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► To cite this version:

Dorothee Brécard, Mireille Chiroleu-Assouline. Information campaigns and ecolabels by environmental NGOs: Effective strategies to eliminate environmentally harmful components?. *Journal of Economics and Management Strategy*, In press, 10.1111/jems.12595 . hal-04592469

HAL Id: hal-04592469

<https://hal.science/hal-04592469>

Submitted on 3 Jun 2024

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Information campaigns and ecolabels by environmental NGOs: Effective strategies to eliminate environmentally harmful components?

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Funding information

Agence Nationale de la Recherche, Grant/Award Numbers: ANR-15-CE05-0008-01, ANR-17-EURE-001

Abstract

Environmental nongovernmental organizations (NGOs) are increasingly using strategies to encourage firms to eliminate product components (e.g., palm oil) that are harmful to the environment (e.g., rainforests) or to replace them with NGO-certified sustainable components. Under what conditions do NGOs' information and ecolabeling strategies succeed in eliminating certain harmful components when these components contribute to the intrinsic quality of a product? The paper addresses these questions using a model of two-dimensional vertical product differentiation in a market with consumers either informed or uninformed about the environmental quality of products and two firms that initially offer a product with the harmful component and a harmful component-free product. We show that the information campaign plays a crucial and effective role in improving environmental quality, although the optimal share of informed consumers for the NGO is large but not always 100%. Ecolabeling cannot replace the information campaign. It is only a complementary tool to an intensive information campaign. Used together, they can succeed in triggering the substitution of the certified sustainable component for the harmful one.

1 | INTRODUCTION

“If a company is doing the right thing, we are proud to stand up with them to advocate for solutions. If they are doing the wrong thing, we can campaign against them all around the globe to bring enough pressure to bear that they are forced to do the right thing.” This statement from Daniel Kessler, a spokesperson for Greenpeace, illustrates the growing pressure that environmental nongovernmental organizations (NGOs) exert on firms' strategies.¹ Different NGO campaigns take various forms and have different environmental goals. They often disclose information about the properties of goods purchased by consumers, the sustainability of production processes, and environmental impacts. For example, in 2010, Greenpeace mounted the campaign “Ask Nestlé to give rainforests a break.”² Relayed largely by social networks, the campaign forced Nestlé to end its partnership with Sinar Mas, the largest palm oil producer in Indonesia, and commit to removing deforestation-related products from its supply chains. In October 2011, Rainforest Foundation Norway and Green Living launched a campaign in Norway to highlight the link between palm oil

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production and deforestation, reduce the Norwegian consumption of palm oil in food, and encourage Norwegian food producers to demand traceability and transparency from their palm oil suppliers. As a result, Norwegian palm oil consumption fell by two-thirds a year later.³

Such campaigns resort to the field that Baron (2009) refers to as “private politics,” which include tactics ranging from simple information disclosure (Baron, 2011; Heyes et al., 2018; or Petrakis et al., 2005) to boycott campaigns (studied by Baron, 2016; Baron et al., 2016; Delacote, 2009; Egorov & Harstad, 2017; Innes, 2006). They have resulted in an increasing number of “component-free products”—that is, products free of damaging components—such as palm oil, pesticides, antibiotics, GMOs, nitrate, and chlorine, as well as paraben-free products used in agrifood products and cosmetic markets and fossil-free products, such as green electricity. In the specific case of palm oil, the Roundtable on Sustainable Palm Oil (RSPO), which includes environmental NGOs, such as the World Wildlife Foundation, promotes the growth and use of certified sustainable palm oil (CSPO) as an alternative to nonsustainable palm oil for firms. Among many others, Ethical Consumer is a British NGO that publishes a list of some products which are palm oil free or contain only sustainable palm oil.⁴ Palm oil is used as an essential ingredient in the food industry, especially in the manufacture of biscuits, in the cosmetics industry,⁵ and in the composition of biofuels. Firms may prefer to use CSPO rather than eliminate (standard) palm oil, for two reasons: First, it does not alter the texture of the product and second (like biofuels), it is less expensive (Van Gelder et al., 2004). We note, however, that the effectiveness of such ecolabels in preventing deforestation has been contested (van der Ven et al., 2018). In addition, consumers are particularly attached to the intrinsic (organoleptic) qualities of certain products containing palm oil, such as chocolate spreads, and only few of them are informed about the nonsustainability of palm oil. Finally, NGOs may have an interest in proposing a certified alternative component when consumer information campaigns fail to eliminate the harmful ingredient.

We have used the example of chocolate and hazelnut spread made with palm oil as an illustration, but the issue studied in this article is obviously broader and concerns many markets and components that are harmful to the environment. In particular, our model allows us to analyze consumer behavior and firm strategies observed in similar markets where a fraction of consumers is uninformed and the other is informed about the harmfulness of the denounced component. We investigate the best strategy that an environmental NGO can use to reduce or eliminate the consumption of products containing the harmful component. Such a strategy is an appropriate combination of an information campaign and the introduction of a certified sustainable component. Considering the resulting changes in market configuration, we address these issues using a two-dimensional vertical product differentiation model.

There is a rich body of theoretical literature on the competition between “green” and “brown” products that studies the efficiency of environmental policies (such as minimum quality standards, voluntary labels, norms, and taxation) depending on firms’ cost structures, abatement methods, environmental consciousness, information, and consumer altruism. Some authors have focused on the role of NGOs as certifying organizations aimed at improving environmental quality (Bonroy & Constantatos, 2015; Bottega & De Freitas, 2009; Brécard, 2014, 2017, 2023; Fischer & Lyon, 2014; Poret, 2019) and the competition issues related to environmental awareness and labels (Ben Elhadj et al., 2015; Ben Elhadj & Tarola, 2015; Conrad, 2005; Heyes & Martin, 2015; Marini et al., 2020). Kraft et al. (2013) explore the issue of NGOs trying to push the industry to replace potentially hazardous components. However, their perspective is somewhat different from ours: they consider NGOs to be pragmatic, so that their objective function takes into account industry profits, and that they have a choice between lobbying regulators or directly influencing the market through consumer sensitivity to the presence of components. Our model shares features with Bottega et al. (2009) and Garcia-Gallego and Georgantzis (2009, 2010). In line with these authors, we assume that the level of requirements of the environmental label issued by the NGO is chosen endogenously to achieve its goal of improving the environment.

However, we depart from this literature by assuming that the NGO combines its ecolabeling strategy with an information campaign on the environmental damage caused by a harmful ingredient.

Recent literature examines the information campaign as a strategy of environmental NGOs to improve environmental quality. The information campaign is either a kind of informative advertising strategy (Bagwell, 2007), where the NGO aims to correct consumers’ perceived environmental quality of a green (or brown) product (Feddersen & Gilligan, 2001; Heijnen, 2013), or a kind of persuasive advertising strategy, where the NGO aims to shape consumers’ preferences to increase their environmental awareness and the resulting willingness to pay (WTP) for the environmental quality of a product (Heijnen & Schoonbeek, 2008; Stathopoulou & Gautier, 2019; van der Made & Schoonbeek, 2009).⁶ In our model, the NGO’s campaign plays a different role on consumer preferences: it leads a fraction of uninformed consumers (about the harmfulness of a product ingredient) to become informed and then willing to pay more for the greener products.⁷ Feddersen and Gilligan (2001) develop a highly stylized model with

identical consumers in which the price effects of firms' quality choices are ignored. They show that the provision of information by an activist about the quality of one of the two goods can improve the social welfare of market exchange. For our part, we assume that the activist provides perfect information to a part of the consumers, and we study its effects in the market by highlighting the role of the degree of consumer heterogeneity in terms of their sensitivity to the environmental quality of the product. Buehler and Schuett (2014) also assume that informed and uninformed consumers coexist, but they focus on an experience good and assume that uninformed consumers buy the good before informed consumers. Sartzetakis et al. (2012) also consider these two groups of consumers in a dynamic model where the government's information campaign increases the stock of accumulated information and thus the fraction of informed consumers. Their research question is somewhat different from ours, as they study the role of information provision as a policy instrument to complement environmental taxation. Heyes et al. (2020) assume that consumers do not initially know the environmental quality associated with each ecolabel, but they can acquire information about the labels themselves. In contrast, in our model, we assume that consumers receive information for free from the NGO without actively searching for information. While the NGO's goal may be the same as in Baron (2011), the strategies and interactions considered are very different. Instead of an activist pressuring a company to adopt a standard set by an industry organization and also pressuring to raise the standard's level of requirements, we assume that it is the NGO that sets the standard and, through its information campaign, nonthreateningly urges informed consumers to demand component-free or labeled products, which in turn may induce firms to change.

Furthermore, we adapt the original model of bidimensional vertical differentiation of Garella and Lambertini (2014). There is indeed a technical reason why firms use denounced components: These components (such as palm oil) may be essential to guarantee the good intrinsic quality (such as texture) of the product. Elimination of these ingredients can cause significant deterioration in intrinsic quality. High intrinsic quality is thus associated with low environmental quality, and vice versa. Therefore, component-free products are viewed as having high environmental quality but possibly low intrinsic quality.⁸ Such an assumption is similar to the hypothesis of Mantovani et al. (2016) that high intrinsic quality of products generates high polluting emissions. However, we depart from their hypothesis by considering that "good attributes" and "bad attributes" have no presupposed inversely proportional relationship. Moreover, we assume that instead of eliminating harmful components—to the detriment of intrinsic quality—firms can replace the components with NGO-certified sustainable components (such as sustainable palm oil) without altering the intrinsic quality of the products. According to Mantovani et al. (2016), consumers have homogeneous preferences for environmental quality and heterogeneous preferences for intrinsic quality; in our model, consumers have heterogeneous preferences for environmental quality (credence) and homogeneous preferences for intrinsic quality (organoleptic for food products).⁹ That is, environmental attributes are the nonhedonic characteristics in their model, but the hedonic characteristics in our model.

Two original assumptions are added to this basic framework, allowing for an innovative analysis. First, we assume that only a fraction of consumers is informed about the environmental quality of products. Thus, uninformed consumers consider only intrinsic quality in their choice, while informed consumers consider both intrinsic and environmental quality. The second assumption is that informed consumers are averse to products that they know are highly polluting: while their WTP for products that are not or only moderately polluting is higher than that of uninformed consumers, their WTP for the polluting product is lower than that of uninformed consumers.

The two parts of the NGO strategy are assumed to occur together, but with different funding implications. Unlike Bottega and De Freitas (2009), we do not assume that the NGO receives income to cover the costs of certification. Nor do we consider the NGO to be a for-profit certifier as in Lizzeri (1999). Instead, we assume that the variable costs paid directly by the producer of the final good to the producers of the component include the certification costs paid to a third party. We assume that the NGO's campaigning efforts are funded by up-front resources (obtained through memberships, donations, and charity). The NGO does not necessarily exhaust its budget, following the principle that NGOs are only subject to the "non-distribution of profits" constraint stated by Hansmann (1980). This does not prevent them from reserving funds for other projects, now or in the future, but justifies the strong transparency requirement (Cabedo et al., 2018).

Using this original framework, we show that as the share of informed consumers increases through the NGO's information campaign, the market configuration changes from segmentation between the green market with informed consumers and the brown market with uninformed consumers, through fragmentation with informed consumers splitting between green and brown products (or nothing), to complete coverage. The efficiency of the NGO campaign depends crucially, on the demand side, on the relative willingness of consumers to pay for environmental quality and intrinsic quality, and their heterogeneity, and, on the supply side, on the cost structure of eliminating the harmful component and replacing it with another sustainable component. Some of our results are in striking contrast to our



initial intuition. First, for the NGO, informing as many consumers as possible is an effective strategy for reducing consumption of the brown product only if the informed consumers are sufficiently heterogeneous, with the most environmentally conscious consumers unwilling to pay for the brown product. Otherwise, the NGO may fall into a “fragmentation trap” where information is counterproductive because some newly informed consumers are encouraged to consume the most competitive brown product, leading to more global consumption of the brown product. Second, the introduction of a certified sustainable component as a complement to the information campaign may be detrimental to environmental quality if the NGO’s budget is too limited to inform a large proportion of consumers. Third, it will only improve environmental quality if the ecolabel is sufficiently lenient to encourage the firm producing the brown product to replace the harmful component with the certified one. As a result, ecolabeling is only a complementary tool to an intensive information campaign. Furthermore, we show that ecolabeling tends to reduce the economic component of welfare and would, therefore, be Pareto optimal only if the marginal social valuation of the environment is sufficiently high.

The remainder of the paper is structured as follows. Section 2 presents the model. Section 3 analyzes the effects of the NGO’s information campaign on consumer and firm decisions and the resulting optimal strategy of the NGO. Section 4 examines the effects of the introduction of an alternative certified sustainable component in the market and the resulting optimal ecolabeling strategy of the NGO. Section 5 offers conclusions.

2 | THE MODEL

Consider a market where two firms can offer different varieties i of a good. These varieties differ in two attributes: a nonhedonic (homogeneous) intrinsic characteristic, such as taste or texture, denoted q_i , and a hedonic (heterogeneous) environmental characteristic e_i , which represents their per unit contribution to the quality of the environment (with $i = B, M, G$, where B, M , and G stand, respectively, for brown, medium, and green). Product B is derived from the polluting component, Product G is “component-free,” while Product M is a variety containing a certified greener version of the controversial component. This is expressed as $e_B < e_M < e_G$. For simplicity’s sake, we assume that the primary quality of the environment in the absence of consumption is e_G . According to this specification, each unit of product deteriorates the environment by $e_i - e_G$.

By assumption, the intrinsic quality q_i is such that $q_B = q_M \geq q_G$: Because Product G does not use the harmful component, the taste or texture of the product may be worse than products that use the component.

2.1 | Consumers

In line with Garella and Lambertini (2014), we assume that consumers decide to buy either one unit or none of the goods. While consumers are fully informed and sensitive to the intrinsic attribute, only a fraction α of them are informed about the different harmfulness of the component contained in each Product i , while $1 - \alpha$ of consumers are uninformed about the environmental impact of their consumption.

Consumer preferences are represented by the following utility functions:

$$u_i(\theta) = \begin{cases} \rho q_i - p_i & \text{for uninformed consumers,} \\ \rho q_i + \theta e_i - p_i & \text{for informed consumers,} \end{cases} \quad i = B, M, G \quad (1)$$

with ρ the constant and positive WTP for intrinsic quality q_i , θ the WTP for environmental quality of informed consumers, which is assumed uniformly distributed over $[0, \bar{\theta}]$. The assumption that the lowest WTP for environmental quality is zero provides continuity between uninformed and informed consumers. p_i denotes the price of Product i .

Once consumers are informed about the environmental quality of the existing varieties, they devalue Product B , due to an aversion effect, and they value Products G and M , especially as they are sensitive to the environmental dimension. This results in scaling the perceived environmental quality e_i so that $e_B < 0 < e_M < e_G$. The strength of the aversion effect of informed consumers is reflected in the absolute value of e_B .

It is assumed that Product G is systematically preferred to Product B by the most environmentally sensitive consumer: $\bar{\theta} e_G + \rho q_G > \bar{\theta} e_B + \rho q_B$. We restrict the analysis to the most interesting case where the most

environmentally sensitive consumer is willing to pay more for the best environmental quality than for the worst intrinsic quality: $\bar{\theta} e_G > \rho q_G > 0$.

2.2 | Firms

For a given share of informed consumers, according to the type of good the firms decide to supply, they earn a profit $\pi_i(p_i) = (p_i - c_i)d_i(p_i) - F_i$, where c_i are unit costs, d_i consumers' demand expressed as market share and F_i are fixed costs of production, with $i = B, M, G$. We assume that the firm that produces the product with the harmful component, denoted as B , bears zero cost, that is, $c_B = 0$ and $F_B = 0$. To supply a component-free product (denoted as G), a firm must engage in research and development (R&D) to innovate a new technology or a new production process. As is usual for differentiation models, we assume that R&D generates only a fixed cost, such as $F_G \geq 0$ and $c_G = 0$. To switch to a certified product (denoted as M), the firm must buy a sustainable component to replace the denounced component; therefore, we assume that it only bears a higher variable production cost than before, equal to $c_M \equiv ce_M \geq 0$, because it incorporates the component produced under sustainable conditions that imply additional constraints for producers and certification costs, leading to higher costs. Because the nature of the component is not altered (i.e., sustainable palm oil is not different from palm oil), there is no fixed cost incurred when adopting the intermediate component ($F_M = 0$).¹⁰ Entry costs are assumed to be prohibitive. This allows the analysis to be limited to the duopoly case.

2.3 | NGO

The environmental NGO seeks to improve the quality of the environment by informing consumers about the harmful effect of the component on the environment and the existence of alternative products. The NGO's information campaign increases the fraction α of informed consumers, which is achieved at a strictly increasing cost, denoted $\sigma(\alpha)$. The campaign is, therefore, a form of informative advertising (Bagwell, 2007; Heijnen, 2013).

The objective of the NGO is to preserve the quality of the environment under its budget constraint. In the general case of three products coexisting in the market, the overall quality of the environment is the sum of the primary quality of the environment e_G and the degradation related to each product, defined as $(e_i - e_G)d_i$ for $i = B, M, G$. We assume that the NGO has an initial budget R that finances its information campaign effort. When it decides to introduce a less environmentally harmful substitutable component, the producers who use it will bear a higher cost of production of that component, the more environmentally friendly it is. For simplicity, we also assume that the component is paid for by the producer at a cost that includes its production cost and the certification fees paid to the third-party certifier.

The quality of the substitutable component is endogenously determined by the NGO and the local producers of this component. As a result, the NGO's program is

$$\begin{cases} \max_{\alpha, e_M} \left[e_G + \sum_{B, M} (e_i - e_G)d_i \right] \equiv \max_{\alpha, e_M} \left[\left(1 - \sum_{B, M} d_i \right) e_G + \sum_{B, M} e_i d_i \right] \\ \text{s.t. } \sigma(\alpha) \leq R. \end{cases}$$

Since it appears only in the NGO's objective function and not in its budget constraint, the trade-off between the two instruments is simplified.

2.4 | Sequence of the game

The game unfolds in a series of actions:

1. Before the NGO's campaign, only a very small share of consumers $\alpha < \alpha_0$ (with α_0 determined in Section 3) are informed about the environmental damage caused by the component (e.g., palm oil for Nutella, coal for electricity) that the first firm uses to produce Product B . The second firm produces the component-free Product G .

2. The NGO decides on the budget for the campaign to increase the share of informed consumers and whether or not to certify a sustainable component of quality e_M .
3. The firms react to the NGO's information campaign. They can either continue to produce their original product, or one of them may decide to use the certified component. Three cases can occur:
 - (a) The status quo case, where firms continue to produce Products B and G .
 - (b) The case of Products B and M , where the first firm continues to produce Product B , while the second firm uses the certified component in its Product M (instead of producing the component-free Product G).
 - (c) The case of Products M and G , where the first firm uses the certified component in its Product M (instead of the harmful component), while the second firm continues to produce Product G .
4. The firms compete on price, and the consumers decide to buy either one unit of the proposed products or none of the products.

We solve this static game backwards in Sections 3 and 4.

3 | PROMOTION OF THE GREEN PRODUCT THROUGH INFORMATION CAMPAIGN

3.1 | Nash equilibrium

The fraction of informed consumers, α , plays a crucial role in the pricing strategies of firms. All else being equal, α *directly* determines the total demand of informed and uninformed consumers, and thus *indirectly* affects the pricing strategies, which in turn determine the fraction of informed consumers who purchase the brown and green products. Therefore, according to α , different Nash equilibria (illustrated in Figure 1)¹¹ can arise.¹²

3.1.1 | Segmentation

Before the NGO's campaign, the fraction of informed consumers is assumed to be low enough to lead to market segmentation into two distinct and independent segments: The large segment of uninformed consumers, who consume only the brown product, and the narrow segment of informed consumers, who either consume the green product or nothing. In the informed segment, those with the highest WTP for environmental quality consume the green product, while those with the lowest WTP for environmental quality consume neither.¹³

Market segmentation occurs when the fraction of informed consumers is lower than α_0 , defined as follows:

$$\alpha_0 \equiv \frac{-\bar{\theta} e_B}{\rho q_B - \bar{\theta} e_B}. \quad (2)$$

The firms then behave like two monopolies in their market segments. The firm that supplies the brown product (hereafter called Firm B) sets a price $p_B^m \equiv \rho q_B$, which is the maximum WTP for Product B . The demand

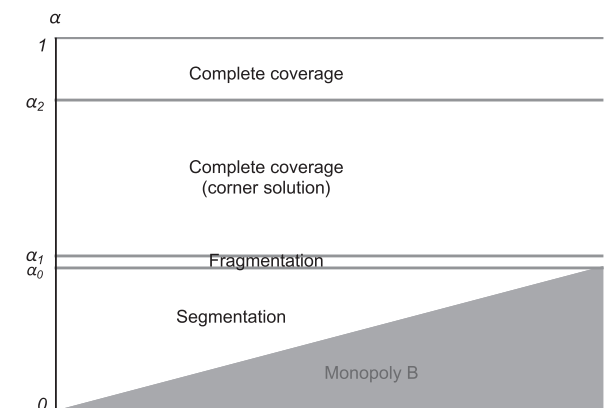


FIGURE 1 Market structures with Products B and G .

of Product B is $d_B^m \equiv 1 - \alpha$ and the profit of Firm B is $\pi_B^m = (1 - \alpha)\rho q_B$. Because Firm B faces high demand from uninformed consumers, it has no incentive to attract informed consumers by lowering its price below its WTP (lower than ρq_B). The firm that supplies the green product (hereafter called Firm G) sets a price p_G^m defined as follows:

$$p_G^m \equiv \frac{\rho q_G + \bar{\theta} e_G}{2}. \quad (3)$$

The demand from informed consumers is

$$d_G^m \equiv \frac{\alpha(\rho q_G + \bar{\theta} e_G)}{2\bar{\theta} e_G}. \quad (4)$$

The profit of Firm G is $\pi_G^m = \alpha(\rho q_G + \bar{\theta} e_G)^2 / (2\bar{\theta} e_G) - F_G$. We assume that F_G is sufficiently low to make Product G cost-effective.

3.1.2 | Fragmentation

When the NGO's campaign increases the fraction of informed consumers beyond α_0 , the narrower segment of uninformed consumers still consumes the brown product, but the larger segment of informed consumers is fragmented: The informed consumers with the highest WTP for the environmental quality consume the green product, while those with the lowest WTP consume the brown product, and those with intermediate WTP consume neither.

Market fragmentation occurs when the fraction of informed consumers is such that $\alpha_0 < \alpha \leq \alpha_1$, with

$$\alpha_1 \equiv \frac{-\bar{\theta} e_G e_B}{\rho(q_B e_G - q_G e_B)}, \quad (5)$$

By assumption, $\bar{\theta} > \rho q_G / e_G$, which ensures the existence of such a fragmented market (i.e., $\alpha_1 > \alpha_0$). And $\alpha_1 < 1$ as soon as $\bar{\theta}$ is lower than $\bar{\theta}_1$ defined as follows:

$$\bar{\theta}_1 \equiv \rho q_G / e_G - \rho q_B / e_B. \quad (6)$$

Firm G still acts as a monopoly, setting its monopoly price p_G^m and earning profit π_G^m . On the other hand, since there are more informed consumers than in the previous case, Firm B has an interest in supplying the brown product to the informed consumers with low WTP for the environmental quality at a lower price than before the campaign. So it sets a price:

$$p_B^f = \frac{\alpha \rho q_B - (1 - \alpha) \bar{\theta} e_B}{2\alpha}. \quad (7)$$

The demand for Product B is then equal to

$$d_B^f = \frac{\alpha \rho q_B - (1 - \alpha) \bar{\theta} e_B}{-2\bar{\theta} e_B}. \quad (8)$$

As a result, its profit is $\pi_B^f = -\bar{\theta} e_B d_B^f / \alpha$, higher than π_B^m . A rise in α from α_0 to α_1 entails a direct positive effect on the demand for Product G and the profit of Firm G . This also decreases p_B^f , and increases the demand for Product B as soon as $\bar{\theta} < -\rho q_B / e_B$. This detrimental effect of the NGO's information campaign is due to the fact that the reduction in the fraction of uninformed consumers is offset by the increase in the demand for Product B by (more) informed consumers.

3.1.3 | Complete coverage

When the NGO's campaign increases the fraction of informed consumers beyond α_1 , the market is completely covered: the narrow segment of uninformed consumers still consumes only the brown product, and the large segment of informed consumers is divided into the informed consumers with the highest WTP for the environmental quality, who consume the green product, and those with lower WTP, who consume the brown product.

Following Wauthy (1996) and Liao (2008), we consider two subcases: a covered market with a corner solution and a covered market with an interior solution (detailed in Appendix A). An interior solution requires that the minimum WTP of informed consumers for the green product be lower than their maximum WTP for the brown product, which in turn requires a sufficiently large segment of informed consumers (such that $\alpha \geq \alpha_2$, defined below). When the segment of informed consumers is smaller (such that $\alpha_1 < \alpha \leq \alpha_2$), there is a corner solution where prices are set to equalize their minimum WTP for the green product and their maximum WTP for the brown product. The Nash equilibrium then corresponds to the prices of the fragmented market when α is at its upper bound of α_1 .¹⁴

The market is covered with a corner solution if $\alpha_1 < \alpha \leq \alpha_2$, with

$$\alpha_2 \equiv \frac{\bar{\theta}(e_G - e_B)(2e_G - e_B)}{\bar{\theta}(e_G^2 - e_B^2) + \rho q_G(e_G - 2e_B) + \rho q_B(2e_G - e_B)}. \quad (9)$$

The price of Product B is then the limit price p_B^f for $\alpha = \alpha_1$:

$$p_B^{BGc} = \rho q_B + \frac{e_B(\bar{\theta} e_G - \rho q_G)}{2e_G}. \quad (10)$$

Firm G still sets its monopoly price p_G^m . The demand for Product B is $d_B^{BGc} = 1 - d_G^m$. The higher α , the higher the market share and the profit of Firm G (at a constant price), to the detriment of Firm B.

The market is covered with an interior solution if $\alpha_2 < \alpha \leq 1$, where $\alpha_2 < 1$ requires that the informed consumers are not too heterogeneous, that is, $\bar{\theta}$ is lower than the threshold $\bar{\theta}_2$ defined as¹⁵

$$\bar{\theta}_2 \equiv \frac{\rho q_G(e_G - 2e_B) + \rho q_B(2e_G - e_B)}{(e_G - e_B)(e_G - 2e_B)} < \bar{\theta}_1. \quad (11)$$

The equilibrium prices are then defined as follows:

$$p_B^{BGc} = \frac{(e_G - e_B)(2 - \alpha)\bar{\theta} + \rho\alpha(q_B - q_G)}{3\alpha}, \quad (12)$$

$$p_G^{BGc} = \frac{(e_G - e_B)(1 + \alpha)\bar{\theta} - \rho\alpha(q_B - q_G)}{3\alpha}. \quad (13)$$

The demands are expressed as $d_i^{BGc} = \alpha p_i^{BGc} / (\bar{\theta}(e_G - e_B))$ for $i = B, G$. The higher α , the higher the demand for Product G (to the detriment of Product B) as soon as the WTP of the most environmentally conscious consumer is higher for the green product than for the brown product: $\rho q_G + \bar{\theta} e_G > \rho q_B + \bar{\theta} e_B$. However, lower prices tend to reduce the profits of both firms. Product G is cost-effective if the fixed cost F_G is lower than the gross profit of Firm G.

Noting that the three thresholds α_0 , α_1 , and α_2 increase with the heterogeneity of consumers' environmental preferences, these results lead to the following lemma:

Lemma 1. *If F_G is low enough for the firm offering Product G to remain cost-effective when competing with Product B, the market configuration depends on the heterogeneity of consumers' environmental preferences $\bar{\theta}$:*

- If it is moderate ($\rho q_G/e_G < \bar{\theta} \leq \bar{\theta}_2 < \bar{\theta}_1$), as the fraction of informed consumers increases, the market is first segmented, then fragmented, then covered with a corner solution, and finally covered.
- If it is large ($\bar{\theta}_2 < \bar{\theta} < \bar{\theta}_1$), then $\alpha_2 > 1$, and for high fractions of informed consumers ($\alpha > \alpha_1$), the market remains covered with a corner solution.
- If it is very large (i.e., $\bar{\theta} \geq \bar{\theta}_1 > -\rho q_B/e_B$), the market remains segmented for any fraction of informed consumers.

Although the heterogeneity of consumers' environmental preferences has a significant impact in the market configuration, it is worth noting that differentiation by intrinsic and environmental qualities plays a crucial role, since it determines the thresholds $\bar{\theta}_1$ and $\bar{\theta}_2$. The more the two products are differentiated on the basis of their intrinsic quality, compared with the differentiation on the basis of their environmental quality, the less attractive Product G will be to the informed consumers. As a consequence, moderate and large heterogeneity in consumers' environmental preferences requires that $-e_G/e_B > q_G/q_B$, which implies a strong aversion effect and a weak differentiation on intrinsic quality.

3.2 | Optimal campaign effort

When the NGO's only lever for changing the market to improve environmental quality is the consumer information campaign, it has an incentive to reduce the market share of Product B . If we assume that Product G does not degrade the environment, then consuming Product G and not consuming have the same positive impact on environmental quality. Thus, the NGO is indifferent to the market share of product G .

Lemma 2. *As soon as the most environmentally conscious consumer is unwilling to pay for Product B , such that $\bar{\theta} e_B + \rho q_B < 0$, and $\bar{\theta} > \max\left\{-\frac{\rho q_B}{e_B}, \bar{\theta}_2\right\}$, a larger share of informed consumers reduces the demand for Product B , regardless of the market configuration.*

Lemma 2 follows directly from the definitions of the demand for Product B in the different market configurations described in Section 3.1, except for complete coverage, which cannot be achieved when $\bar{\theta} > \bar{\theta}_2$ and $\alpha_2 > 1$. It gives the sufficient condition for a positive effect of α on environmental quality through a decrease in the demand for Product B (see proofs in Appendix B).¹⁶ This implies that informing the largest number of consumers will always improve environmental quality if consumers are sufficiently heterogeneous, with high $\bar{\theta}$, or the aversion effect is relatively strong, with high $|e_B|$ (for a given ρq_B).

We therefore deduce Proposition 1.

Proposition 1. *If F_G is low enough to ensure the cost-effectiveness of Product G , and if consumers' environmental preferences are highly heterogeneous ($\bar{\theta} > \max\left\{-\frac{\rho q_B}{e_B}, \bar{\theta}_2\right\}$), the NGO's optimal strategy is simply to increase α as much as its budget allows until all consumers are informed if possible.*

However, if consumers' environmental preferences are less heterogeneous, such that $\bar{\theta} < -\rho q_B/e_B$, then increasing α beyond α_0 leads to a fragmented market in which the demand for Product B increases, worsening environmental quality (as illustrated in Figure 2).

Therefore, the NGO's optimal effort is discontinuous for $\alpha \in [\alpha_0, \alpha_1]$: keep the fraction of informed consumers at α_0 and then "jump" to a fraction $\alpha'_1 > \alpha_1$, for which the market is covered with a corner solution and the (increasing) environmental quality regains to its level achieved with α_0 : $E^{BGcc}(\alpha'_1) = E^{BGm}(\alpha_0)$. There is then a kind of "fragmentation trap" in the region $]\alpha_0, \alpha'_1[$ of informed consumers. Moreover, we show that the NGO has no incentive to increase α beyond α_2 because the quality of the environment falls significantly when the market configuration changes to a covered market with an interior solution due to a sudden increase in the demand for Product B explained by a significant decrease in its price (see proofs in Appendix C).¹⁷ Contrary to intuition, systematically increasing the share of informed consumers is not optimal. The NGO will not spend its entire budget if that share allows it to move

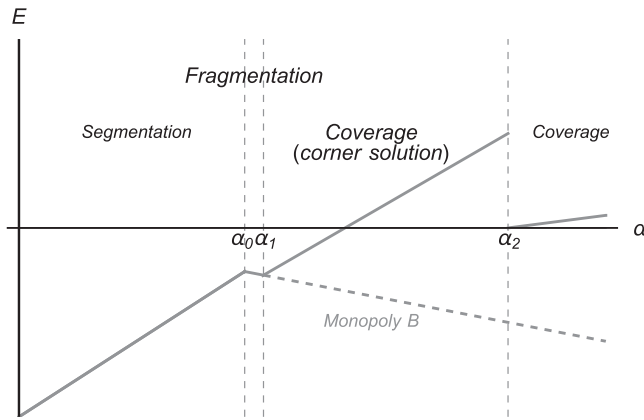


FIGURE 2 Environmental quality according to α for $\bar{\theta} < -\rho q_B / e_B$.

from a segmented to a fragmented market. Nor will it do so for a higher share of informed consumers if the result is a covered market with an interior solution. This is summarized in Proposition 2.¹⁸

Proposition 2. *If consumers' environmental preferences are moderately heterogeneous, that is, $\frac{\rho q_G}{e_G} < \bar{\theta} < \min\left\{-\frac{\rho q_B}{e_B}, \bar{\theta}_2\right\}$, the NGO's optimal strategy is to use all or part of its budget R to reach the largest possible fraction of informed consumers, outside the fragmentation trap $]\alpha_0, \alpha'_1[$ and at most equal to $\alpha_2 < 1$.*

Proposition 2 is consistent with the results of Heyes et al. (2020), that an information campaign does not always lead to better environmental quality. Their framework differs significantly from ours in that they assume that consumers actively (and costly) acquire information about the stringency of the ecolabels, while we assume that consumers passively (and not costly) acquire information about the environmental damage caused by a harmful component of the product. Nevertheless, it confirms that a “fragmentation trap” can exist and that, in some cases, improving information about the environmental quality of products is detrimental to the environment.

4 | NGO'S PROPOSAL FOR AN ALTERNATIVE CERTIFIED COMPONENT

The environmental NGO may have an interest in supplying a sustainable certified component to the firms for two reasons: a limited budget for the information campaign or a strong degradation of the intrinsic quality of the green product compared with the brown product. These factors may prevent the NGO from substantially improving the quality of the environment through an information campaign alone.

4.1 | Nash equilibrium

When a new certified component is proposed by the NGO, Firm G may decide to use this sustainable component instead of eliminating the harmful component, or Firm B may decide to use it instead of the denounced component. We analyze these two situations in the following subsections.

4.1.1 | Duopoly with Products B and M

Since the certified Product M has the same intrinsic quality and better environmental quality than the brown Product B ($q_M = q_B$ and $e_M > 0 > e_B$), it is clearly vertically differentiated from the brown product in the eyes of informed consumers. As a result, all informed consumers are willing to pay more for the certified product than for the brown product ($\rho q_B + \theta e_M > \rho q_B + \theta e_B$ for all θ). On the other hand, uninformed consumers consider Products B and M as perfectly substitutable. Moreover, the unit cost of Product M is higher than the production cost of Product B ($ce_M > 0$), which tends to increase the price of M relative to the price of B . Therefore, depending on the part of informed

consumers, α , and on the environmental quality of the certified product, e_M , different Nash equilibria can arise when Firm G substitutes Product M for Product G .¹⁹ Figure 3 illustrates the conditions for the different market configurations with Products B and M .²⁰

Segmentation ($\alpha \leq \alpha_0$ and $ce_M \in [\rho q_B - \bar{\theta} e_M, \rho q_B + \bar{\theta} e_M]$)

If, despite the NGO's campaign, the proportion of informed consumers remains below α_0 , the market is segmented. The large segment of uninformed consumers buys the brown product sold by Firm B at its monopoly price p_B^m . In the narrow segment of informed consumers, those with high WTP for environmental quality consume the certified product, while others abstain from consuming it.

The firm that now supplies Product M (hereafter called Firm M) sells its product at the following price:

$$p_M^m = \frac{\rho q_B + \bar{\theta} e_M + ce_M}{2}. \quad (14)$$

Firm M then benefits from the following demand:

$$d_M^m = \alpha \frac{\rho q_B + \bar{\theta} e_M - ce_M}{2\bar{\theta} e_M}. \quad (15)$$

Demand and profit are positive if its production cost is lower than the maximum WTP for Product M , that is, $ce_M \leq \bar{\theta} e_M + \rho q_B$, but not too low (for reasons explained below), that is, $ce_M \geq \rho q_B - \bar{\theta} e_M$.

Fragmentation ($\alpha_0 < \alpha \leq \alpha_3$ and $ce_M \in [\rho q_B - \bar{\theta} e_M, \rho q_B + \bar{\theta} e_M]$)

When the NGO's campaign increases the proportion of informed consumers above α_0 , Firm B has an interest in serving all uninformed consumers and informed consumers whose WTP for environmental quality is low. The segment of informed consumers is then fragmented: the informed consumers with the lowest WTP for the environmental quality consume Product B , while those with the highest WTP consume Product M , and those with intermediate WTP consume neither.

Fragmentation requires a moderate cost of production of Product M ($ce_M \in [\rho q_B - \bar{\theta} e_M, \rho q_B + \bar{\theta} e_M]$) and either sufficiently heterogeneous consumers or α lower than α_3 , defined as follows²¹:

$$\alpha_3 \equiv \frac{-\bar{\theta} e_M e_B}{ce_M e_B + \rho q_B (e_M - e_B)}. \quad (16)$$

Firm B then sets price p_B^f , benefits from demand d_B^f and earns profit π_B^f . Meanwhile, Firm M sets the monopoly price p_M^m . The number of informed consumers who abstain from consuming the good decreases with α . As a result, the higher α , the greater the demand for Product M by informed consumers, but also the higher their demand for Product B whenever the most environmentally conscious informed consumer is ready to pay for Product B , that is, $\rho q_B + \bar{\theta} e_B > 0$.

Complete coverage ($\alpha \geq \alpha_3$ and $ce_M \in [\rho q_B - \bar{\theta} e_M, \rho q_B + \bar{\theta} e_M]$)

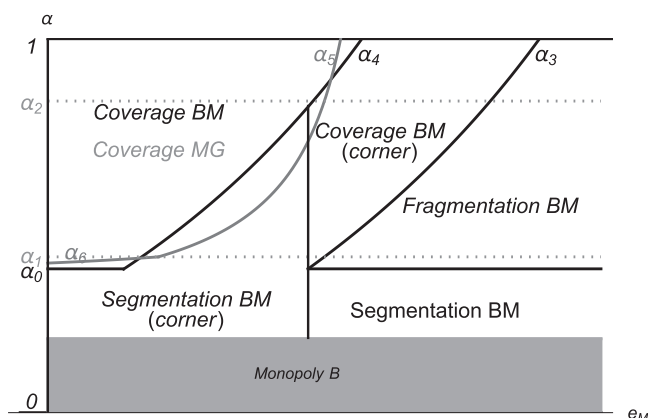


FIGURE 3 Market configurations with Product M .

When the proportion of informed consumers is increased above α_3 , the market is completely covered: the narrow segment of uninformed consumers still buys the brown product, while the large segment of informed consumers buys either the certified or the brown product.

The market is covered with a corner solution if $\alpha_3 < \alpha \leq \alpha_4$, with²²

$$\alpha_4 \equiv \frac{\bar{\theta}(2e_M - e_B)(e_M - e_B)}{-ce_M(e_M - 2e_B) + (e_M - e_B)(\bar{\theta}(e_M + e_B) + 3\rho q_B)}. \quad (17)$$

The price of Product B is then equal to price p_B^f with α set at the upper limit of the fragmented market α_3 :

$$p_B^{BMcc} = \frac{(c + \bar{\theta})e_B e_M + \rho q_B(2e_M - e_B)}{2e_M}, \quad (18)$$

while the price of Product M is p_M^m . Prices are, therefore, independent of α . The demands are d_M^m and $d_B^{BMcc} = 1 - d_M^m$. A larger proportion of informed consumers leads to a greater demand for Product M , to the detriment of Product B .

When the NGO's campaign further increases the proportion of informed consumers, such that $\alpha > \alpha_4$, the market is covered with an interior solution. The equilibrium prices are defined as follows:

$$p_B^{BMc} = \frac{\alpha ce_M + (2 - \alpha)\bar{\theta}(e_M - e_B)}{3\alpha}, \quad (19)$$

$$p_M^{BMc} = \frac{2\alpha ce_M + (1 + \alpha)\bar{\theta}(e_M - e_B)}{3\alpha}. \quad (20)$$

The demand for Product M is then equal to

$$d_M^{BMc} = \frac{1 + \alpha}{3} - \frac{\alpha ce_M}{3\bar{\theta}(e_M - e_B)}, \quad (21)$$

while the demand for Product B is $d_B^{BMc} = 1 - d_M^{BMc}$. The higher the proportion of informed consumers, the higher the consumption of Product M to the detriment of Product B , provided the unit cost is not too high (i.e., $ce_M < \bar{\theta}(e_M - e_B)$). Otherwise, if the production cost is higher, the information campaign paradoxically leads consumers to consume more Product B , because it is cheaper than Product M .

Segmentation and complete coverage ($\alpha \leq \alpha_4$ and $ce_M \leq \rho q_B - \bar{\theta} e_M$)

When the production cost of Product M is very low and the proportion of consumers is not too high, such that $\alpha < \alpha_4$, the price competition is fierce and the market is segmented and covered with a corner solution (see Appendix D): both firms set the same limit price $p_M^{mc} = p_B^m = \rho q_B$ and we assume that uninformed consumers all consume Product B while informed consumers all consume Product M .²³ Obviously, the higher the proportion of informed consumers, the higher the demand of Product M , until α reaches α_4 . Profits are then π_B^m and $\pi_M^{mc} = \alpha(\rho q_B - ce_M)$.

4.1.2 | Duopoly with Products M and G

Product M has better intrinsic quality and lower environmental quality than Product G ($q_M = q_B > q_G$ and $e_G > e_M$). The nature of the product differentiation between the two products can be described as horizontal in the market of informed consumers, since informed consumers do not all prefer the same product when sold at the same price. Conversely, both products are vertically differentiated for uninformed consumers. Moreover, the unit production cost of Product M has a direct impact on its price, whereas the fixed production cost of Product G only has an impact on the profit of Firm G . As a result, the outcome of the competition between these two products is not obvious.

The market with only the two Products M and G cannot be fragmented. Indeed, the informed consumers who could abstain from the consumption of the good are those with the lowest WTP for environmental quality. Therefore, uninformed consumers should also abstain if some informed consumers abstain (because their WTP for Product M is lower). But uninformed consumers prefer to consume Product B (at a price less than or equal to ρq_B) rather than nothing. Therefore, in a fragmented market with Products M and/or G , it is cost efficient to produce B . The resulting market structure is then a triopoly with Products B , M , and G , or a duopoly with Products B and M or G .²⁴

After the NGO's campaign, Product M can drive Product B out of the market, leading to a covered market with Products M and G , only if the proportion of informed consumers, α , satisfies the following conditions (illustrated in gray in Figure 3):

$$\alpha > \alpha_5 \equiv \frac{\bar{\theta}(e_G - e_M)}{-ce_M + 2\bar{\theta}(e_G - e_M) + \rho(q_B - q_G)}, \quad (22a)$$

$$\alpha > \alpha_6 \equiv \frac{2\bar{\theta}(e_G - e_M)}{-2ce_M + \bar{\theta}(e_G - e_M) + \rho(2q_B + q_G)}. \quad (22b)$$

The bounds α_5 and α_6 are positive, higher than α_0 and lower than 1, and therefore binding, under the appropriate conditions on the various parameters (developed in Appendix E). Under these conditions, the equilibrium prices are defined as follows:

$$p_M^{MGc} = \frac{2\alpha ce_M + (2 - \alpha)\bar{\theta}(e_G - e_M) + \alpha\rho(q_B - q_G)}{3\alpha}, \quad (23)$$

$$p_G^{MGc} = \frac{\alpha ce_M + (1 + \alpha)\bar{\theta}(e_G - e_M) - \alpha\rho(q_B - q_G)}{3\alpha} \quad (24)$$

and the demand for Product M is

$$d_M^{MGc} = \frac{-\alpha ce_M + (e_G - e_M)(2 - \alpha)\bar{\theta} + \alpha\rho(q_B - q_G)}{3\bar{\theta}(e_G - e_M)}, \quad (25)$$

while the demand for Product G is $d_G^{MGc} = 1 - d_M^{MGc}$. The profits are then defined by $\pi_M^{MGc} = \bar{\theta}(e_G - e_M)d_M^{MGc}/\alpha$ and $\pi_G^{MGc} = \bar{\theta}(e_G - e_M)d_G^{MGc}/\alpha - F_G$. The higher the fraction of informed consumers, the lower both prices. The demand for Product G is an increasing function of α , and the demand for Product M is a decreasing function of α , if the production cost is sufficiently high ($ce_M > \rho q_B + \bar{\theta}e_M - (\rho q_G + \bar{\theta}e_G)$) or the most environmentally conscious consumer is willing to pay more for Product G than for Product M ($\rho q_G + \bar{\theta}e_G > \rho q_B + \bar{\theta}e_M$).

4.1.3 | Subgame perfect equilibria

Having characterized all possible Nash equilibria, we can now examine under which conditions Firm G (resp., B) has a real incentive to substitute Product M for Product G (B). The conditions for a subgame perfect Nash equilibrium (SPNE) with Products B (G) and M result from the conditions (detailed in Appendix F) that allow Product M to provide a higher profit than Product G (B) when it competes with Product B (G), and ensure that Product B (G) is the best response to Product M for Firm B (G). Figure 4a,b illustrates the (e_M, α) pairs leading to an SNPE with Products B and M (in white), with Products B and G (in light gray), and with Products M and G (in the dark gray).²⁵ This shows that the higher e_M , the lower the maximum share α compatible with an SPNE with Products B and M , because a low share of informed consumers (for a given e_M) leads to a higher profit for Firm M than for Firm G (competing with Firm B), and a larger share of informed consumers increases the profit of Firm G (for a given fixed cost of production) and decreases the profit of Firm M (including its variable cost of production of Product M).²⁶

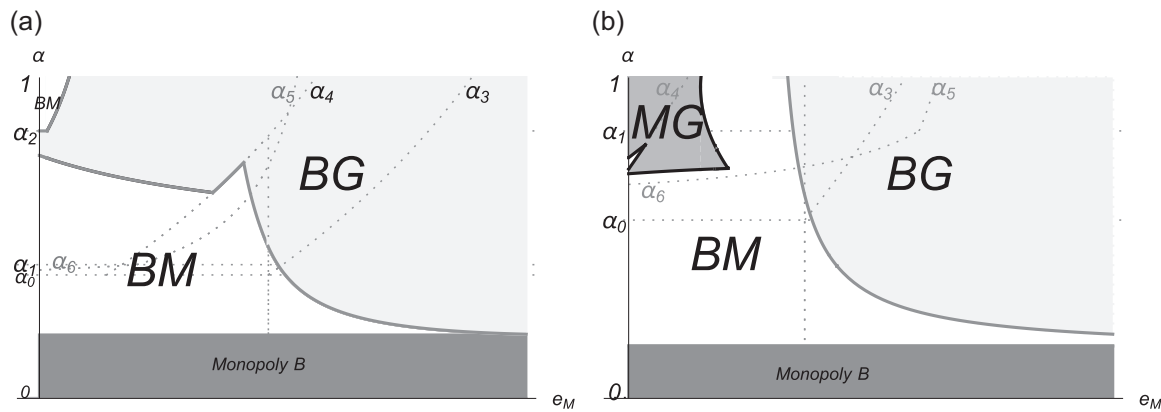


FIGURE 4 Subgame perfect Nash equilibria. (a) Low heterogeneity ($\bar{\theta} = 2.5$) and (b) High heterogeneity ($\bar{\theta} = 5$).

The SNPE where Firm B decides to substitute Product M for Product B arises under specific conditions, because Product B benefits from the captive market of uninformed consumers and can be produced at no cost. The conditions (detailed in Appendix F) for such a strategy to be also an SPNE are even more restrictive. We can show that this SPNE arises when the environmental quality (and production cost) of Product M is low and the informed consumers are sufficiently numerous and heterogeneous to raise the profit from Product M above the profit from the highly competitive Product B .²⁷

4.2 | NGO's strategies

Does the NGO have an interest in introducing the certified sustainable component to improve environmental quality beyond the level achieved by the information campaign alone? When the NGO introduces a certified sustainable component for which it sets the minimal environmental quality e_M , it perfectly anticipates whether it will be used by Firm B or G in the SPNE. Therefore, we limit the analysis of the NGO's strategy to cases where α and e_M are such that one of the firms will adopt the certified component when it is proposed by the NGO (i.e., $ce_M < \rho q_B - \bar{\theta} e_M$).

Proposition 3. *The NGO cannot improve environmental quality by introducing a certified component if it has a very low campaign budget, so the market remains segmented after the information campaign.*

Proposition 3 follows from the segmentation of the market when $\alpha < \alpha_0$. In this case, the consumers who abstain from consumption and the consumers of green Product G both contribute to the preservation of the environment (assuming that Product G is perfectly clean). As a result, substituting Product G for Product M would worsen environmental quality, since $e_M < e_G$. Conversely, replacing Product B with Product M would improve environmental quality. However, since $\alpha_5 > \alpha_0$ and $\alpha_6 > \alpha_0$, Firm B cannot consider changing the component to produce Product M , which would be unprofitable because of the additional variable costs. Therefore, the NGO has no interest in offering the certified component when the market is segmented. The impact of the introduction of the certified component on the environmental quality is less straightforward in a fragmented or covered market (i.e., $\alpha > \alpha_0$), but the most likely effects can be highlighted.

The NGO cannot generally improve environmental quality by introducing certified Product M if it replaces green Product G , while brown Product B remains in the market. Indeed, Product M has a lower environmental quality than Product G , and its consumption is less good for the environment than no consumption at all. The only exception would be a situation where such substitution would lead to a significant reduction in the consumption of Product B by the informed consumers (see conditions in Appendix H). Except in this specific case, the NGO and Firm G have opposite interests: The NGO prefers not to offer the certified component, which would be profitable for Firm G . Therefore, the NGO's ecolabeling strategy does not aim only to reduce the consumption of Product B , but rather to eliminate Product B altogether.

The NGO can generally improve environmental quality by introducing certified Product M if it replaces brown Product B . Such an SPNE where Firm B makes more profit by switching to Product M than by continuing to sell

Product B (i.e., π_M^{MGc} higher than π_B^{BGc} , π_B^{BGcc} , and π_B^f) requires that the environmental quality e_M of Product M is sufficiently low and that the proportion α of informed consumers is higher than the thresholds α_5 and α_6 (see Appendix F and Figure 4), and thus that the NGO has a large campaign budget. The market is then covered with Products M and G , as with Products B and G if $\alpha \geq \alpha_1$. Replacing Product B with Product M will then improve environmental quality because Product M has a better environmental quality than Product B , and would be consumed by uninformed consumers and a fraction of informed consumers. However, if some informed consumers who initially abstain or consume Product G decide to consume Product M , this reduces environmental quality. In most cases, such a detrimental effect is outweighed by the positive effect of eliminating the brown product (see Appendix H). The NGO's information campaign and sustainable component strategies are then complementary.

When it is in the NGO's interest to offer a certified component as a complement to its information campaign, what is the environmental quality e_M that maximizes environmental quality (for a given α)? To ensure the substitution of Product B by Product M , the NGO must set a sufficiently low minimum quality e_M . Furthermore, Lemma 3 shows the counterproductive effect of increasing the stringency of the ecolabel on the demand for the certified Product M .

Lemma 3. *A greater environmental quality of Product M , e_M , always decreases the demand for Product M when it is in competition with Product B . It also decreases the demand for Product M when it is in competition with Product G if $\rho q_B - \rho q_G < ce_G$.*

Lemma 3 follows from the increase in the price of Product M when its unit cost increases due to higher e_M , which also explains why firms do not want to substitute their products with Product M when e_M is high (see Figure 4). The environmental quality can still be improved if the quality effect due to higher e_M outweighs the quantity effect due to lower demand for Product M . In particular, when both green Products M and G are consumed, increasing the environmental quality e_M of the sustainable component is only beneficial for the environment, and therefore desirable for the NGO, if $c < 3\bar{\theta}$, or otherwise only if the proportion of informed consumers does not exceed a certain threshold α_7 (see Appendix H).

Therefore, the NGO's ecolabeling strategy complements, but cannot replace, the information campaign to improve environmental quality. Indeed, the sustainable component can only interest Firm B if the proportion of informed consumers is sufficient. In addition, the NGO's ecolabel cannot be too strict or it will be useless because the labeled sustainable component will not be used.

4.3 | Social welfare consequences

Social welfare SW^* in any market configuration (denoted by $*$), expressed in monetary units, is defined as the sum of consumer surplus, firm profits, NGO's surplus and environmental quality:

$$\begin{aligned} SW^* &= (1 - \alpha)CS_{Un}^* + \alpha CS_{In}^* + \pi_i^* + \pi_{j \neq i}^* + (R - \sigma(\alpha)) + \delta E^*, \\ CS_{Un}^* &= (\rho q_B - p_i^*), \\ CS_{In}^* &= \frac{1}{\bar{\theta}} \int_{\Theta_i} (\rho q_i + \theta e_i - p_i^*) d\theta + \frac{1}{\bar{\theta}} \int_{\Theta_j} (\rho q_j + \theta e_j - p_j^*) d\theta, \\ &\text{with } \{i, j\} \in \{\{B, G\}, \{B, M\}, \{M, G\}\}, \end{aligned}$$

where CS_{In}^* and CS_{Un}^* are the surplus of the informed consumer and the surplus of the uninformed consumer in the market configuration $*$, Θ_i the segment of informed consumers who buy Product i , π_i^* Firm i 's profit, $\sigma(\alpha)$ the information costs incurred by the NGO and R its initial budget, and δE^* the level of positive externality due to environmental quality (with marginal valuation $\delta > 0$).

Insofar as the strategies implemented by the NGO often affect the profits of firms, the surplus of consumers, and the quality of the environment in the opposite direction, the optimal social solution cannot be determined in a general way by conducting simple welfare comparisons between different market configurations. Indeed, the respective weights of the economic and environmental components of social welfare depend on the marginal valuation of the quality of the environment δ . Nevertheless, it is interesting to examine the influence of the NGO's strategies on the different components of welfare.

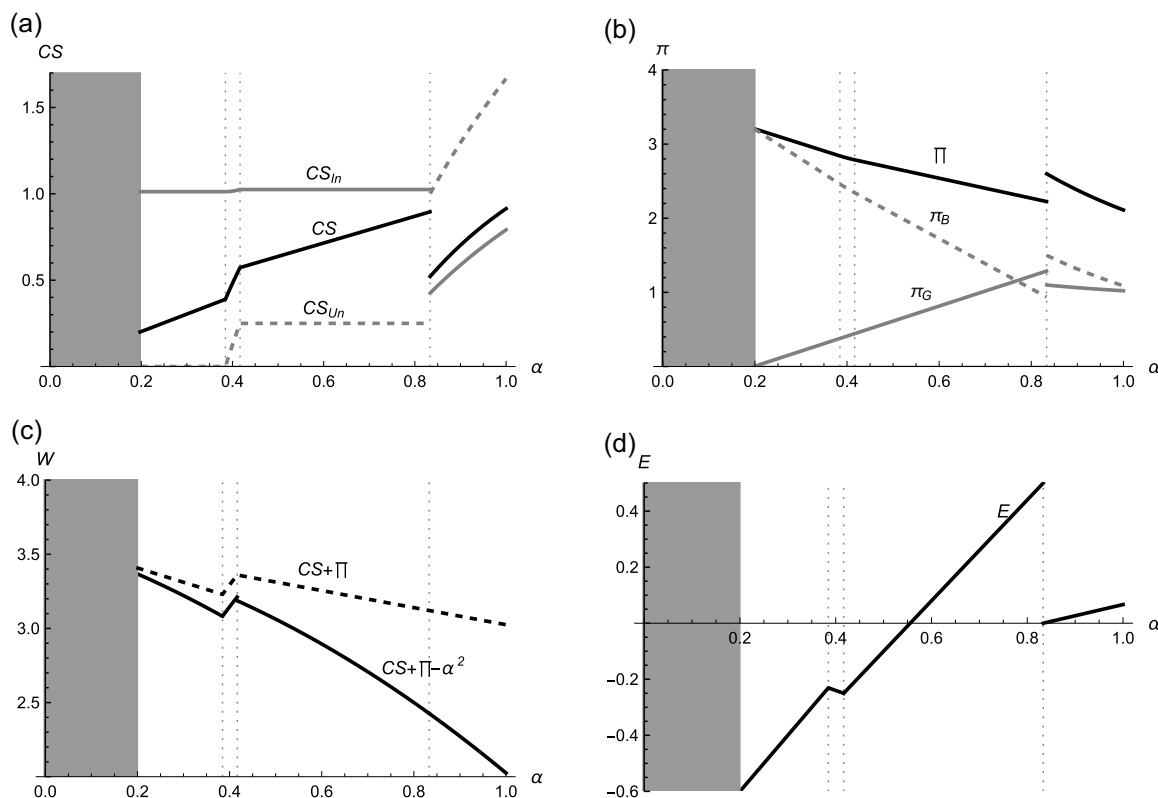


FIGURE 5 Welfare components according to α (for $\bar{\theta} = 2.5$). (a) Consumer surplus, (b) profits, (c) economic welfare, and (d) environmental quality.

Figures 5 and 6 show the changes in the components of social welfare as a function of the share of informed consumers α in the absence of a certified component (i.e., with only Products B and G).²⁸ They illustrate two contrasting cases of low and high heterogeneity in consumers' environmental awareness ($\bar{\theta} = 2.5$ or 5).

In the case of low heterogeneity ($\bar{\theta} = 2.5$), whatever the market configuration, environmental quality and economic surplus (even without information costs) move in opposite directions as a function of α . A discontinuity appears at α_2 , where the two firms switch from their limit prices to duopoly prices in a covered market. This causes the price of Product B to fall sharply, leading to a sharp increase in the profit of Firm B and the surplus of uninformed consumers, while the profit of Firm G and the surplus of uninformed consumers move symmetrically (Figure 5). As stated in Proposition 2, as long as its budget allows, the NGO finds it optimal to increase its information effort up to α_2 , except in the fragmentation trap, where it keeps the fraction of informed consumers constant and equal to α_0 . The total economic surplus would therefore decrease with α outside the fragmentation trap, but remain constant (and not increasing as in Figure 5) in the fragmentation trap. This shows that when the valuation of the quality of the environment is weak, the interests of the NGO and those of the regulator never coincide.

In the case of high heterogeneity ($\bar{\theta} = 5$), the optimal strategy of the NGO is simply to increase α , since there is neither a fragmentation trap nor the possibility of a covered market with an interior solution (i.e., $\alpha_2 > 1$). Comparing Figure 6 (with $\bar{\theta} = 5$) with Figure 5 (with $\bar{\theta} = 2.5$), we can see that the higher $\bar{\theta}$, the higher the surplus of informed consumers relative to uninformed ones, and the higher the profit of Firm G, which exceeds the profit of Firm B for a lower threshold of α . Thus the NGO's optimal information campaign is more and more likely to be consistent with increasing pure economic welfare, unless the cost of information is too high.²⁹

We now examine whether the NGO's strategy of offering the certified component is consistent with the welfare objective. Figures 7 and 8 are based on the assumption that Product M is available independently of α and e_M , but is used by only one or none of the firms in the SPNE shown in Figure 4. They show how a variation in e_M would affect economic welfare and environmental quality for a given α (starting from the initial market configuration with Products B and G on the right of the figure, reasoning for a given α amounts to following a horizontal line where the decrease in e_M leads to market configurations with B and M, then possibly with M and G). The changes in the environmental

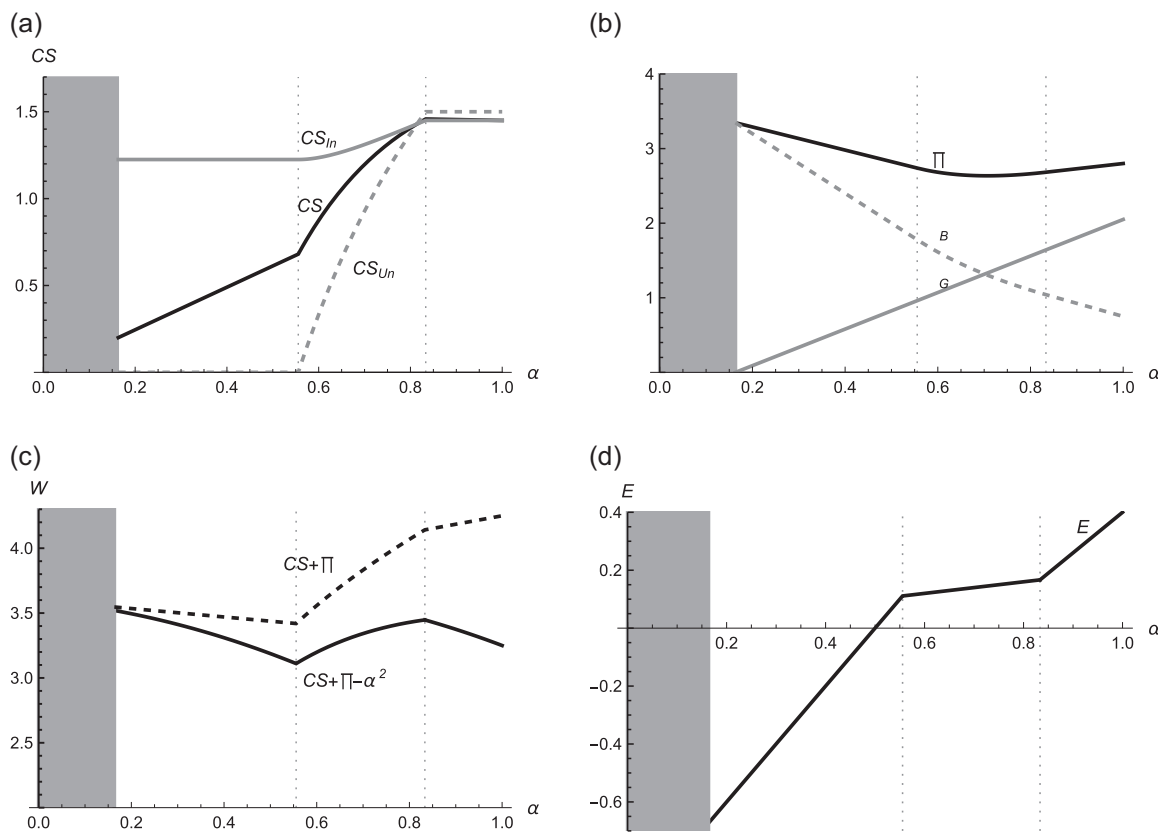


FIGURE 6 Welfare components according to α (for $\bar{\theta} = 5$). (a) Consumer surplus, (b) profits, (c) economic welfare, and (d) environmental quality.

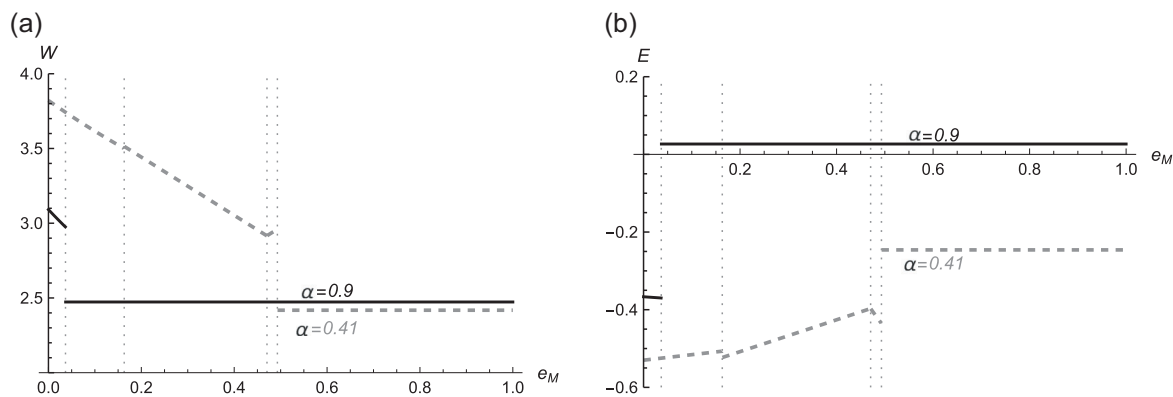


FIGURE 7 Economic welfare and environment according to e_M (for $\bar{\theta} = 2.5$). (a) Economic welfare and (b) environmental quality.

quality indicate whether it is in the NGO's interest to introduce the certified component (and at what e_M), while the changes in economic welfare indicate whether such an introduction would be welfare improving.

In the case of low heterogeneity ($\bar{\theta} = 2.5$), Figure 7 shows the two cases where the introduction of Product M might make sense: the fragmentation trap (simulated for $\alpha = 0.41$) and the case where the market is covered with an interior solution ($\alpha = 0.9$). In both cases, the introduction of Product M (which would only be used for low e_M in the SPNE) would degrade environmental quality, but would improve economic welfare. As a result, the optimal strategy of the NGO is not to propose the certified component, which could have improved global welfare if the marginal valuation of the environmental quality were not too high.

In the case of high heterogeneity ($\bar{\theta} = 5$), in Figure 8, it is clear that the introduction of the certified component can make it possible to improve the quality of the environment as long as the substitution of Product M for Product B is

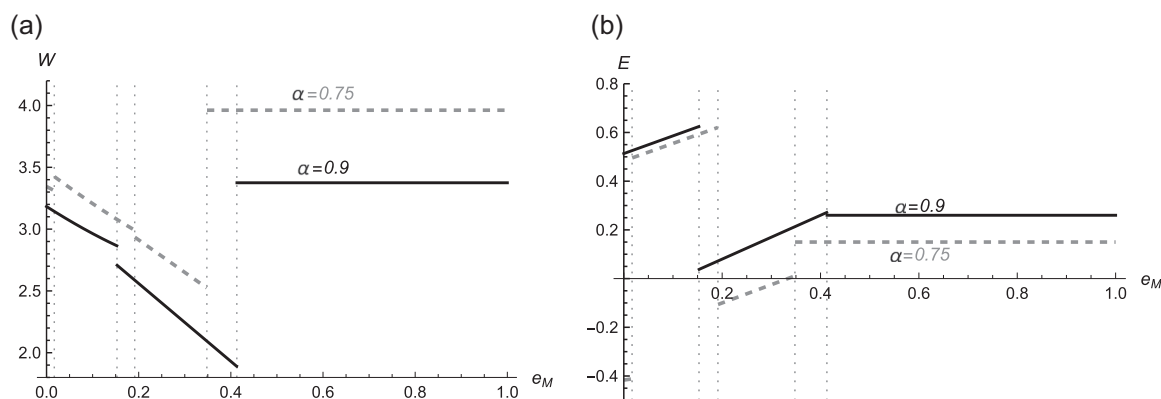


FIGURE 8 Economic welfare and environment according to e_M (for $\bar{\theta} = 5$). (a) Economic welfare and (b) environmental quality.

viable (i.e., the SNPE MG in Figure 4), while this is not the case when Product M is substituted for Product G (i.e., the SNPE BM). This requires $\bar{\theta}$ to be high, which in our framework does not depend on the NGO, but also on α , which must then be high, and e_M , which must then be at the limit of the switch from the SPNE MG to the SNE BM . Whether M replaces B or G implies worsening economic welfare.

As shown in Appendix H, environmental quality increases with α and e_M when Product M is offered against Product G , if the cost of the certified component is not too high compared with the maximal environmental sensitivity ($c < 3\bar{\theta}$, which is the case illustrated in Figure 8). The NGO's optimal strategy here is, therefore, to increase the proportion of informed consumers up to the limit of its available budget and to offer a certified component with the highest possible quality in the limit of $e_M(\alpha)$, which describes the boundary between the SNPE MG and BM in Figure 4. But this increases the loss of economic welfare compared with the SNPE BG . Only if environmental quality is highly valued in terms of welfare will the NGO's strategy be Pareto optimal.

5 | CONCLUSION

Under what conditions the information and ecolabeling strategies of environmental NGOs succeed in eliminating certain components that are harmful to the environment, when these components contribute to the intrinsic quality of a product? This question arises for palm oil in chocolate and hazelnut spread, which is our flagship example, but also for many other products (cosmetics, agrifood products, etc.) and other harmful components (pesticides, chemical substances, etc.).

In this paper, we consider a two-dimensional vertical product differentiation model, where the product is characterized by both its environmental (hedonic) quality and its intrinsic (nonhedonic) quality. The environmental NGO campaigns to open the eyes of consumers to the harmful nature of the “environmental” component, thereby increasing the proportion of informed consumers relative to uninformed consumers. It may also offer a certified sustainable component, as an alternative to the harmful component. A duopoly initially provides a brown product containing the harmful component, but of high intrinsic quality, and a green product without the harmful component, but of low intrinsic quality. Faced with a growing proportion of informed consumers and the availability of a certified component, each firm faces two possible strategies: status quo, by still supplying the brown or the green product, and substitution, by using the certified sustainable component without altering the intrinsic quality.

The brown product is assumed to have all the characteristics of this type of product in the food, cosmetics, and other markets: its production costs, and therefore its price, are low, its intrinsic quality is high, and a certain proportion of consumers are unaware that it contains a harmful component. The brown product is thus highly competitive, and it is a real challenge for the NGO to try to eliminate it or at least significantly reduce its consumption in favor of greener, more expensive products.

Indeed, we show that the NGO's information campaign is an effective strategy for reducing the consumption of the brown product only if the informed consumers are sufficiently heterogeneous, with the most environmentally conscious consumer unwilling to pay for the brown product. In this case, the NGO's optimal strategy is to inform as many consumers as possible by spending its entire budget on the campaign. Otherwise, informing consumers who are

slightly heterogeneous, and thus not very environmentally conscious, could lead to a “fragmentation trap” where some newly informed consumers continue to consume the most competitive brown product. In this case, the optimal proportion of informed consumers is large but not 100%. In all cases, an insufficient budget may prevent the NGO from reaching the optimal proportion of informed consumers.

Can ecolabeling efficiently complement or replace the information campaign? We show that, paradoxically, if the NGO has a limited campaign budget, the ecolabel is useless because it would harm the environmental quality, one firm would replace the greenest product with the certified one, or the other firm would not be interested in replacing the brown product with the certified one. Moreover, contrary to intuition, the NGO is only interested in offering a certified sustainable component if it has a large campaign budget, that is, if it can inform a large proportion of consumers. In addition, for the ecolabel to be effective, it must be sufficiently nondemanding to induce the firm offering the brown product to replace the harmful component with the certified one. The ecolabel is, therefore, only a complementary tool to the information campaign; the ecolabel strategy alone cannot achieve better environmental quality by reducing or eliminating the consumption of the brown product. This result is particularly important because it shows that studying the NGO's (or other certifier's) ecolabeling strategy alone can be biased if we do not consider the existence of consumers who are unaware of the environmental damage caused by the brown product.

Finally, we show that, in the absence of a certified product, the NGO's information campaign will enhance economic welfare only if consumers' environmental preferences are highly heterogeneous and a large fraction of consumers is informed. When the NGO's optimal strategy is to propose the certified component, because it improves the environmental quality, it ends to reduce the economic welfare. It can be, nevertheless, Pareto optimal, if environmental quality is sufficiently valued in terms of welfare.

To extend our analysis, it would be worth considering the possibility for the NGO to combine the information campaign with an awareness-raising campaign aimed at increasing the environmental awareness (i.e., the WTP for environmental quality) of informed consumers, thus increasing the effectiveness of the information campaign. Finally, the nature of the RSPO, which involves NGOs but also companies, such as Unilever, suggests that the partnership between NGOs and industry leading to the establishment of the certification requirement should be modeled. These are all avenues for developing our analysis of the strategies used by environmental NGOs to push for the replacement of certain harmful components of products.

ACKNOWLEDGMENTS

This research has been funded by the French National Research Agency (ANR-15-CE05-0008-01) and the program Investissements d'Avenir of the French government (ANR-17-EURE-001). The authors thank seminar audiences at the ASSA-AERE 2019 Annual Meeting, the 5th Annual FAERE Conference, the 6th World Congress of Environmental and Resource Economists, the SURED 2018 Conference, the 35th Journées de Microéconomie Appliquée, the Montpellier Workshop on the Economic Role of Environmental NGOs and the Paris Workshop on Environmental NGOs and Public Policy for their helpful comments on a previous version circulated under the title *The Market for “Harmful Component-Free” Products under Pressure from the NGOs*. They are grateful to the coeditor and two anonymous reviewers for their wise suggestions and to the seminar audiences at University College Dublin, Galatasaray University and the AERNA-CE3 Durham-UAM webinar for their attention to this new version.

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NOTES

- ¹ <https://www.greenbiz.com/article/how-ngo-partnerships-have-changed-over-20-earth-days> (accessed 2021/03/09).
- ² <http://www.greenpeace.org/international/en/campaigns/climate-change/kitkat/> (accessed 2021/05/15).
- ³ <https://www.regnskog.no/en/what-we-do/how-we-achieve-political-change/running-a-successful-palm-oil-campaign> (accessed 2021/05/15).
- ⁴ <https://www.ethicalconsumer.org/palm-oil/palm-oil-free-list> (accessed 2021/05/15).
- ⁵ Palm oil and its derivatives are used as emollients, emulsifiers and antioxidants in 70% of cosmetics products, see Bom et al. (2019).
- ⁶ Despite the abundant literature on boycotts initiated by NGOs (e.g., Baron & Diermeier, 2007; Easley & Lenox, 2006; Lenox & Easley, 2009), we consider that the NGO acts only indirectly to drive out the component harmful to the market environment and does not call for a boycott of the products concerned. As argued by Gupta and Innes (2014), other tactics may be preferred to boycott in cases

(like ours) of very noncompetitive markets, in which the product is highly attractive to consumers and where consumers are initially unaware of its environmental consequences.

- ⁷ While some papers assume that firms can advertise to mislead consumers about the quality of their products (Glaeser & Ujhelyi, 2010; Rhodes & Wilson, 2018), we assume that firms are honest.
- ⁸ This assumption makes it all the more difficult to replace the harmful component, and the NGO's intervention is all the more necessary.
- ⁹ In Marini et al. (2020), consumers are homogeneous towards the environmental quality of products and heterogeneous with respect to the psychic costs (resp., benefits) they feel from the consumption of a brown (resp., green) product.
- ¹⁰ Our analytical framework is thus a simplified version of the more general framework in which $c_B \leq c_G \leq c_M$ and $F_B \leq F_M \leq F_G$. This allows us to isolate the main drivers from competition between the three products: only the variable costs differ between Products *B* and *M*, while only the fixed costs differ between Products *B* and *G*.
- ¹¹ Figure 1 has been drawn using parameters $\bar{\theta} = 2.5$, $\rho = 2$, $q_B = 2$, $q_G = 1$, $e_B = -1$, and $e_G = 1$. These parameters have been chosen to allow all market structures to arise, depending on the values of F_G and α .
- ¹² The proofs for this section are in Appendix A.
- ¹³ The consumers who refrain from consuming the good are the informed consumers with the lowest WTP for environmental quality because of our assumption that $e_B < 0 < e_G$, which implies that informed consumers always have a lower WTP for the brown product than the uninformed consumers.
- ¹⁴ Contrary to the standard model of vertical differentiation of Wauthy (1996) and Liao (2008), our corner solution does not correspond to a low-quality price equal to the lowest WTP of consumers. Indeed, in our model, the consumers who refrain from consuming the good in the fragmented market are the informed consumers with a medium WTP. Therefore, the corner solution corresponds to the limited situation where none of these consumers refrain from consuming anymore.
- ¹⁵ Note that $\bar{\theta}_2$ increases with ρ , q_B , q_G , and e_B , while it can increase or decrease with e_G depending on the degree of differentiation in both attributes.
- ¹⁶ Note that in both segmented and fragmented market configurations, the environmental quality is not different from that which would result from a monopoly offering Product *B*.
- ¹⁷ Recall that the prices are independent of α when the market is uncovered with a corner solution.
- ¹⁸ Figure 2 has been drawn with the same parameters as before.
- ¹⁹ The proofs and the details of the Nash equilibria are in Appendix D.
- ²⁰ Figure 3 has been drawn with the same parameters as before and $c = 6$.
- ²¹ We have $\alpha_3 \leq 1$ only if $\bar{\theta} \leq \frac{ce_B e_M + \rho q_B (e_M - e_B)}{-e_B e_M}$. Otherwise, the market is fragmented for all $\alpha > \alpha_0$.
- ²² We assume that $c < \frac{(e_M - e_B)(\bar{\theta}(e_M + e_B) + 3\rho q_B)}{e_M(e_M - 2e_B)}$, ensuring that $\alpha_4 > 0$. Note that this inequality is always satisfied when $ce_M < \rho q_B + \bar{\theta} e_M$ and $\rho q_B + \bar{\theta} e_B > 0$. Moreover, $\alpha_4 \leq 1$ if $\bar{\theta} \leq \frac{3\rho q_B}{e_M - 2e_B}$.
- ²³ Such an assumption is in line with the usual assumption of an equal distribution of demand between two firms competing à la Bertrand in a homogeneous market.
- ²⁴ The assumption of high entry costs prevents the existence of a triopoly in the Nash equilibrium.
- ²⁵ Figure 4 has been drawn using the same parameters as for previous figures. The gray curve corresponds to $\pi_G^{BG} = \pi_M^{BM}$ (and $\pi_B^{BM} = \pi_G^{MG}$ when *MG* can arise) and the black curves to $\pi_B^{BG} = \pi_M^{MG}$ and $\pi_G^{MG} = \pi_B^{BM}$ (when *MG* can arise). *BG*, *BM*, and *MG* denote the regions where the SPNE is a duopoly with, respectively, Products *B* and *G*, *B* and *M*, and *M* and *G*.
- ²⁶ Figure 4a shows that in a specific case where e_M is close to 0 and $\alpha \geq \alpha_2$, the SNPE is *BM* because the profit of Firm *G* falls sharply below that of Firm *M* when α crosses the threshold α_2 . Once e_M is slightly higher, the sharp drop in the profit of Firm *G* does not prevent it from remaining higher than the profit of Firm *M*.
- ²⁷ Figure 4b shows a small white zone in the region where e_M is close to 0 and α is high enough to lead to the SNPE *MG*. This corresponds to an unstable Nash equilibrium where Firm *G* (competing with Firm *M*) may be tempted to deviate towards Product *B* because the profits π_G^{MG} and π_B^{BM} are very close, in such a way that π_G^{MG} is slightly higher than π_B^{BM} for α close to the lower bound of the region *MG* (where *BM* is segmented with a corner solution), then slightly lower as α increases a little (in the region where *MG* or *BM* are completely covered with an interior solution), and again slightly higher as α increases again.
- ²⁸ As the level of the economic surplus depends on the assumptions on the NGO surplus, Figures 5 and 6 are drawn for $R = 0$ and $\sigma(\alpha) = \alpha^2$. The parameters other than $\bar{\theta}$ are set to the same levels as in the previous figures.
- ²⁹ Unlike Feddersen and Gilligan (2001), the social welfare of market exchange increases only when consumer heterogeneity is low ($\bar{\theta} = 2.5$) for the fragmentation trap, and when it is high ($\bar{\theta} = 5$) for the segmented market case.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Brécard, D., & Chiroleu-Assouline, M. (2024). Information campaigns and ecolabels by environmental NGOs: Effective strategies to eliminate environmentally harmful components? *Journal of Economics & Management Strategy*, 1–32. <https://doi.org/10.1111/jems.12595>

APPENDIX A: PROOF OF LEMMA 1

To prove Lemma 1, we characterize the Nash equilibria for all possible market configurations (segmented, fragmented, covered with an interior solution and covered with a corner solution).

Uninformed consumers consume Product B if $p_B \leq \rho q_B$. We define the informed consumer of type $\tilde{\theta}_B$ as the consumer indifferent between consuming Product B or nothing, and the consumer of type $\tilde{\theta}_G$ as the consumer indifferent between consuming Product G or nothing, with

$$\tilde{\theta}_B = \frac{\rho q_B - p_B}{-e_B},$$

$$\tilde{\theta}_G = \frac{p_G - \rho q_G}{e_G},$$

Consumers with $\theta \leq \tilde{\theta}_B$ accept to buy Product B , while consumers with $\theta \geq \tilde{\theta}_G$ want to buy Product G . We also define the informed consumer of type $\tilde{\theta}_{BG}$ as the consumer indifferent between both products:

$$\tilde{\theta}_{BG} = \frac{p_G - p_B + \rho(q_B - q_G)}{(e_G - e_B)}.$$

Informed consumers with $\theta \geq \tilde{\theta}_{BG}$ prefer Product G to Product B , while consumers with $\theta < \tilde{\theta}_{BG}$ prefer Product B to Product G .

A.1 | Fragmentation

The market is fragmented if $0 < \tilde{\theta}_B \leq \tilde{\theta}_{BG} \leq \tilde{\theta}_G \leq \bar{\theta}$, as illustrated in Figure A1.

In a fragmented market, the profit of Firm B is defined by $\pi_B^f = p_B d_B^f$ with $d_B^f = (1 - \alpha) + \alpha \tilde{\theta}_B / \bar{\theta}$. The price maximizing the profit is then defined by

$$p_B^f = \frac{\alpha \rho q_B - \bar{\theta} e_B (1 - \alpha)}{2\alpha}. \quad (\text{A1})$$

The demand is then equal to $d_B^f = -\alpha p_B^f / (\bar{\theta} e_B)$ and the profit to $\pi_B^f = \frac{-\bar{\theta} e_B}{\alpha} d_B^f$. The profit of Firm G is defined by $\pi_G^m = p_G \alpha (\bar{\theta} - \tilde{\theta}_G) / \bar{\theta} - F_G$. The price maximizing the profit is

$$p_G^m = \frac{\bar{\theta} e_G + \rho q_G}{2}. \quad (\text{A2})$$

The demand is then equal to $d_G^m = \alpha (\bar{\theta} e_G + \rho q_G) / (2\bar{\theta} e_G)$ and the profit is $\pi_G^m = \alpha (\bar{\theta} e_G + \rho q_G)^2 / (4\bar{\theta} e_G) - F_G$. The conditions for the existence of a fragmented duopoly are as follows:

- $\alpha \geq \alpha_0 \equiv -\bar{\theta} e_B / (\rho q_B - \bar{\theta} e_B)$ ensures that $p_B^f \leq \rho q_B$;
- $\bar{\theta} e_G > \rho q_G$ ensures that $p_G^m > \rho q_G$;
- $0 \leq \alpha < \alpha_1 \equiv \frac{-\bar{\theta} e_G e_B}{\rho (q_B e_G - q_G e_B)}$ ensures that the market is fragmented (i.e., $\tilde{\theta}_B < \tilde{\theta}_G$);
- $F_G \leq \frac{\alpha (\bar{\theta} e_G + \rho q_G)^2}{4\bar{\theta} e_G}$ ensures that $\pi_G^m \geq 0$.

A.2 | Complete coverage

A.2.1 | Covered market with an interior solution

The market is covered if $\tilde{\theta}_G < \tilde{\theta}_{BG} < \tilde{\theta}_B$, as illustrated in Figure A2.

The maximization of profits of both firms leads to the following prices:

$$p_B^{BGc} = \frac{(e_G - e_B)(2 - \alpha)\bar{\theta} + \rho\alpha(q_B - q_G)}{3\alpha}, \quad (\text{A3})$$

$$p_G^{BGc} = \frac{(e_G - e_B)(1 + \alpha)\bar{\theta} - \rho\alpha(q_B - q_G)}{3\alpha}. \quad (\text{A4})$$

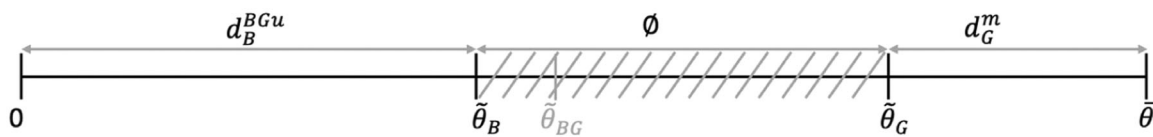


FIGURE A1 Market sharing for informed consumers when the market is fragmented.

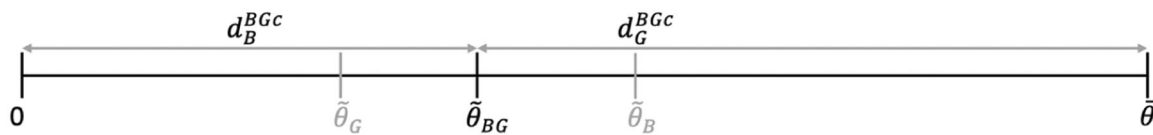


FIGURE A2 Market sharing with Products B and G when the market is covered.

Using these prices, the conditions $\tilde{\theta}_G < \tilde{\theta}_{BG} < \tilde{\theta}_B$ boil down to

$$\frac{\rho(q_B - q_G)}{e_G - e_B} < \bar{\theta} \leq \bar{\theta}_2 \equiv \frac{\rho q_G(e_G - 2e_B) + \rho q_B(2e_G - e_B)}{(e_G - e_B)(e_G - 2e_B)},$$

$$\alpha_2 \equiv \frac{\bar{\theta}(e_G - e_B)(2e_G - e_B)}{\bar{\theta}(e_G^2 - e_B^2) + \rho q_G(e_G - 2e_B) + \rho q_B(2e_G - e_B)} < \alpha \leq 1.$$

For higher $\bar{\theta}$, $\alpha_2 > 1$ and the market is never covered regardless of α . Moreover, Product G is cost-effective if

$$F_G \leq \frac{((e_G - e_B)(1 + \alpha)\bar{\theta} - \alpha\rho(q_B - q_G))^2}{9\alpha\bar{\theta}(e_G - e_B)}.$$

A.2.2 | Covered market with a corner solution

If $\alpha_1 \leq \alpha \leq \alpha_2$, the prices in a fragmented market, p_B^f and p_G^m , lead to $\tilde{\theta}_G < \tilde{\theta}_B$, which contradicts the condition for a fragmented market; the equilibrium prices in a covered market, p_B^{BGc} and p_G^{BGc} , lead to $\tilde{\theta}_G > \tilde{\theta}_B$ which contradicts the condition for a covered market. Therefore, there is a corner solution where the prices are such that $\tilde{\theta}_G = \tilde{\theta}_{BG} = \tilde{\theta}_B$ for all $\alpha \in [\alpha_1, \alpha_2]$. All consumers with a lower marginal WTP than $\tilde{\theta}_i$ buy Product B while all the other informed consumers buy Product G . To find the equilibrium, we calculate p_B^f for $\alpha = \alpha_1$, and we define the limit price of Product B as p_B^{BGc} in Equation (10). The price of Product G remains the monopoly price p_G^m , which does not depend on α .

APPENDIX B: PROOF OF PROPOSITION 1

Assuming $\bar{\theta} > \bar{\theta}_2$, which implies that $\alpha_2 > 1$, the levels of environmental quality in the segmented market (denoted m), fragmented market (denoted f) and covered market (with a corner solution (denoted cc)) are

$$E^{BGm} = e_B + \alpha(e_G - e_B), \quad (B1)$$

$$E^{BGf} = \frac{\bar{\theta} e_B(e_G + e_B) + \alpha(e_G - e_B)(\bar{\theta} e_B + \rho q_B)}{2\bar{\theta} e_B}, \quad (B2)$$

$$E^{BGcc} = \frac{\bar{\theta} e_G((2 - \alpha)e_B + \alpha e_G) + \alpha\rho q_G(e_G - e_B)}{2\bar{\theta} e_G}. \quad (B3)$$

The derivative of E^k ($k = BGm, BGf, BGcc$) with respect to α are

$$\frac{\partial E^{BGm}}{\partial \alpha} = (e_G - e_B) > 0,$$

$$\frac{\partial E^{BGf}}{\partial \alpha} = \frac{(e_G - e_B)(\bar{\theta} e_B + \rho q_B)}{2\bar{\theta} e_B} > 0 \quad \text{if } \bar{\theta} > -\frac{\rho q_B}{e_B},$$

$$\frac{\partial E^{BGcc}}{\partial \alpha} = \frac{(e_G - e_B)(\bar{\theta} e_G + \rho q_G)}{2\bar{\theta} e_G} > 0.$$

As a result, as stated in Proposition 1, environmental quality increases with α in all market configurations if $\bar{\theta} > -\rho q_B/e_B$ and $\bar{\theta} > \bar{\theta}_2$.

APPENDIX C: PROOF OF PROPOSITION 2

Assuming $\bar{\theta} < \bar{\theta}_2$, the level of environmental quality in covered market with an interior solution is

$$E^{BGc} = \frac{(2 - \alpha)\bar{\theta} e_B + (1 + \alpha)\bar{\theta} e_G - \alpha\rho(q_B - q_G)}{3\bar{\theta}}. \quad (C1)$$

The impact of α on E^{BGc} is characterized by

$$\frac{\partial E^{BGc}}{\partial \alpha} = \frac{(\bar{\theta} e_G + \rho q_G) - (\bar{\theta} e_B + \rho q_B)}{3\bar{\theta}} > 0.$$

Since $E^{BGm}(\alpha_0) = E^{BGf}(\alpha_0)$ and $E^{BGf}(\alpha_1) = E^{BGcc}(\alpha_1)$, the environmental quality is a continuous increasing function of α , except in α_2 , where

$$E^{BGcc}(\alpha_2) - E^{BGc}(\alpha_2) = -\frac{(e_G - e_B)^2 e_B (\bar{\theta} e_G + \rho q_G)}{2e_G \left(\bar{\theta} (e_G^2 - e_B^2) + \rho q_G (e_G - 2e_B) + \rho q_B (2e_G - e_B) \right)} > 0.$$

Moreover, $E^{BGcc}(\alpha_2) > E^{BGc}(1)$ because

$$\frac{\partial E^{BGc}}{\partial \alpha} < \frac{\partial E^{BGcc}}{\partial \alpha} \quad \forall \bar{\theta}.$$

This ensures that, as stated in Proposition 2, when $\alpha_2 < 1$, the environmental quality reaches a maximum in α_2 . Moreover, if $\bar{\theta} < -\rho q_B / e_B$, E^{BGf} is a decreasing function of $\alpha \in [\alpha_0, \alpha_1]$. Because E^{BGcc} is an increasing function of $\alpha \in [\alpha_1, \alpha_2]$, there exists a threshold α'_1 such that $E^{BGcc}(\alpha'_1) = E^{BGm}(\alpha_0)$. Therefore, the NGO maximizes environmental quality in spending only the part of its budget equal to $\sigma(\alpha_0)$ when its budget is $R \leq \sigma(\alpha'_1)$.

APPENDIX D: PROOFS OF NASH EQUILIBRIA WITH PRODUCTS B AND M

We define the informed consumer of type $\tilde{\theta}_M$ as the consumer indifferent between consuming Product M or nothing, with

$$\tilde{\theta}_M = \frac{p_M - \rho q_B}{e_M}.$$

Consumers with $\theta \geq \tilde{\theta}_M$ accept to buy Product M . We also define the consumer of type $\tilde{\theta}_{BM}$, as the consumers indifferent between both products:

$$\tilde{\theta}_{BM} = \frac{p_M - p_B}{(e_M - e_B)}.$$

Informed consumers with $\theta \geq \tilde{\theta}_{BM}$ prefer Product M to Product B , while consumers with $\theta < \tilde{\theta}_{BM}$ prefer Product B to Product M .

D.1 | Fragmentation

The market is fragmented if $0 < \tilde{\theta}_B \leq \tilde{\theta}_{BM} \leq \tilde{\theta}_M \leq \bar{\theta}$. In this case, the pricing strategy of Firm B is unchanged with a price p_B^f . The profit of Firm M is defined by $\pi_M = (p_M - ce_M)d_M$, with $d_M = \alpha(\bar{\theta} - \tilde{\theta}_M)/\bar{\theta}$. The price maximizing its profit is

$$p_M^m = \frac{ce_M + \bar{\theta} e_M + \rho q_B}{2}. \quad (D1)$$

The demand is then equal to

$$d_M^m = \frac{\alpha(-ce_M + \bar{\theta} e_M + \rho q_B)}{2\bar{\theta} e_M}. \quad (D2)$$

Firm M 's profit is therefore defined as $\pi_M^m = \bar{\theta} e_M d_M^m / \alpha$, with d_M^m and π_M^m positive if $ce_M \leq \bar{\theta} e_M + \rho q_B$. The conditions for the existence of a fragmented market are as follows:

- $\alpha \geq \alpha_0 \equiv -\bar{\theta} e_B / (\rho q_B - \bar{\theta} e_B)$ ensures that $p_B^{BMu} < \rho q_B$.
- $\alpha_0 < \alpha \leq \alpha_3 \equiv \frac{-\bar{\theta} e_M e_B}{(ce_M)e_B + \rho q_B(e_M - e_B)}$ ensures that the market is fragmented (i.e., $\tilde{\theta}_B < \tilde{\theta}_M$).
- $c > (\rho q_B - \bar{\theta} e_M) / e_M$ ensures that $p_M^m > \rho q_B$.

If $c \leq (\rho q_B - \bar{\theta} e_M) / e_M$, the market is segmented with a corner solution because $p_M^m \leq \rho q_B$: Firms M and B set the limit price ρq_B . We then assume that all uninformed consumers consume Product B while all informed consumers consume Product M .

If $\alpha < \alpha_0$, the market is segmented. Firm B sets a price p_B^m and earns a profit π_B^m . Firm M still supplies Product M at price p_M^m and earns profit π_M^m .

D.2 | Complete coverage

D.2.1 | Covered market with an interior solution

The market is covered with an interior solution if $\tilde{\theta}_M < \tilde{\theta}_{BM} < \tilde{\theta}_B$. In this case, maximization of profits $\pi_B = p_B((1 - \alpha) + \alpha \tilde{\theta}_{BM} / \bar{\theta})$ and $\pi_M = (p_M - ce_M)(\alpha(\bar{\theta} - \tilde{\theta}_{BM}) / \bar{\theta})$ leads to the equilibrium prices p_B^{BMc} and p_M^{BMc} defined in Equations (19) and (20). Using these prices, the conditions $\tilde{\theta}_M < \tilde{\theta}_{BM} < \tilde{\theta}_B$ boil down to

$$\begin{aligned} \bar{\theta}(e_M - 2e_B) &\leq 3\rho q_B \text{ that requires that } \bar{\theta} < -\frac{3\rho q_B}{2e_B}, \\ c &< \frac{(e_M - e_B)(-\bar{\theta}(e_M - 2e_B) + 3\rho q_B)}{(e_M - 2e_B)e_M}, \\ \alpha_4 &\equiv \frac{\bar{\theta}(2e_M - e_B)(e_M - e_B)}{-ce_M(e_M - 2e_B) + (e_M - e_B)(\bar{\theta}(e_M + e_B) + 3\rho q_B)} < \alpha \leq 1. \end{aligned}$$

The demand for Product M , d_M^{BMc} defined in Equation (21), is positive if $ce_M \leq 2\bar{\theta}(e_M - e_B)$ or, otherwise, if $ce_M > 2\bar{\theta}(e_M - e_B)$ and $\alpha < \frac{\bar{\theta}(e_M - e_B)}{ce_M - 2\bar{\theta}(e_M - e_B)}$, while the demand for Product B is always positive. Under these conditions, firms earn positive profits: $\pi_B^{BMc} = -\bar{\theta}(e_B - e_M)d_B^{BMc2} / \alpha$ and $\pi_M^{BMc} = \bar{\theta}(e_B - e_M)d_M^{BMc2} / \alpha$.

D.2.2 | Covered market with a corner solution

We have to distinguish two cases of covered market with corner solution, depending on the values of c and α . In both cases, the firms set a limit price because neither the conditions for a fragmented market nor the conditions for a covered market are satisfied.

If $c \leq (\rho q_B - \bar{\theta} e_M) / e_M$ and $\alpha_0 \leq \alpha \leq \alpha_4$, Firms M and B set the limit price ρq_B that allows them to capture the demand of all consumers in their market segments (as explained above).

If $c > (\rho q_B - \bar{\theta} e_M) / e_M$ and $\alpha_3 \leq \alpha \leq \alpha_4$, there is a corner solution where the prices are such that $\tilde{\theta}_M = \tilde{\theta}_{BM} = \tilde{\theta}_B$ for all $\alpha \in [\alpha_3, \alpha_4]$. All consumers with a lower marginal WTP than $\tilde{\theta}_i$ buy Product B while all the other informed consumers buy Product M . To find the equilibrium, we calculate p_B^f for $\alpha = \alpha_3$, and we define the limit price of Product B as p_B^{BMcc} characterized in Equation (18). The price of Product M remains the monopoly price p_M^m .

APPENDIX E: PROOFS OF NASH EQUILIBRIA WITH PRODUCTS M AND G

We define the informed consumer of type $\tilde{\theta}_{MG}$ as the consumer indifferent between Products M and G :

$$\tilde{\theta}_{MG} = \frac{p_G - p_M + \rho(q_B - q_G)}{e_G - e_M}.$$

Informed consumers with $\theta \geq \tilde{\theta}_{MG}$ prefer Product G to Product M , while consumers with $\theta < \tilde{\theta}_{MG}$ prefer Product M to Product G .

E.1 | Fragmentation

The market with only Products M and G cannot be fragmented. To prove this, we note that informed consumers with $\theta \leq \tilde{\theta}_M$ do not consume, those with $\theta \geq \tilde{\theta}_M$ accept to buy Product M , and those with $\theta \geq \tilde{\theta}_G$ accept to buy Product G . The market is fragmented if $\tilde{\theta}_M > 0$ and $\tilde{\theta}_G > 0$, that requires $p_M > \rho q_B$ and $p_G > \rho q_G$. In this case, the uninformed consumers do not accept to buy M or G , but they are still willing to buy Product B at a price lower than or equal to $p_B^m = \rho q_B$. Therefore, the market structure can be a triopoly supplying the three Products B, M , and G if $\tilde{\theta}_B < 0 < \tilde{\theta}_M < \tilde{\theta}_G < \tilde{\theta}_{MG} < \bar{\theta}$, or a duopoly supplying Products B and M if $\tilde{\theta}_B < 0 < \tilde{\theta}_M < \tilde{\theta}_G < \bar{\theta} < \tilde{\theta}_{MG}$, or a duopoly supplying Products B and G if $\tilde{\theta}_{MG} < 0 < \tilde{\theta}_G < \tilde{\theta}_M < \bar{\theta}$.

E.2 | Complete coverage

The market is covered if $\tilde{\theta}_M \leq 0 \leq \tilde{\theta}_G \leq \tilde{\theta}_{MG} < \bar{\theta}$. In this case, the demands are then defined as follows: $d_G^{MGc} = \alpha(\bar{\theta} - \tilde{\theta}_{BG})/\bar{\theta}$ and $d_M^{MGc} = 1 - \alpha + \alpha\tilde{\theta}_{BG}/\bar{\theta}$. Maximization of profits $\pi_M = (p_M - ce_M)d_M^{MGc}$ and $\pi_G = p_G d_G^{MGc} - F_G$ leads to the equilibrium prices p_M^{MGc} and p_G^{MGc} defined in Equations (23) and (24) and the demand for Product M , d_M^{MGc} defined in Equation (25). The conditions for the positivity of prices and demands and for the uninformed consumers to consume Product M ($p_M^{MGc} \leq \rho q_B$ and $\rho q_B - p_M^{MGc} > \rho q_G - p_G^{MGc}$) are expressed as follows:

$$\alpha > \alpha_5 \equiv \frac{\bar{\theta}(e_G - e_M)}{-ce_M + 2\bar{\theta}(e_G - e_M) + \rho(q_B - q_G)},$$

$$\alpha > \alpha_6 \equiv \frac{2\bar{\theta}(e_G - e_M)}{-2ce_M + \bar{\theta}(e_G - e_M) + \rho(2q_B + q_G)},$$

where the lower bounds can be negative or positive, depending on the level of the unit production cost of Product M , c , compared with the WTP for environmental and intrinsic qualities.

The effects of a higher fraction of informed consumers on prices and demands are given by the following derivatives:

$$\frac{\partial p_M^{MGc}}{\partial \alpha} = \frac{-2\bar{\theta}(e_G - e_M)}{(3\alpha^2)} < 0,$$

$$\frac{\partial p_G^{MGc}}{\partial \alpha} = \frac{-\bar{\theta}(e_G - e_M)}{(3\alpha^2)} < 0,$$

$$\frac{\partial d_M^{MGc}}{\partial \alpha} = \frac{-ce_M - \bar{\theta}(e_G - e_M) + \rho(q_B - q_G)}{3\bar{\theta}(e_G - e_M)},$$

$$\frac{\partial d_G^{MGc}}{\partial \alpha} = \frac{ce_M + \bar{\theta}(e_G - e_M) - \rho(q_B - q_G)}{3\bar{\theta}(e_G - e_M)}.$$

APPENDIX F: PROOFS OF SUBGAME PERFECT NASH EQUILIBRIA

In stage 3, one of the firms decides to replace its product with Product M if it will increase its profits or to continue offering the same product otherwise. The resulting SPNE depends on the market structure (segmented, fragmented, or covered) determined by α and e_M , and satisfies the following nondeviation conditions:

- The SNPE with Products B and G requires $\pi_G^{BG} > \pi_M^{BM}$ and $\pi_B^{BG} > \pi_M^{MG}$.

- The SNPE with Products B and M requires $\pi_M^{BM} > \pi_G^{BG}$ and $\pi_M^{BM} > \pi_G^{MG}$.
- The SNPE with Products M and G requires $\pi_M^{MG} > \pi_B^{BG}$ and $\pi_G^{MG} > \pi_B^{BM}$.

F.1 | Subgame perfect Nash equilibria with Products B and M

According to the strategies α and e_M of the NGO, Firm G decides to replace Product G with Product M when its competitor still produces Product B if $\pi_M^{BM} > \pi_G^{BG}$. To detail all the conditions according to e_M and α would be laborious. For example, the conditions obtained for $0 < \alpha \leq \alpha_0$ are

- If $e_M < \rho q_B / (\bar{\theta} + c)$: $\alpha < \frac{4\bar{\theta} e_G F_G}{(\bar{\theta} e_G + \rho q_G)^2 - 4\bar{\theta} e_G (\rho q_B - ce_M)}$.
- If $e_M > \rho q_B / (\bar{\theta} + c)$:

$$\alpha < \frac{4\bar{\theta} e_G e_M F_G}{(e_M e_G (-c^2 e_M + \bar{\theta}^2 (e_G - e_M) - 2\bar{\theta} \rho (q_B - q_G) + 2c(\bar{\theta} e_M + \rho q_B)) + \rho^2 (e_M q_G^2 - e_G q_B^2))}$$

The boundary such that $\pi_M^{BM} = \pi_G^{BG}$ (illustrated in Figure 4) is a decreasing and convex function because, in all configurations of the market, π_M^{BM} is a decreasing and convex function of e_M under the following conditions:

$$\begin{aligned} \frac{\partial \pi_M^{mc}}{\partial e_M} &= -\alpha c e_M < 0, \\ \frac{\partial \pi_M^m}{\partial e_M} &= \frac{-ce_M + \bar{\theta} e_M - \rho q_B}{2e_M} d_M^m < 0 \quad \text{if } -\bar{\theta} e_M + \rho q_B < ce_M < \bar{\theta} e_M - \rho q_B, \\ \frac{\partial^2 \pi_M^m}{\partial e_M^2} &= \frac{\alpha \rho^2 q_B^2}{2\bar{\theta} e_M^3} > 0, \\ \frac{\partial \pi_M^{BMc}}{\partial e_M} &= \frac{-\alpha c (e_M - 2e_B) + (1 + \alpha) \bar{\theta} (e_M - e_B)}{3\alpha (e_M - e_B)} d_M^{BMc} < 0 \quad \text{if } \alpha > \frac{\bar{\theta} (e_M - e_B)}{c(e_M - 2e_B) - \bar{\theta} (e_M - e_B)}, \\ \frac{\partial^2 \pi_M^{BMc}}{\partial e_M^2} &= \frac{2\alpha c^2 e_B^2}{9\bar{\theta} (e_M - e_B)^3} > 0. \end{aligned}$$

Moreover, π_M^{BM} and π_G^{BG} are both increasing functions of α when the market is fragmented or covered with a corner solution and decreasing functions when the market is covered with an interior solution:

$$\begin{aligned} \frac{\partial \pi_M^{mc}}{\partial \alpha} &= \rho q_B - ce_M > 0, \\ \frac{\partial \pi_M^m}{\partial \alpha} &= \frac{(-ce_M + \bar{\theta} e_M + \rho q_B)^2}{4\bar{\theta} e_M} > 0, \\ \frac{\partial \pi_M^{BMc}}{\partial \alpha} &= \frac{-\alpha ce_M - (1 - \alpha) \bar{\theta} (e_M - e_B)}{3\alpha^2} d_M^{BMc} < 0, \\ \frac{\partial \pi_G^m}{\partial \alpha} &= \frac{(\bar{\theta} e_G + \rho q_G)^2}{4\bar{\theta} e_G} > 0, \\ \frac{\partial \pi_G^{BGc}}{\partial \alpha} &= \frac{-(1 - \alpha) \bar{\theta} (e_G - e_B) - \alpha \rho (q_B - q_G)}{3\alpha^2} d_G^{BGc} < 0. \end{aligned}$$

As a result, the boundary α such that $\pi_M^{BM} = \pi_G^{BG}$ is a decreasing and convex function of e_M as soon as the conditions ensuring that π_M^{BM} is a decreasing function of e_M are satisfied. The condition for the nondeviation of Firm B , such that $\pi_B^{BM} > \pi_G^{MG}$, does not affect the shape of the boundary.

F.2 | Subgame perfect Nash equilibria with Products M and G

According to the strategies α and e_M of the NGO, Firm B decides to replace Product B with Product M when its competitor still produces Product G if $\pi_M^{MG} > \pi_B^{BG}$. First of all, note that $\pi_M^{MGc} < \pi_B^{BGc}$ as soon as $\rho(q_B - q_G)(e_M - e_B) < ce_M(e_G - e_B)$. Moreover, from the definitions of profits, we can see that the conditions for $\pi_M^{MG} > \pi_B^{BG}$ can all be expressed as conditions for quadratic polynomials in α to be positive. The conditions on α and e_M for polynomials to be positive can be deduced from the analysis of the sign of the discriminant and the sign of the coefficient of α^2 of each polynomial function (which depends on e_M). Details of all conditions are not of interest to the analysis. Illustrations are given in Figure 4.

APPENDIX G: PROOF OF PROPOSITION 3

When $\alpha < \alpha_0$, the market is segmented (denoted with superscript m) and also covered if the production cost of Product M is low (denoted with superscript mc). The associated levels of environmental quality are

$$E^{BMmc} = (1 - \alpha)e_B + \alpha e_M,$$

$$E^{BMm} = (1 - \alpha)e_B + \alpha \frac{ce_M(e_G - e_M) + \bar{\theta} e_M(e_G + e_M) - \rho q_B(e_G - e_M)}{2\bar{\theta} e_M}.$$

Because $E^{BGm} = (1 - \alpha)e_B + \alpha e_G$, it is clear that $E^{BGm} > E^{BMmc}$. Moreover, $E^{BGm} > E^{BMm}$ because αe_G is higher than the second term of E^{BMm} : the difference between both terms is characterized by $\alpha(e_G - e_M)(-ce_M + \bar{\theta} e_M + \rho q_B)/(2\bar{\theta} e_M) > 0$.

APPENDIX H: PROOFS OF NGO'S STRATEGIES IN FRAGMENTED AND COVERED MARKETS

H.1 | The environmental quality with Products B and M

For $\alpha \geq \alpha_0$, the levels of environmental quality associated with a fragmented market (f), a covered market with a corner solution (cc) and a covered market with an interior solution (c) are

$$E^{BMf} = \frac{e_G + e_B}{2} + \alpha \frac{(e_M - e_B)(\bar{\theta} e_M e_B + \rho q_B e_G) + ce_M e_B(e_G - e_M)}{2\bar{\theta} e_B e_M}, \quad (H1)$$

$$E^{BMcc} = e_B + \alpha \frac{(e_M - e_B)(\bar{\theta} e_M + \rho q_B - ce_M)}{2\bar{\theta} e_M}, \quad (H2)$$

$$E^{BMc} = \frac{e_M + 2e_B}{3} + \alpha \frac{\bar{\theta}(e_M - e_B) - ce_M}{3\bar{\theta}}. \quad (H3)$$

We compare the environmental quality E^{BMk} with E^{BGk} ($k = m, mc, f, c, cc$) in the only cases where there is an SPNE with Products B and M . The analysis is therefore limited to the cases where $e_M < \frac{\rho q_B}{c + \bar{\theta}}$.

(1) *The cases with $\alpha_0 \leq \alpha < \alpha_1$*

- For $\alpha_0 < \alpha < \min\{\alpha_4, \alpha_1\}$, the market with B and M is segmented with a corner solution (mc), while the market with B and G is fragmented (f). A necessary condition for

$$E^{BMmc} = e_G + (e_B - e_G)d_B^{mc} + (e_M - e_G)d_M^{mc} > E^{BGf} = e_G + (e_B - e_G)d_B^f$$

is $d_B^{mc} = 1 - \alpha < d_B^f$, that is satisfied when $\bar{\theta} e_G > \rho q_G$ and $\alpha > \alpha_0$. However, we have

$$E^{BMmc} - E^{BGf} = \frac{\bar{\theta} e_B (e_G - e_B) + \alpha [(\bar{\theta} e_B + \rho q_B) e_G - (2\bar{\theta} e_M + \rho q_B - \bar{\theta} e_B) e_B]}{-2\bar{\theta} e_B},$$

$$E^{BMmc} - E^{BGf}|_{\alpha=\alpha_0} = \frac{\bar{\theta} e_B (e_G - e_B)}{\rho q_B - \bar{\theta} e_B} < 0,$$

$$E^{BMmc} - E^{BGf}|_{\alpha=\alpha_1} = \frac{e_B (\bar{\theta} e_G (e_G - 2e_M + e_B) + \rho q_G (e_G - e_B))}{2\rho (q_B e_G - q_G e_B)},$$

$$E^{BMmc} - E^{BGf}|_{\alpha=\alpha_1} < 0 \quad \text{if } e_M < \frac{e_G + e_B}{2} + \frac{\rho q_G (e_G - e_B)}{2\bar{\theta} e_G},$$

$$\text{with } \frac{e_G + e_B}{2} + \frac{\rho q_G (e_G - e_B)}{2\bar{\theta} e_G} < \frac{\rho q_B}{c + \bar{\theta}} \quad \text{if } c > -\bar{\theta} + \frac{2\rho q_B \bar{\theta} e_G}{\bar{\theta} e_G (e_G + e_B) + \rho q_G (e_G - e_B)}$$

and $E^{BMmc} - E^{BGf}$ is a linear function of α . Therefore, $E^{BMmc} < E^{BGf}$ as soon as e_M is lower than the above thresholds and c sufficiently high. However, an increase in e_M improves E^{BMmc} (since $\partial E^{BMmc} / \partial e_M = \alpha$) and can then lead to $E^{BMmc} > E^{BGf}$ for a high e_M (in the limit of the region (e_M, α) compatible with an SNPE with B and M).

- For $\max\{\alpha_0, \alpha_4\} < \alpha < \alpha_1$, the market with B and M is covered (c) while the market with B and G is fragmented (f). A necessary condition for $E^{BMc} > E^{BGf}$ is $d_B^{BMc} < d_B^f$, that is satisfied if $\alpha > \hat{\alpha} \equiv \frac{-\bar{\theta} e_B (e_M - e_B)}{(\bar{\theta} e_B + 3\rho q_B)(e_M - e_B) + 2ce_B e_M} > 0$, with

$$\hat{\alpha}|_{e_M=0} = \alpha_4|_{e_M=0} = \frac{-\bar{\theta} e_B}{\bar{\theta} e_B + 3\rho q_B},$$

$$\frac{\partial \hat{\alpha}}{\partial e_M} \Big|_{e_M=0} = \frac{\bar{\theta} (-2ce_B + 3\bar{\theta} e_B + 6\rho q_B)}{(\bar{\theta} e_B + 3\rho q_B)^2},$$

$$\frac{\partial \alpha_4}{\partial e_M} \Big|_{e_M=0} = \frac{-2c\bar{\theta} e_B}{(\bar{\theta} e_B + 3\rho q_B)^2} > \frac{\hat{\alpha}}{\partial e_M} \Big|_{e_M=0} \quad \text{if } \bar{\theta} e_B + 2\rho q_B > 0.$$

Therefore, $\alpha > \alpha_4 > \hat{\alpha}$ and $d_B^{BMc} < d_B^f$ if $\bar{\theta} e_B + 2\rho q_B > 0$. However, we have

$$E^{BMc} - E^{BGf} = \frac{-\bar{\theta} e_B (e_B + 2e_M - 3e_G) + \alpha [-2e_B (\bar{\theta} e_M + \rho q_B - ce_M) + (\bar{\theta} e_B + \rho q_B)(3e_G - e_B)]}{-6\bar{\theta} e_B},$$

$$E^{BMc} - E^{BGf}|_{\alpha=\alpha_0} = \frac{\bar{\theta} e_B (3e_G - 2e_M - e_B) + \rho q_B (e_M - e_B) + ce_B e_M}{-3\bar{\theta} e_B + 3\rho q_B},$$

$$E^{BMc} - E^{BGf}|_{\alpha=\alpha_0} < 0 \quad \text{if } e_M < \frac{-e_B (3\bar{\theta} e_G - \bar{\theta} e_B - \rho q_B)}{-2\bar{\theta} e_B + \rho q_B + ce_B},$$

$$E^{BMc} - E^{BGf}|_{\alpha=\alpha_1} = \frac{(\bar{\theta} e_G + \rho q_G)(3e_G - 2e_M - e_B)e_B + 2\rho q_B (e_M - e_B)e_G + 2ce_B e_M e_G}{6(\rho q_B e_G - \rho q_G e_B)},$$

$$E^{BMc} - E^{BGf}|_{\alpha=\alpha_1} < 0 \quad \text{if } e_M < \frac{-(\bar{\theta} e_G + \rho q_G)(3e_G - e_B)e_B + 2\rho q_B e_B e_G}{-2e_B (\bar{\theta} e_G + \rho q_G) + 2\rho q_B e_G + 2ce_B e_G}$$

and $E^{BMc} - E^{BGf}$ is a linear function of α . Therefore, $E^{BMc} < E^{BGf}$ as soon as e_M is lower than both of the above thresholds, which increase with c . However, an increase in e_M can improve E^{BMc} :

$$\frac{\partial E^{BMc}}{\partial e_M} = \frac{\alpha(\bar{\theta} - c) + \bar{\theta}}{3\bar{\theta}} > 0$$

if $\alpha(\bar{\theta} - c) + \bar{\theta} > 0$. This can then lead to $E^{BMc} > E^{BGf}$ for a high e_M (in the limit of the region (e_M, α) compatible with an SNPE with B and M).

(2) *The case with $\max\{\alpha_1, \alpha_4\} \leq \alpha < \alpha_2$*

The market with B and M is covered (c), while the market with B and G is covered with a corner solution (cc). We have

$$E^{BMc} - E^{BGcc} = \frac{2\bar{\theta} e_G (e_M - e_B) - \alpha (\bar{\theta} e_G (3e_G - 2e_M - e_B) + 3\rho q_G (e_G - e_B) + 2ce_M e_G)}{6\bar{\theta} e_G},$$

$$E^{BMc} - E^{BGcc}|_{\alpha=\alpha_1} = \frac{(\bar{\theta} e_G + \rho q_G)(3e_G - 2e_M - e_B)e_B + 2\rho q_B (e_M - e_B)e_G + 2ce_B e_M e_G}{6(\rho q_B e_G - \rho q_G e_B)} < 0,$$

if $e_M < \frac{-(\bar{\theta} e_G + \rho q_G)(3e_G - e_B)e_B + 2\rho q_B e_B e_G}{-2e_B(\bar{\theta} e_G + \rho q_G) + 2\rho q_B e_G + 2ce_B e_G}$.

$E^{BMc} - E^{BGcc}$ is a decreasing function of α , negative for $\alpha = \alpha_1$ as soon as e_M is lower than the above threshold, which increases with c . In this case, $E^{BMc} < E^{BGcc}$. However, an increase in e_M improves E^{BMc} if $\alpha(\bar{\theta} - c) + \bar{\theta} > 0$ and can then lead to $E^{BMc} > E^{BGcc}$ for a high e_M (in the limit of the region (e_M, α) compatible with an SNPE with B and M).

(3) *The case with $\max\{\alpha_2, \alpha_4\} \leq \alpha \leq 1$*

The markets with B and M and with B and G are covered (c). We have

$$E^{BMc} - E^{BGc} = \frac{-\bar{\theta}(e_G - e_M) - \alpha(\bar{\theta} e_G + \rho q_G - (\bar{\theta} e_M + \rho q_B - ce_M))}{3\bar{\theta}}$$

< 0 if $\bar{\theta} e_G + \rho q_G > \bar{\theta} e_M + \rho q_B$.

H.2 | The environmental quality with Products M and G

The environmental quality in the covered market with Products M and G is

$$E^{MGc} = \frac{e_G + 2e_M}{3} + \alpha \frac{\bar{\theta} e_G + \rho q_G - \bar{\theta} e_M - \rho q_B + ce_M}{3\bar{\theta}}.$$

(1) *The case with $\alpha_0 < \max\{\alpha_5, \alpha_6\} < \alpha < \alpha_1$*

The market with Products B and G is initially fragmented. We have

$$E^{MGc} - E^{BGf} = \frac{-e_G + 4e_M - 3e_B}{6} + \alpha \frac{-\bar{\theta} e_B (e_G + 2e_M - 3e_B) - \rho q_B (3e_G - e_B) + 2\rho q_G e_B + 2ce_M e_B}{6\bar{\theta} e_B},$$

$$E^{MGc} - E^{BGf}|_{\alpha=\alpha_0} = \frac{\bar{\theta} e_B e_G + \rho q_B e_G - \rho q_G e_B - (c + \bar{\theta}) e_B e_M + 2\rho q_B (e_M - e_B)}{3(\rho q_B - \bar{\theta} e_B)},$$

$$E^{MGc} - E^{BGf}|_{\alpha=\alpha_1} = \frac{\bar{\theta} e_G e_B (e_G + 2e_M - 3e_B) - \rho q_G e_B (e_G + 4e_M - 3e_B) + 2\rho q_B e_G (e_G + 2e_M - 2e_B) - 2ce_G e_M e_B}{6(\rho q_B e_G - \rho q_G e_B)}.$$

As $E^{MGc} - E^{BGf}$ is monotonous and positive when $\alpha = \alpha_0$ and α_1 as soon as $\bar{\theta} < \bar{\theta}_1$, it is positive for any $\alpha \in [\alpha_0, \alpha_1]$ and any $e_M \geq 0$.

(2) *The case with $\max\{\alpha_1, \alpha_5, \alpha_6\} < \alpha < \alpha_2$*

The market with Products B and G is initially covered with a corner solution. We have

$$E^{MGc} - E^{BGcc} = \frac{e_G + 2e_M - 3e_B}{3} - \alpha \frac{2e_G(\bar{\theta} e_M + \rho q_B - ce_M) + (e_G - 3e_B)(\bar{\theta} e_G + \rho q_G)}{6\bar{\theta} e_G},$$

$$E^{MGc} - E^{BGcc} > 0 \quad \text{if } \alpha < \tilde{\alpha} \equiv \frac{2\bar{\theta} e_G(e_G + 2e_M - 3e_B)}{2e_G(\bar{\theta} e_M + \rho q_B - ce_M) + (e_G - 3e_B)(\bar{\theta} e_G + \rho q_G)},$$

with $\frac{\partial \tilde{\alpha}}{\partial e_M} > 0$ and $\tilde{\alpha} < 1$ if $e_M < \frac{\rho q_B}{\bar{\theta} + c} - \frac{(\bar{\theta} e_G - \rho q_G)(e_G - 3e_B)}{2(\bar{\theta} + c)e_G} < \frac{\rho q_B}{\bar{\theta} + c}$ if $\bar{\theta} e_G > \rho q_G$,

$$E^{MGc} - E^{BGcc}|_{e_M=0} > 0 \quad \text{if } \alpha < \tilde{\alpha}|_{e_M=0} \quad \text{when } \bar{\theta} < \frac{\rho q_G}{e_G} + \frac{2\rho q_B}{e_G - 3e_B} \text{ or if } \bar{\theta} \geq \frac{\rho q_G}{e_G} + \frac{2\rho q_B}{e_G - 3e_B},$$

$$\frac{\partial(E^{MGc} - E^{BGcc})}{\partial e_M} = \frac{(2 - \alpha)\bar{\theta} + \alpha c}{3} > 0.$$

Therefore $E^{MGc} - E^{BGcc}$ is positive when $\max\{\alpha_1, \alpha_5, \alpha_6\} < \alpha < \min\{\alpha_2, \tilde{\alpha}\}$. It can be negative only in the specific case where $\tilde{\alpha} < \alpha < \alpha_2$, which requires that e_M is close to zero and $\bar{\theta} < \frac{\rho q_G}{e_G} + \frac{2\rho q_B}{e_G - 3e_B} < \bar{\theta}_1$.

(3) The case with $\max\{\alpha_2, \alpha_5, \alpha_6\} < \alpha$

The market with Products B and G is initially covered with an interior solution. We have

$$E^{MGc} - E^{BGc} = \frac{(2 - \alpha)\bar{\theta}(e_M - e_B) + \alpha ce_M}{3\bar{\theta}} > 0 \quad \forall \alpha, \forall e_M.$$

The resulting covered market with Products M and G is unambiguously of better environmental quality, except in the specific case of low $\bar{\theta}$ and e_M close to 0, and $\tilde{\alpha} < \alpha < \alpha_2$. In addition, an increase in α and e_M improves environmental quality E^{MGc} if

$$\frac{\partial E^{MGc}}{\partial \alpha} = \frac{\bar{\theta} e_G + \rho q_G - \bar{\theta} e_M - \rho q_B + ce_M}{3\bar{\theta}} > 0 \quad \text{if } \bar{\theta} e_G + \rho q_G > \bar{\theta} e_M + \rho q_B,$$

$$\frac{\partial E^{MGc}}{\partial e_M} = \frac{1}{3} \left(2 + \alpha \left(\frac{\bar{\theta} - c}{\bar{\theta}} \right) \right) > 0 \quad \text{if } \alpha > 0 \quad \text{when } c < \bar{\theta},$$

or $\alpha < \alpha_7 \equiv 2\bar{\theta} / (c - \bar{\theta})$ when $c > \bar{\theta}$ with $\alpha_7 \leq 1$ if $c > 3\bar{\theta}$.