necessity of promoting eco-labeled green products and addressing greenwashing should not be jeopardized.

Appendix 1: Price equilibrium

Case of perfect eco-labels

From Eqs. (11) to (13) and definitions of demand functions, the following market shares of the three firms are deduced:

$$d^*_{LM} = \frac{c\left(\underline{q}\right) - \theta\underline{q}}{3\theta q_{LM}} + \frac{c\left(q_{LH}\right)q_{LM} + \left(2\theta q_{LM} - c\left(q_{LM}\right)\right)\left(2q_{LH} + 3q_{LM}\right)}{6\theta q_{LM}\left(q_{LH} + q_{LM}\right)} \quad (17)$$

$$d^*_{LH} = \frac{c\left(\underline{q}\right) - \theta\underline{q}}{3\theta q_{LH}} + \frac{c\left(q_{LM}\right)q_{LH} + \left(2\theta q_{LH} - c\left(q_{LH}\right)\right)\left(3q_{LH} + 2q_{LM}\right)}{6\theta q_{LH}\left(q_{LM} + q_{LH}\right)}, \quad (18)$$

and $d^*_{NL} = 1 - d^*_{LM} - d^*_{LH}$. Profits are $\pi^*_{NL} = \frac{\theta q_{LM} q_{LH}}{q_{LM}+q_{LH}} d^{*2}_{NL}$, $\pi^*_{LM} = \theta q_{LM} d^{*2}_{LM} - k_{LM}$ and $\pi^*_{LH} = \theta q_{LH} d^{*2}_{LH} - k_{LH}$.

The three conditions for triopoly, $d^*_{NL} \geq 0$, $d^*_{LM} \geq 0$ and $d^*_{LH} \geq 0$, can be translated into the conditions $\theta \leq \theta_{NL}$, $\theta \geq \theta_{LM}$ and $\theta \geq \theta_{LH}$, where the thresholds are defined as follows:

[29] http://www.pinocchio-awards.org/ (accessed 2015/12/16).

[30] In the line with Gabszewicz and Thisse (1980), only a limited number of eco-labels can coexist in a differentiated industry because of the vertical aspect of production differentiation.

$$\theta_{NL} \equiv \frac{c\left(q_{LH}\right) q_{LM} + c\left(q_{LM}\right) q_{LH} - \left(q_{LM} + q_{LH}\right) c\left(\underline{q}\right)}{2q_{LM}q_{LH} - \left(q_{LM} + q_{LH}\right)\underline{q}} \tag{19}$$

$$\theta_{LM} \equiv \frac{-c\left(q_{LH}\right) q_{LM} + c\left(q_{LM}\right)\left(2q_{LH} + 3q_{LM}\right) - 2\left(q_{LM} + q_{LH}\right) c\left(\underline{q}\right)}{6q_{LM}^2 + 4q_{LM}q_{LH} - 2\left(q_{LM} + q_{LH}\right)\underline{q}} \tag{20}$$

$$\theta_{LH} \equiv \frac{c\left(q_{LH}\right)\left(3q_{LH} + 2q_{LM}\right) - c\left(q_{LM}\right) q_{LH} - 2\left(q_{LM} + q_{LH}\right) c\left(\underline{q}\right)}{6q_{LH}^2 + 4q_{LM}q_{LH} - 2\left(q_{LM} + q_{LH}\right)\underline{q}}. \tag{21}$$

Case of imperfect eco-labels

From Eqs. (14) to (16) and definitions of demand functions, the following market shares of the three firms can be deduced:

$$\tilde{d}_{NL}^{*} = \frac{c\left(q_{LM}\right) + c\left(q_{LH}\right) - 2c\left(\underline{q}\right) - 2\theta\left(q_L - \underline{q}\right)}{12\theta q_L} \tag{22}$$

$$\tilde{d}_{LM}^{*} = \frac{4c\left(\underline{q}\right) - 5c\left(q_{LM}\right) + c\left(q_{LH}\right) + 2\theta\left(5q_L - 4\underline{q}\right)}{12\theta q_L} \tag{23}$$

$$\tilde{d}_{LH}^{*} = \frac{4c\left(\underline{q}\right) + c\left(q_{LM}\right) - 5c\left(q_{LH}\right) + 2\theta\left(5q_L - 4\underline{q}\right)}{12\theta q_L}. \tag{24}$$

The existence conditions for triopoly are characterized by marginal WTP $\tilde{\theta}_{NL}$, $\tilde{\theta}_{LM}$ and $\tilde{\theta}_{LH}$ such as $\tilde{d}_{NL}^{*} \geq 0$ when $\theta \leq \tilde{\theta}_{NL}$, $\tilde{d}_{LM}^{*} \geq 0$ when $\theta \geq \tilde{\theta}_{LM}$ and $\tilde{d}_{LH}^{*} \geq 0$ when $\theta \geq \tilde{\theta}_{LH}$:

$$\tilde{\theta}_{NL} \equiv \frac{c\left(q_{LH}\right) + c\left(q_{LM}\right) - 2c\left(\underline{q}\right)}{2\left(q_L - \underline{q}\right)} \tag{25}$$

$$\tilde{\theta}_{LM} \equiv \frac{-c\left(q_{LH}\right) + 5c\left(q_{LM}\right) - 4c\left(\underline{q}\right)}{10q_L - 4\underline{q}} \tag{26}$$

$$\tilde{\theta}_{LH} \equiv \frac{5c\left(q_{LH}\right) - c\left(q_{LM}\right) - 4c\left(\underline{q}\right)}{10q_L - 4\underline{q}}. \tag{27}$$

Appendix 2: Effects of consumer misperception on market equilibrium

The green product

From Eq. (16), it is evident that price $\tilde{p}_{LH}^{*}$ is an increasing function of q_L. Thus, to prove that $p_{LH}^{*} \geq \tilde{p}_{LH}^{*}$, it is sufficient to demonstrate that this inequality is true

for $q_L = q_{LH}$. Because $p^*_{LH} - \tilde{p}^*_{LH}\big|_{q_L=q_{LH}} = \frac{(q_{LH}-q_{LM})(2\theta q_{LH}-c(q_{LH})+c(q_{LM}))}{12(q_{LM}+q_{LH})}$ and $c(q_{LH}) \leq 2\theta q_{LH}$, $p^*_{LH} \geq \tilde{p}^*_{LH}$ is always fulfilled.

Similarly, it is evident that $\tilde{d}^*_{LH}$ is an increasing function of q_L and that $d^*_{LH} \geq \tilde{d}^*_{LH}$ for $q_L = q_{LH}$, as $d^*_{LH} - \tilde{d}^*_{LH}\Big|_{q_L=q_{LH}} = \frac{(q_{LH}-q_{LM})(2\theta q_{LH}-c(q_{LH})+c(q_{LM}))}{12\theta q_{LH}(q_{LH}+q_{LM})} \geq 0$, and thus for all $q_L \leq q_{LH}$. Finally, because consumer misperception decreases both the price and the market share of the green product, it also lowers the profit of the green firm.

The blue product

From Eq. (15), it follows that $\tilde{p}^*_{LM}$ declines with q_L. Moreover $p^*_{LM} \leq \tilde{p}^*_{LM}$ when $q_L = q_{LM}$ because $p^*_{LM} - \tilde{p}^*_{LM}\big|_{q_L=q_{LM}} = \frac{-(q_{LH}-q_{LM})(c(q_{LH})-c(q_{LM})+2\theta q_{LM})}{12(q_{LM}+q_{LH})} \leq 0$. Consequently, $p^*_{LM} \leq \tilde{p}^*_{LM}$ for all $q_L \geq q_{LM}$.

From Eq. (23), $\frac{\partial \tilde{d}^*_{LM}}{\partial q_L} = \frac{5}{6q_L} - \frac{\tilde{d}_{LM}}{q_L}$, which is positive when the blue product captures less than five sixths of the market. Furthermore, $d^*_{LM} \leq \tilde{d}^*_{LM}$ for $q_L = q_{LM}$, as $d^*_{LM} - \tilde{d}^*_{LM}\Big|_{q_L=q_{LM}} = \frac{-(q_{LH}-q_{LM})(2\theta q_{LM}+c(q_{LH})-c(q_{LM}))}{12\theta q_{LM}(q_{LH}+q_{LM})} \leq 0$, and thus for all $q_L \geq q_{LM}$. In summary, the profit of the firm producing the blue product is increased by consumer misperception about the perfect information case.

The brown product

From Eq. (14), it appears that $\tilde{p}^*_{NL}$ is a decreasing function of q_L. In addition,

$$p^*_{NL} - \tilde{p}^*_{NL}\big|_{q_L=q_{LM}} = \frac{-(q_{LH}-q_{LM})(2\theta q_{LM}+c(q_{LH})-c(q_{LM}))}{6(q_{LH}+q_{LM})} \leq 0,$$

$$p^*_{NL} - \tilde{p}^*_{NL}\big|_{q_L=q_{LH}} = \frac{(q_{LH}-q_{LM})(2\theta q_{LH}-c(q_{LH})+c(q_{LM}))}{6(q_{LH}+q_{LM})} \geq 0.$$

Therefore, there is a threshold $\hat{q}_L$ such that $\tilde{p}_{NL} > p_{NL}$ when $q_L \leq \hat{q}_L$, and $\tilde{p}_{NL} < p_{NL}$ otherwise. This threshold is defined as $\hat{q}_L = \frac{2\theta q_{LM}q_{LH}+(q_{LH}-q_{LM})(c(q_{LH})-c(q_{LM}))}{2\theta(q_{LM}+q_{LH})}$.

From Eq. (22), it follows that $\frac{\partial \tilde{d}^*_{NL}}{\partial q_L} = \frac{-c(q_{LH})-c(q_{LM})+2c\left(\underline{q}\right)-2\theta\underline{q}}{3\theta q_L^2} \leq 0$. Moreover,

$$d^*_{NL} - \tilde{d}^*_{NL}\Big|_{q_L=q_{LM}} = \frac{-(q_{LH}-q_{LM})\left(c(q_{LH})-c\left(\underline{q}\right)+\theta\underline{q}\right)}{3\theta q_{LM}q_{LH}} \leq 0$$

$$d^*_{NL} - \tilde{d}^*_{NL}\Big|_{q_L=q_{LH}} = \frac{(q_{LH}-q_{LM})\left(c(q_{LM})-c\left(\underline{q}\right)+\theta\underline{q}\right)}{3\theta q_{LM}q_{LH}} \geq 0.$$

Consequently, there is a threshold $\hat{\tilde{q}}_L$ such that $\tilde{d}_{NL} > d_{NL}$ when $q_L \leq \hat{\tilde{q}}_L$, and $\tilde{d}_{NL} < d_{NL}$ otherwise. The profit of the brown firm follows the same development,

which translates to better performance when q_L is close to q_{LM} and worse performance when q_L is close to q_{LH}.

Appendix 3: Effects of consumer misperception on the quality of the environment

The derivative of global environmental quality in the imperfect information case is characterized by

$$\frac{\partial \tilde{Q}}{\partial q_L} = \frac{\left(5q_{LH} - q_{LM} - 4\underline{q}\right) c\left(q_{LH}\right) - \left(q_{LH} - 5q_{LM} - 4\underline{q}\right) c\left(q_{LM}\right) + 4\left(q_{LH} + q_{LM} - 2\underline{q}\right)\left(\theta q_{NL} - c\left(\underline{q}\right)\right)}{12\theta q_L^2}$$

Because the second term of the numerator is necessarily lower than the first term and the third term is positive, the global environmental quality rises with perceived quality q_L. Furthermore, using the fully coverage property, it is possible to characterize $Q^* - \tilde{Q}^*$ in two ways:

$$\begin{aligned} Q^* - \tilde{Q}^* &= \left(q_{LM} - q_{LH}\right)\left(d_{LM}^* - \tilde{d}_{LM}^*\right) \\ &\quad + \left(\underline{q} - q_{LH}\right)\left(d_{NL}^* - \tilde{d}_{NL}^*\right) \geq 0 \quad \text{if} \quad q_L \leq \hat{\tilde{q}}_L, \text{ and} \\ Q^* - \tilde{Q}^* &= \left(q_{LH} - q_{LM}\right)\left(d_{LH}^* - \tilde{d}_{LH}^*\right) \\ &\quad + \left(\underline{q} - q_{LM}\right)\left(d_{NL}^* - \tilde{d}_{NL}^*\right) \leq 0 \quad \text{if} \quad q_L \geq \hat{\tilde{q}}_L. \end{aligned}$$

Therefore, when the perceived quality is low (high), the global environmental quality is lower (greater) than that occurring in the perfect information case.

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