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Prescriptive Labeling of Food Products: a suitable Policy Instrument?

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Prescriptive labels, which include the use of "traffic light" rankings on food products and energy efficiency classifications on electrical appliances, modify firms' decisions. Thus, a labeling policy that accounts only for consumer responses may not achieve its intended outcome. This study uses a vertical differentiation model in which three firms compete in a market to examine the changes in consumers' quality perceptions caused by prescriptive labeling and to identify how these policies impact market share, prices and welfare. We examine two cases faced by the public regulator. When the regulator wants to reinforce the valorization of the dominant quality attribute, we find that a rewarding labeling strategy yields more weighted quality in the market than a penalizing strategy. Furthermore, a mildly stringent rewarding strategy generates the highest results. In the case where the regulator wants to weaken this quality perception, a penalizing labeling strategy is the best scenario.

vertical differentiation model – prescriptive labeling – firm strategy

L'étiquetage prescriptif des produits alimentaires est-il un instrument de politique publique pertinent ?

L'étiquetage prescriptif, tel que le système de code couleur appelé « traffic light » qui permet de classer et hiérarchiser les produits, modifie le comportement des entreprises. Ainsi, une politique publique d'étiquetage qui prend seulement en compte le comportement des consommateurs peut ne pas atteindre les objectifs fixés. Cette étude utilise un modèle de différenciation verticale dans lequel trois firmes se concurrencent sur un marché. L'objectif est d'analyser les effets d'un étiquetage prescriptif qui engendre une modification de la perception des consommateurs sur la qualité des produits et d'identifier comment une politique publique d'étiquetage affecte les parts de marché des entreprises, les prix et le bien-être. Nous examinons deux cas. Dans le premier, le régulateur veut renforcer la valorisation de l'attribut de qualité dominant. Nous montrons qu'un étiquetage récompensant les firmes entraine une amélioration de la qualité fournie sur le marché. De plus, une politique d'étiquetage modérément contraignante génère de meilleurs résultats. Dans le second cas, le régulateur veut atténuer la perception de qualité sur l'attribut dominant. Un étiquetage sanctionnant l'attribut qualité dominant est le meilleur scenario.

modèle de différenciation verticale – étiquetage prescriptif – stratégie d'entreprise

Classification JEL : L13, L15, D83

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1. Introduction

The extensive literature on consumer responses to food labeling suggests that the overall impact of labeling remains modest (see Grunert and Wills [2007] for recent surveys and Drichoutis *et al.* [2005] for nutritional issues). For instance, this finding is related to consumer difficulties in interpreting the information on labels, limited time to process information in-store, and complex consumer trade-offs between price, taste, health concerns, and environmental factors. To strengthen the impact of product labeling, some health and environmental agencies have suggested that labels should not only inform consumers about product quality but also influence their choices more strongly by ranking products and providing explicit information about consequences for consumer health and the environment. Some countries have implemented such "prescriptive" labels to raise awareness of nutritional issues (*e.g.*, traffic lights on food products in the U.K., green keyholes in Denmark) and ecological issues (*e.g.*, energy efficiency classes for electrical appliances).

Few studies have addressed the effects of prescriptive labels, although they are increasingly cited in public debates as a tool for achieving better outcomes from labeling policies. The first issue is to determine the extent to which labels influence consumers' decisions. Empirical studies tend to report that prescriptive labels have a greater impact on consumers than simple informative labels (Aschemann-Witzel *et al.* [2013]; Hieke and Wilczynski [2011]). In the nutritional field, Balcombe *et al.* [2010] use a choice experiment to examine how consumers change their food choices when they receive a basket of goods marked with traffic lights. They show that consumers understand the traffic lights better than other labels and thus reduce the number of foods with a red light in their basket. Feunekes *et al.* [2008] study the impact of eight front-of-pack (FOP) nutrition labeling formats in four European countries. Their results indicate that the participants needed significantly less time to evaluate simpler FOP labeling than they did for more complex labeling formats. Van Herpen and van Trijp [2011] focus on consumer attention to, and processing of, labels. They show that a nutrition table did not stimulate healthy choices but that traffic light labels, especially logos, enhanced healthy product choices, even when consumers were under time pressure. Muller and Ruffieux [2012] study the impacts of labeling on consumer behavior by assessing the effects of green/red nutritional logos on consumer purchases. They compare several labeling policies: logos based on synthetic versus nutrient-by-nutrient rankings and labels that ranked products within food categories versus between food categories. They show that label formats had a significant impact on the results and that formats that rank the entire product had a greater impact than complex, nutrient-by-nutrient formats. Thus, FOP labeling appears to modify consumer behavior and exploit the salient effect to capture consumers' attention. Chetty *et al.* [2009] find that consumers are sensitive to information that they can easily compute. In a store experiment designed to examine how consumers react to a tax, these authors find that sales decrease by approxi-

mately 8% when the tax-inclusive price is posted below the initial price on the shelf display rather than being added at the register. Luca and Smith [2013] confirm that ranking salience has a significant impact on college applications because it facilitates information processing and comparison among products, thereby reducing information costs.

A second important issue is related to the effects of labeling policies on firms' decisions[3]. It is well known (Caswell and Mojduska [1996]) that a labeling policy assessment must account for both consumer choices and firms' decisions about quality and price because the latter may also affect final policy outcomes. Indeed, although not all consumers respond to food labels, labels that highlight a good's characteristics may cause firms to strategically react to the potential change in demand, leading to changes in price and product quality. For instance, Moorman *et al.* [2012] investigate firms' responses to the standardized nutrition labels on food products that are required by the US Nutrition Labeling and Education Act (NLEA). They find that the NLEA has a negative effect on brand nutrition levels compared to control brands that are not required to have a nutrition label. When consumers think that nutrition is negatively correlated with taste and value taste more highly than nutrition, firms strategically respond to the NLEA by decreasing nutritional quality to avoid discouraging consumption. This response is reinforced by the fact that price is also a key variable for consumers; moreover, more nutritious products are likely to be more expensive. Allais *et al.* [2015] evaluate firms' strategic price reactions to an FOP policy in an oligopolistic setting with differentiated products and heterogeneous demand. They study the French market for *fromages blancs* and dessert yogurts by estimating a structural econometric model that allowed for strategic pricing and using it to estimate how firms react to different policy regulations. Their results suggest that ignoring firms' price reactions can lead to erroneous conclusions. They find that, when consumers ignored firms' strategic pricing, the implementation of an FOP label (signaling the fat content of a product) reduced the annual average fat purchase per household by approximately 12%. This result is explained by the fact that consumers significantly decreased their dessert yogurt purchases. However, when firms were free to adjust their prices, the overall fat consumption increased by approximately 5%. This result occurred because firms producing dessert yogurts dramatically decreased their prices to limit profit losses. Given the elasticity of demand for their products, it was profitable for these firms to cut their margins to recover their market share. These studies show that labeling policies may impact consumers and lead firms to change their price and quality policies in ways that can cause either positive or negative impacts.

The aim of this paper is to propose a theoretical analysis of firms' price and quality decisions under a prescriptive labeling policy and to identify the conditions under which such a policy improves public health or environmental outcomes. The implementation of a prescriptive labeling policy requires the consideration of several points. First, such a policy relies on a product ranking that discriminates between good (green logos) and bad (red logos)

3. Bonroy and Constantatos [2015] provide a recent review of the effects of labeling on the functioning of markets.

products. Therefore, a qualified agency must determine quality thresholds to distinguish "bad" and "good" products for health or the environment. These thresholds are unlikely to be neutral for either consumers or firms. Similarly, on the supply side, the quality thresholds used to characterize high/low fat content or carbon footprints may affect firms' decisions. Furthermore, it is unclear whether it is preferable to establish a stringent threshold (*e.g.*, only the highest-quality products obtain a green logo or avoid a red logo) or a mildly stringent threshold that allows many products to win a green logo. Once the quality thresholds are chosen, we must raise a second question regarding reward/penalty trade-offs. Is it more efficient to reward only high-quality products (*i.e.*, exclusively green logos), to penalize only low-quality products (*i.e.*, exclusively red logos), or to combine both strategies? Once again, this choice is not neutral and is likely to influence firms' and consumers' choices differently. Finally, should the adoption of prescriptive labels be voluntary or mandatory? It is clear that no firm would choose to adopt a red logo, but what may be the market consequences of the voluntary adoption of green logos? Assuming some effects at the consumer level, we address these three questions and assess how various prescriptive labeling policies can modify firms' behaviors and impact consumption, social welfare and health-related/environmental externalities in market equilibrium. More precisely, we analyze prescriptive labeling policies and assess their effects on both consumers' and firms' decisions using the setting defined by Scarpa [1998], whose model characteristics are used here to define the benchmark case. As in Scarpa, we introduce an intermediate quality product in a vertical differentiation model and thus a market with three products rather than two, as in most theoretical papers that have used a vertical differentiation model in a duopoly framework (Amacher *et al.* [2004]; Bansal and Gangopadhyay [2003]; Bansal [2008]; Ben Youssef and Abderrazak [2009]; Brécard [2013]; Crampes and Hollander [1995]; Ibanez and Grolleau [2008]; Lombardini-Riipinen [2005]). This model allows us to address both the regulator's choice between rewarding or penalizing labeling strategies and the choice of the quality threshold that discriminates good and bad products either already in the market or being launched. Regarding the effect of prescriptive labels on consumers, we consider that they modify consumers' quality perceptions because they give consumers a quality cue that will allow them to better adjust their quality perception of the product (Steenkamp [1990]). The regulator may face two situations; he may wish to either reinforce or weaken consumers' quality perceptions of products.

In this setting, we show that (i) a prescriptive labeling policy changes market and nutritional/environmental outcomes; (ii) the choice of a rewarding vs. a penalizing strategy and the stringency level of the quality threshold depend on consumers' initial valorization of the products that the regulator wants to favor to obtain higher health-related or environmental benefits; (iii) under some conditions, a prescriptive labelling policy performs better than a minimum quality standard (MQS). In the same game setting, Scarpa [1998] shows that the implementation or reinforcement of a MQS is not necessarily the best way to reduce a negative externality. Garella and Petrakis [2008] find that a MQS in a duopoly framework can achieve an improvement in social welfare when some consumers have imperfect information about the

product. Our analysis demonstrates that a prescriptive labeling policy, if well designed, can reduce negative externalities better than a MQS.

In Section 2, we present our model. In Section 3, we first discuss the analytical results when firms only adjust prices because of some inertia to changes in quality. Then, we explore the effects of the prescriptive labeling strategy on market outcomes when prescriptive labeling aims at amplifying the product differentiation and firms adjust their quality levels. We discuss a second situation when the regulator wants to weaken the valorization of the dominant attribute in Section 4. We conclude the paper in Section 5.

2. The model

As Steenkamp [1990] emphasizes, product quality is a key element in firms' strategy and a major criterion for consumers in selecting products. However, a gap exists between the product quality range that firms offer on the market and what consumers would actually like to purchase. This perception gap leads consumers to use quality cues to infer the quality attributes that they seek. For foodstuffs, taste and convenience are the dominant quality attributes often considered by consumers (Escalon *et al.* [2009]). In that sense, taste or convenience can be defined as our vertical quality dimension for food products. This quality attribute is observable and can be qualified as an experience attribute. By repeating their purchase over time, consumers are able to rank products based on this dominant attribute. However, products have other attributes that are not necessarily known and/or taken into account by consumers. These other dimensions may matter from the regulator's perspective because they may have detrimental effects for public health or the environment.

To capture this tension, we assume that consumers evaluate food products based on a dominant vertical quality attribute (taste, convenience…) and that the regulator wants to alter this evaluation by making a second dimension more salient through a prescriptive label. Thus, the public regulator can influence the overall the consumer quality perception through a logo, which can be either green or red, to make other quality attributes that are unobservable (*e.g.*, carbon footprint, nutritional value, ethics) and of public interest more salient. Two situations can occur. In the first, the prescriptive labeling strategy aims at amplifying product differentiation. The product that gains the highest dominant quality attribute also achieves the best nutritional contents or the best environmentally-friendly production methods, whereas the product that has the lowest dominant quality attribute obtain the poorest nutritional contents or the worst effect on the environment. For instance, local foods are increasingly preferred by consumers because they appear to be fresher and tastier. However, because they have lower carbon footprints, environmental agencies may also want to favor their consumption. In this case, the regulator wants to reinforce the consumers' valorization of the dominant quality attribute; we present this case in detail in Section 3. In the second situation, the regulator wants to weaken

the valorization of the dominant attribute by consumers. The product that gains the highest dominant quality attribute has the poorest nutritional contents or the worst impacts on the environment. For instance, saltier products are preferred by consumers (dominant attribute), but they induce detrimental effects on public health. More processed foods appear to be more convenient to consumers (dominant attribute), but they may have higher carbon footprints. In section 4, we briefly present the results obtained in the second case.

We consider three firms that compete in a vertically differentiated market using the model of Scarpa [1998]. Each firm offers a good whose quality level k_i varies, $i = L, M, H$ (low, medium, high quality) along the interval $[0, 1]$. Each firm produces a single variant, and consumers are assumed to be able to rank each product by quality k_i. Consumers choose whether to buy one product unit or none. As in the classic setting of Mussa and Rosen [1978], consumers differ in their valuation θ of the quality, which is uniformly distributed along the interval $[0, 1]$. The firm's profit is given by $\Pi_i = p_i D_i - C(k_i)$, with a fixed quadratic cost function $C(k_i) = k_i^2/2$.

Compared to this benchmark case, we consider a case in which the regulator implements a prescriptive labeling policy by requiring firms to append a green (red) logo to "good" ("bad") quality products. We assume that this logo affects consumers' perceptions of product differentiation and thereby their willingness to pay because it reveals other quality attributes such as environmental/health/ethics characteristics of which they may be unaware. The green logo rewards high-quality products, and the red logo penalizes low-quality products.

Other theoretical studies in the advertisement literature (Buehler and Halbheer [2012]; Johnson and Myatt [2006]; Hattori and Higashida [2014])[4] and in the vertical differentiation literature (Garcia-Gallego and Georgantzis [2009]; Garella and Petrakis [2008]) have considered that consumers' valuations can be altered and thus can impact firms' strategies. Here, we assume that the perceived quality is defined by αk_i, where α is the weighting factor that modifies the dominant quality attribute:

— $\alpha < 1$ when a red logo is appended to the product. It signals that the product has other quality attributes that diminish its overall quality;

— $\alpha > 1$ when a green logo is appended to the product. It signals that the product has other quality attributes that enhance its overall quality;

— $\alpha = 1$ when no logo is used (or if it is not efficient because it does not modify consumers' quality perceptions).

Parameter α reflects that product quality not only is based on the dominant quality attribute but also includes other quality attributes such as nutritional contents or environmental impacts. The quality production cost depends on quality k; however, price and quality decisions depend on logo implementation and, consequently, on the value of the parameter α. We note α_i ($i = L, M, H$), the rate of change in the quality perception induced by logo implementation for each product.

4. Bagwell [2007] provides a detailed review of the economic analysis of advertising.

The surplus for a consumer of type θ is defined as follows:

$$CS = \begin{cases} \theta\alpha_i k_i - p_i & \text{if he buys the product} \\ 0 & \text{otherwise} \end{cases} \quad [1]$$

The market is uncovered[5], which means that some consumers do not purchase any product. This market configuration occurs when $\frac{p_M - p_L}{\alpha_M k_M - \alpha_L k_L} > \frac{p_L}{\alpha_L k_L} > 0$. Consequently, the demands D_i are given by:

$$D_L = \frac{p_M - p_L}{\alpha_M k_M - \alpha_L k_L} - \frac{p_L}{\alpha_L k_L} = \frac{\alpha_L k_L p_M - \alpha_M k_M p_L}{\alpha_L k_L (\alpha_M k_M - \alpha_L k_L)} \quad [2]$$

$$D_M = \frac{p_H - p_M}{\alpha_H k_H - \alpha_M k_M} - \frac{p_M - p_L}{\alpha_M k_M - \alpha_L k_L} = \frac{(\alpha_M k_M - \alpha_L k_L)p_H - (\alpha_H k_H - \alpha_L k_L)p_M + (\alpha_H k_H - \alpha_M k_M)p_L}{(\alpha_H k_H - \alpha_M k_M)(\alpha_M k_M - \alpha_L k_L)} \quad [3]$$

$$D_H = 1 - \frac{p_H - p_M}{\alpha_H k_H - \alpha_M k_M} \quad [4]$$

We solve a two-stage game by backward induction: in the first stage, the three firms choose the product quality k_i, and in the second stage, they compete on price. The sub-game results provide information on firms' reactions when they cannot change a product's quality. Inertia to change exists due to firm resources that are insufficiently mobile and heterogeneous (Barney [1991]). When firms do not obtain human, physical or organizational resources to adjust a product's quality, they only choose to change their prices. The first stage of the game provides the firms' price and quality reactions. As in Scarpa [1998], all of the outputs are found analytically except for the quality levels. These qualities are thus derived numerically.

In the second stage, we compute the first- and second-order conditions for profit maximization (Appendix 1) that yield the equilibrium prices as functions of the quality levels, which are given in Equations (5) to (7).

$$\hat{p}_L = \frac{1}{2\omega}(\alpha_L k_L(\alpha_M k_M - \alpha_L k_L)(\alpha_H k_H - \alpha_M k_M)) \quad [5]$$

$$\hat{p}_M = \frac{1}{\omega}(\alpha_M k_M(\alpha_M k_M - \alpha_L k_L)(\alpha_H k_H - \alpha_M k_M)) \quad [6]$$

$$\hat{p}_H = \frac{(\alpha_H k_H - \alpha_M k_M)}{2\omega}(4\alpha_H k_H \alpha_M k_M - 3\alpha_M k_M \alpha_L k_L - \alpha_H k_H \alpha_L k_L) \quad [7]$$

with $\omega \equiv 4\alpha_H k_H \alpha_M k_M - 2\alpha_M k_M \alpha_L k_L - \alpha_H k_H \alpha_L k_L - \alpha_M^2 k_M^2 > 0$.

5. As noted by one reviewer, the market configuration has implications for market outcomes; more details can be found in Wauthy [1996].

The consumer surplus is given by: $CS \equiv \int_0^{\hat{\theta}_{L,M}} (\theta k_L - \hat{p}_L) d\theta + \int_{\hat{\theta}_{L,M}}^{\hat{\theta}_{M,H}} (\theta k_M - \hat{p}_M) d\theta + \int_{\hat{\theta}_{M,H}}^{1} (\theta k_H - \hat{p}_H) d\theta$ with $\hat{\theta}_{L,M} = \frac{\hat{p}_M - \hat{p}_L}{\alpha_M k_M - \alpha_L k_L}$ and $\hat{\theta}_{M,H} = \frac{\hat{p}_H - \hat{p}_M}{\alpha_H k_H - \alpha_M k_M}$

Thus, the social welfare is the sum of the consumer surplus and the profits of the three firms; it is given by: $\widehat{W} = CS + \sum_{i=L,M,H} \widehat{\Pi}_i$.

The labeling policy is implemented by the regulator to favor changes on the market leading to improvements in public health or environmental outcomes. To measure this effect, we define the variable $WQ \equiv \sum_{i=L,M,H} k_i D_i$, which represents the weighted dominant quality of the market. This value can be viewed as an indicator of the entire environmental or nutritional quality of the market. The analytical expression of the weighted quality is given by:

$$WQ = \frac{k_H (\alpha_H k_H (4\alpha_M k_M - \alpha_L k_L) - 3\alpha_M k_M \alpha_L k_L) + 2k_M (\alpha_H k_H \alpha_M k_M - \alpha_M k_M \alpha_L k_L) + k_L (\alpha_H k_H \alpha_M k_M - \alpha_M^2 k_M^2)}{2 (\alpha_H k_H (4\alpha_M k_M - \alpha_L k_L) - \alpha_M k_M (2\alpha_L k_L + \alpha_M k_M))} \quad [8]$$

We consider five labeling policies (S1 to S5), shown in Figure 1 and Table 1. In the first labeling strategy, the regulator sets a stringent rewarding label: only a green logo is used to reward the highest-quality good. In the second labeling strategy, the regulator is less stringent: he rewards both intermediate- and high-quality products with the green logo. In the third labeling strategy, the regulator appends a penalizing red logo to the lowest-quality product. In the fourth labeling strategy, the regulator sets a stringent penalizing strategy, appending a red logo to both the intermediate- and lowest-quality products. In the fifth strategy, the regulator implements both green and red logos.

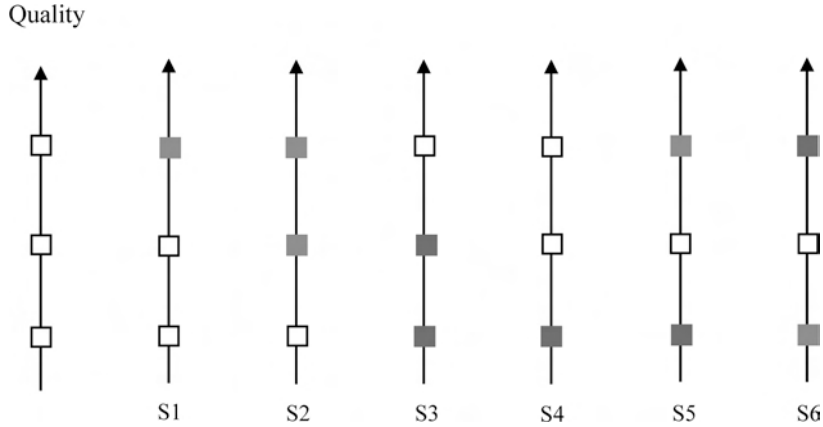

Figure 1. Prescriptive labeling strategies

Table 1. Labeling strategies

	Stringent threshold	Mildly stringent threshold
Reward highest quality products	(S1) H = green ($\alpha_H > 1$, $\alpha_M = \alpha_L = 1$	(S2) H = green, M = green ($\alpha_H = \alpha_M > 1$, $\alpha_L = 1$)
Penalize lowest quality products	(S3) L = red, M = red ($\alpha_H = 1$, $\alpha_M = \alpha_L < 1$	(S4) L = red ($\alpha_H = \alpha_M = 1$, $\alpha_L < 1$)
Mixed strategy	(S5) L = red, H = green ($\alpha_L < 1$, $\alpha_M = 1$, $\alpha_H > 1$)	
	(S6) L = green, H = red ($\alpha_L > 1$, $\alpha_M = 1$, $\alpha_H < 1$)	

3. Firms' responses when the secondary attribute amplifies consumer preferences for the dominant quality attribute

3.1. Labeling and firms' price responses

We first examine how the implementation of prescriptive labeling affects firms' decisions to change their prices, assuming no changes in product quality. Then, we determine how the consumer surplus, social welfare, and public outcomes vary, depending on the labeling policy. Regarding firms' reactions in prices, we show the following:

Proposition 1:

Implementing a rewarding labeling strategy increases all product prices compared to the benchmark case, regardless of the threshold quality level. Implementing a penalizing labeling strategy decreases the intermediate product price when the label is mildly stringent.

Proof: see Appendix 2.

Therefore, when the regulator requires prescriptive labeling that informs consumers of a product's good/bad secondary characteristics, firms adjust their decisions on price and market share compared to the benchmark (see Table 2).

Table 2. Variation of prices, demand, profit, consumer surplus, sustainable gains, and welfare when firms adjust their price, as compared to the benchmark case (no labeling)

	S1 H green	S2 H and M green	S3 L and M red	S4 L red	S5 L red and H green	S6 L green and H red
p_L	+	+	–	–	–	+
p_M	+	+	–	+	+	–
p_H	+	+	+	=	+	–
x_L	+	–	+	–	+	–
x_M	–	–	–	–	–	+
x_H	–	+	–	+	–	+
π_L	+	+	–	–	–	+
π_M	+	+	–	+	+	–
π_H	+	+	+	=	+	–
CS	+	+	–	–	+	–
WQ	–	+	–	+	–	+
W	+	+	–	+	+	–

Green prescriptive labeling leads all firms to increase their prices compared to the benchmark case. In this case, the label strengthens product differentiation and reduces price competition. A rewarding label increases social welfare; the consumer surplus increases because consumers are aware of other quality attributes (nutritional contents or environmental characteristics), increasing the overall quality of the product. However, all prices increase, and the demand for both the intermediate- and the high-quality products decreases. Although a mildly stringent rewarding label leads to an increase in all prices, it generates a different effect on market share: low-quality product demand decreases, whereas high-quality product demand increases. All firms reach higher profits when the regulator chooses rewarding labeling.

We find different impacts when we examine penalizing labeling. A stringent penalizing label generates counterproductive effects on the price, demand, profits and consumer surplus compared to the benchmark case. By increasing product differentiation, the red logo increases the price of the high-quality product and decreases its market share. The high-quality firm's profit thus increases. The low-quality firm is not able to compensate for the decrease in price with an increase in demand, and its profit decreases. The intermediate-quality firm loses market share, leading to a decrease in profit.

In this labeling strategy, the consumer surplus deteriorates compared to the benchmark case. A mildly stringent penalizing label generates different results. The low-quality firm sees its situation deteriorating compared to the benchmark case (decreases in price, demand, and profit), whereas the high-quality firm increases its profit (increases in both price and market share). The intermediate-quality firm increases its profit because the increase in the intermediate-quality product's price compensates for the loss in market share.

In terms of public outcomes, we demonstrate the following:

Proposition 2:

When implementing a prescriptive labeling strategy, the regulator improves the weighted quality of the market WG by imposing a mildly stringent threshold compared to the benchmark case (strategies S2 and S4). The greatest increase in WG is obtained when the lowest-quality product is mildly penalized (strategy S4).

Proof: see Appendix 3.

When we analyze the weighted quality of the market, it appears that a less stringent regulator will obtain better effects (only appending a red logo to the lowest-quality product or appending a green logo to both the intermediate- and the high-quality products). As the market is uncovered, the result is directly linked to the effects on market shares when firms can only adjust their price strategy. In mildly stringent labeling, the demand for the high-quality product increases, whereas the demand for the low quality product decreases. The second result demonstrates that a penalizing scenario further increases the weighted quality of the market.

3.2. Labeling and firms' quality responses

In this section, we consider that firms can react not only in prices but also in quality. The quality reactions are obtained by using the first-order conditions for profit maximization:

$$k_i^* \in \arg\max_{k_i} \Pi_i(k_i),$$

where the reduced-form profit function is defined as a function of quality levels:

$$\widehat{\Pi}_L = \frac{\alpha_M k_M \alpha_L k_L (\alpha_M k_M - \alpha_L k_L)(\alpha_H k_H - \alpha_M k_M)^2}{4w^2} - \frac{\beta k_L^2}{2} \quad [9]$$

$$\widehat{\Pi}_M = \frac{\alpha_M^2 k_M^2 (\alpha_H k_H - \alpha_M k_M)(\alpha_M k_M - \alpha_L k_L)(\alpha_H k_H - \alpha_L k_L)}{w^2} - \frac{\beta k_M^2}{2} \quad [10]$$

$$\widehat{\Pi}_H = \frac{(\alpha_H k_H - \alpha_M k_M)(4\alpha_H k_H \alpha_M k_M - 3\alpha_M k_M \alpha_L k_L - \alpha_H k_H \alpha_L k_L)}{4w^2} - \frac{\beta k_H^2}{2} \quad [11]$$

It should be noted that profits are determined using Demand Equations (2) to (4) and Price Equations (5) to (7).

As in Scarpa [1998], it is not possible to analytically obtain the equilibrium values for the product qualities. Therefore, we estimate them numerically and compare them to the benchmark situation (Scarpa [1998]), in which the optimal qualities are equal to $k_L = 0.0095$, $k_M = 0.0497$ and $k_H = 0.2527$. The implementation of a labeling strategy modifies the optimal value of each quality. Table 3 shows the optimal levels for the specific values of α_i when we assume symmetric effects for green and red logos: $\alpha_i = 0.8$ for a red logo and $\alpha_i = 1.2$ for a green logo. Table 4 shows the benchmark situation[6].

Table 3. Optimal qualities chosen by firms for each labeling strategy

	Stringent threshold	Mildly stringent threshold
Reward high quality products	(S1) $\alpha_L = \alpha_M = 1$; $\alpha_H = 1.2$ $k_L = 0.0109$ $k_M = 0.0535$ $k_H = 0.3017$	(S2) $\alpha_L = 1$; $\alpha_M = \alpha_H = 1.2$ $k_L = 0.0101$ $k_M = 0.0590$ $k_H = 0.3034$
Penalize low quality products	(S3) $\alpha_L = \alpha_M = 0.8$; $\alpha_H = 1$ $k_L = 0.0083$ $k_M = 0.0434$ $k_H = 0.2512$	(S4) $\alpha_L = 0.8$; $\alpha_M = \alpha_H = 1$ $k_L = 0.0081$ $k_M = 0.0491$ $k_H = 0.2529$
Mixed strategy	(S5) $\alpha_L = 0.8$; $\alpha_M = 1$; $\alpha_H = 1.2$ $k_L = 0.0088$ $k_M = 0.0530$ $k_H = 0.3019$	
	(S6) $\alpha_L = 1.2$; $\alpha_M = 1$; $\alpha_H = 0.8$ $k_L = 0.0095$ $k_M = 0.0444$ $k_H = 0.2040$	

6. We perform the calculations using the Mathematica software (Wolfram, Oxfordshire, UK).

Table 4. Variation in quality, price, demand, profit, consumer surplus, and sustainable gains when firms adjust price and quality compared to the benchmark case

	S1 H green	S2 H and M green	S3 L and M red	S4 L red	S5 L red and H green	S6 L green and H red
k_L	+	+	−	−	−	=
k_M	+	+	−	=	+	−
k_H	+	+	=	=	+	−
CS	+	+	−	−	+	−
WQ	+	+	−	−	+	+
W	+	+	−	+	+	−

As Tables 3 and 4 show, all firms adjust their quality when the regulator sets a prescriptive label, but the quality reaction clearly depends on the labeling strategy. The rewarding labeling strategies improve the quality level of each product. However, the improvement in quality is greater for the high-quality product than it is for the low-quality product. The penalizing labeling strategies primarily reduce the quality level for both the low- and the intermediate-quality products. It has very little effect on the high-quality product. Consequently, the change in optimal quality levels leads to different conclusions with regard to the effects of labeling strategies on the weighted quality.

We highlight several conclusions when firms can adjust price and quality, depending on labeling strategies (Figure 2). The consumer surplus increases when the regulator rewards products because the three firms improve their overall quality. The stringent penalizing labeling induces a decrease in the consumer surplus because of the reduction in quality. The weighted quality of the market further increases under rewarding labeling strategies but decreases under penalizing strategies. The largest increase in the weighted quality of the market occurs when a policy is mildly stringent and rewards high-quality products (S2). The less stringent penalizing labeling strategy has little effect on the profit, consumer surplus, welfare and weighted quality of the market.

All firms benefit from a rewarding labeling strategy and will therefore offer them voluntarily. Even the firm that produces the lowest quality level indirectly benefits from this labeling scheme, which reduces price competition by increasing product differentiation. The firm producing the highest quality level will voluntarily adopt this labeling scheme because its profits are always higher than in the benchmark case. The intermediate firm also benefits from this scheme, both when it is rewarded and when its product is not

labeled. However, the penalizing label policy deteriorates the profit of the firm producing the lowest-quality product. The intermediate firm's profit deteriorates when the regulator implements a more stringent penalizing labeling policy.

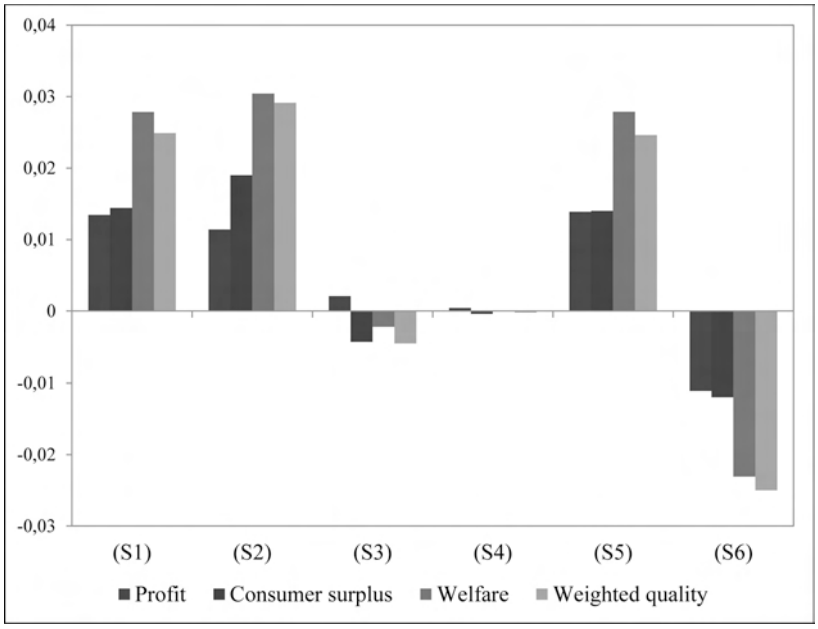

Figure 2. Variation of the weighted quality, total profit, consumer surplus, and welfare for each labeling strategy compared to the benchmark case

When we consider that green and red logos produce symmetric effects on consumer perceptions of quality, the strategy ranking remains the same, regardless of the α_i values. The greater the impact on the quality perception (*i.e.*, the greater α_i is with a green logo and the smaller α_i is with a red logo) is, the greater the effects on the weighted quality of the market (see Figure 3). However, the effects on the weighted quality of the market differ according to the labeling strategy. Rewarding strategies cause the greatest changes in the weighted quality of the market, whereas penalizing strategies either moderately affect it or have little effect.

Finally, we consider the case in which the public regulator adopts a mixed policy based on a combination of green and red logos. In this labeling strategy (S5), the regulator appends a red logo to the lowest-quality product and a green logo to the highest-quality product. Firms adjust their quality level. The firm producing the low-quality product reduces its quality level. To compensate for the decrease in quality, it decreases its price. The firm producing the intermediate-quality product benefits from the increase in product differentiation; it increases its quality level and its price. This labeling

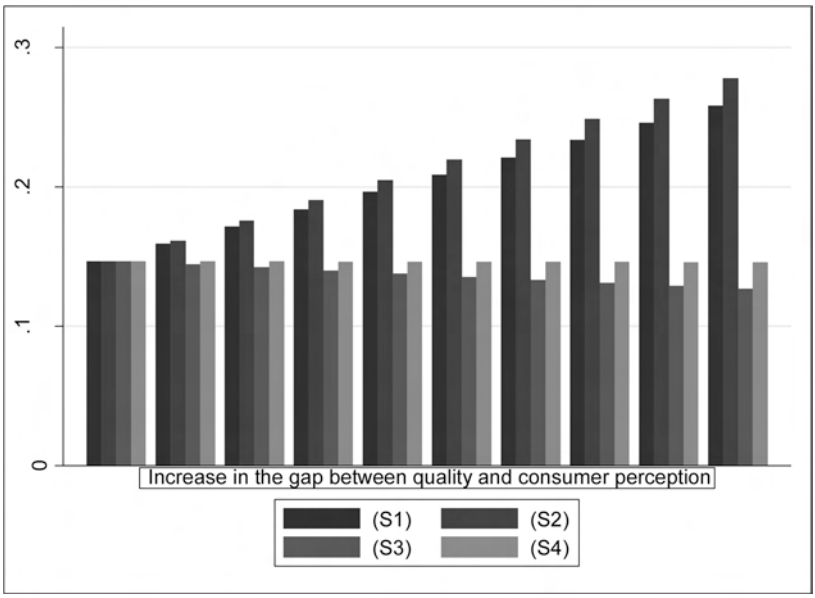

Figure 3. Changes in the weighted quality of the market when the gap between quality and consumer perception increases

strategy increases the weighted quality of the market because the increase in quality more than offsets the decrease in market shares in both the intermediate- and the high-quality products. This labeling strategy leads to a lower weighted quality of the market than the mildly stringent rewarding labeling strategy because it leads to a decrease in the market share of the high-quality product and firms improve their quality level less than in the mildly stringent rewarding strategy.

4. Firms' responses when the secondary attribute reduces consumer preferences for the dominant quality attribute

As noted above, in some cases, the dominant quality attribute and the secondary one that the regulator wishes to promote may be in conflict with consumer preferences. For instance, the salt content in foodstuffs increases not only tastiness (the dominant attribute for consumers) but also the risks to public health. Therefore, the regulator may design a policy to make consumers more aware of the bad effects of food products with the highest

dominant quality attribute (for the consumer) and increase the consumption of the products that exhibit the lowest dominant quality attribute. In this situation, we expect the prescriptive labeling strategy to decrease the weighted quality of the market compared to the benchmark situation.

We discuss two scenarios where logos affect consumers' perceptions in the direction opposite to their perception of the dominant quality attribute. First, when the regulator appends a red logo to the highest dominant quality attribute to increase consumers' consciousness of the secondary attribute, all firms modify their quality choice in equilibrium. They all reduce their quality level, which is beneficial for the regulator. However, as the three firms reduce their quality differentiation, price competition increases. All firms lower their price, and as a result, all profits decrease. This scenario affects market shares in the wrong direction for the public regulator; the demand for the lowest dominant quality product decreases, whereas demand for both the intermediate- and the highest-quality products increases. However, due to the decrease in each firm' quality level, the weighted quality of the market also decreases compared to the benchmark.

Second, the regulator appends a green logo to the lowest dominant quality attribute. The changes in quality choice are moderate. In contrast to the high dominant quality firm, both the low and the intermediate firms increase their quality levels. Price competition increases; the low-quality firm increases its price, whereas both the intermediate- and the high-quality firm reduce theirs. Market shares increase for the low and the intermediate firms but decrease for the high-quality firm. Consequently, the low-quality firm increases its profit, whereas the other firms' profits decrease. The consumer surplus increases in this scenario. From a public policy perspective, this scenario also leads to a reduction in the weighted quality of the market, albeit to a lower extent compared to the penalizing labeling strategy.

The mixed labeling strategy (S6) allows us to discuss the combination of the two previous scenarios. The red logo may signal poor nutritional contents for a product that consumers typically perceive as a high-quality product. This labeling scheme induces strong firm reactions. The firm producing the highest-quality product decreases its quality level and its price. By doing so, this firm increases its market share. To a lower extent, the firm producing the intermediate-quality product adopts a similar strategy. Consequently, the consumer surplus decreases because of the decrease in overall quality. The mixed strategy leads to a decrease in the weighted quality of the market. In all of these scenarios, social welfare decreases because of the reduction in profit.

5. Discussion and conclusion

To the best of our knowledge, there is still relatively little research on prescriptive labels despite the fact that such labels are increasingly cited in public debates on the efficiency of labeling policies. This paper attempts to

fill this gap by examining the extent to which prescriptive labels impact market and sustainable outcomes, accounting for both consumer and firm reactions. We mainly examine a symmetric effect of prescriptive labeling. Nevertheless, the effects of green/red logos can be asymmetric. For instance, Bull [2012] studies the use of energy-efficient appliances and consumer choices based on label formats. He finds that consumers chose differently when they are given information about emissions or the running costs of washing machines. He also shows that information framing is a crucial attribute: a loss-frame gave better results than a gain-frame. Thus, negative information has a larger impact than positive information because consumers prefer avoiding losses over making gains. Similarly, Muller and Ruffieux [2012] find that red and green nutritional logos have asymmetric impacts on consumer choices. Marking a "bad" product is found, on average, to be more efficient than only marking good products (*i.e.*, green logo only).

Based on these results, a focus on better labeling efficiency for consumers would favor a penalizing strategy, at least in terms of the weighted quality of the market when the public regulator wants to weaken the dominant quality. However, with regard to the case where the regulator wants to amplify consumer perceptions of the dominant quality dimension and if we also consider the effects of labeling on the supply side and in market equilibrium, penalizing strategies no longer appear beneficial. Due to firms' reactions in price and quality, these strategies actually decrease the weighted quality of the market compared to the benchmark situation. Thus, if only red logos impact consumer quality perceptions, it is better to avoid prescriptive labeling policies than it is to use red logos exclusively. Moreover, even if rewarding logos have only a small effect on consumer perceptions, rewarding strategies provide greater weighted quality in the market than the benchmark situation. A rewarding strategy based on a mildly stringent threshold allows for the greatest gains. Contrary to the increase in the MQS studied by Scarpa [1998], this strategy, and not the benchmark, should be implemented due to the benefits it provides. It is worth noting that, when some consumers have imperfect information about the product, Garella and Petrakis [2008] find that a MQS in a duopoly framework can enhance social welfare. The reason is that consumers who do not assess the true quality are willing to pay more when a MQS is introduced, increasing demand and thus overall profits.

This study could have selected other utility functions. For example, it is possible to consider that the utility that a consumer derives from a product depends on the difference between the average product quality in the market and the quality of the specific product. In this case, a green/red logo could inform consumers about this gap, and a label could therefore reduce consumers' information costs. We intend to study whether this assumption modifies outcomes in future research. García-Gallego and Georgantzís [2009] provide a first attempt at examining how changes in the distribution of consumers can modify the market structure and thus impact social welfare. However, it is clear that, to date, we do not fully understand the effects of labeling on consumer information processing. In this vein, behavioral studies may help identify how labels change quality perceptions and, ultimately, consumer utility.

Future studies may also assess the potential impact of a mixed policy that combines taxation and labeling policies. Finally, although this study adopted a simple model of vertical differentiation, it will be necessary for researchers to adopt a double differentiation framework to address the question of favoring substitutions between and within product categories through the labeling policy. A double differentiation framework would also allow us to assume that a change in the secondary dimension could increase the firm's cost of production. All of these questions should be addressed in further research.

Appendix 1:

The maximization program for the firm L is

$$p_L \equiv \arg\max_{p_L \in \mathbb{R}^+} \left[p_L \left(\frac{\alpha_L k_L p_M - \alpha_M k_M p_L}{\alpha_L k_L (\alpha_M k_M - \alpha_L k_L)} \right) - \frac{\beta}{2} k_L^2 \right]$$

The first-order condition is

$$\frac{1}{\alpha_L k_L (\alpha_M k_M - \alpha_L k_L)} (\alpha_L k_L p_M - 2\alpha_M k_M p_L) = 0$$

$$\Leftrightarrow p_L^*(p_M) = \frac{\alpha_L k_L}{2\alpha_M k_M} p_M$$

The second order condition is $\frac{\partial^2 \Pi_L}{\partial p_L^2} = \frac{-2\alpha_M k_M}{\alpha_L k_L (\alpha_M k_M - \alpha_L k_L)} < 0.$

The maximization program for the firm M is

$$p_M \equiv \arg\max_{p_M \in \mathbb{R}^+} \left[p_M \left(\frac{p_H (\alpha_M k_M - \alpha_L k_L) - p_M (\alpha_H k_H - \alpha_L k_L) + p_L (\alpha_H k_H - \alpha_M k_M)}{(\alpha_H k_H - \alpha_M k_M)(\alpha_M k_M - \alpha_L k_L)} \right) - \frac{\beta}{2} k_M^2 \right].$$

The first-order condition is

$$\frac{p_H (\alpha_M k_M - \alpha_L k_L) - 2p_M (\alpha_H k_H - \alpha_L k_L) + p_L (\alpha_H k_H - \alpha_M k_M)}{(\alpha_H k_H - \alpha_M k_M)(\alpha_M k_M - \alpha_L k_L)} = 0$$

$$\Leftrightarrow \frac{p_H - 2p_M}{\alpha_H k_H - \alpha_M k_M} - \frac{2p_M - p_L}{\alpha_M k_M - \alpha_L k_L} = 0$$

$$\Leftrightarrow p_M^*(p_L, p_H) = \frac{1}{2(\alpha_H k_H - \alpha_L k_L)} (p_H (\alpha_M k_M - \alpha_L k_L) + p_L (\alpha_H k_H - \alpha_M k_M))$$

The second order condition is $\frac{\partial^2 \Pi_M}{\partial p_M^2} = \frac{-2(\alpha_H k_H - \alpha_L k_L)}{(\alpha_H k_H - \alpha_M k_M)(\alpha_M k_M - \alpha_L k_L)} < 0.$

The maximization program for the firm H is

$$p_H \equiv \arg\max_{p_H \in \mathbb{R}^+} \left[p_H \left(1 - \frac{p_H - p_M}{\alpha_H k_H - \alpha_M k_M} \right) - \frac{\beta}{2} k_L^2 \right]$$

The first-order condition is

$$1 - \frac{2p_H - p_M}{\alpha_H k_H - \alpha_M k_M} = 0$$

$$\Leftrightarrow p_H^*(p_M) = \frac{\alpha_H k_H - \alpha_M k_M}{2} + \frac{p_M}{2}$$

The second order condition is $\frac{\partial^2 \Pi_H}{\partial p_H^2} = \frac{-2}{\alpha_H k_H - \alpha_M k_M} < 0.$

The demands are given by

$$\hat{D}_L = \frac{\alpha_M k_M (\alpha_H k_H - \alpha_M k_M)}{2\omega}$$

$$\hat{D}_M = \frac{\alpha_M k_M (\alpha_H k_H - \alpha_L k_L)}{\omega}$$

$$\hat{D}_H = \frac{4\alpha_H k_H \alpha_M k_M - 3\alpha_M k_M \alpha_L k_L - \alpha_L k_L \alpha_H k_H}{2\omega}$$

With $\omega \equiv 4\alpha_H k_H \alpha_M k_M - 2\alpha_M k_M \alpha_L k_L - \alpha_H k_H \alpha_L k_L - \alpha_M^2 k_M^2 > 0.$

Appendix 2: proof of proposition 1

Labeling strategy 1: Restrictive labeling – Green signal on the high quality product

$$\frac{\partial p_L}{\partial \alpha} = \frac{3k_H k_M k_L (k_L - k_M)^2}{2(\alpha k_H (k_L - 4k_M) + k_M (2k_L + k_M))^2} > 0 \ \forall \ \alpha$$

$$\frac{\partial p_M}{\partial \alpha} = \frac{3k_H k_M^2 (k_L - k_M)^2}{2(\alpha k_H (k_L - 4k_M) + k_M (2k_L + k_M))^2} > 0 \ \forall \ \alpha$$

$$\frac{\partial p_H}{\partial \alpha} = \frac{k_H}{2}\left(1 + \frac{3k_M^2 (k_L - k_M)^2}{2\,(\alpha k_H (k_L - 4k_M) + k_M (2k_L + k_M))^2}\right) > 0 \;\forall\; \alpha$$

Labeling strategy 2: Mildly restrictive labeling – Green signal on both the high and intermediate quality products

We only examine the numerator of each partial derivative (the denominator is positive).

For $\partial p_L / \partial \alpha$, the numerator is written $3\alpha^2 k_L^2 k_M (k_H - k_M)^2$ which is positive for all α.

For $\partial p_M / \partial \alpha$, the numerator is written $\alpha^2 (4k_M^2 k_H - k_M^3) - 2\alpha (k_H k_M k_L + 2k_M^2 k_L) + k_H k_L^2 + 2k_L^2 k_M$. The determinant $-12k_H^2 k_L^2 k_M^2 - 12k_L^2 k_M^3 k_H + 16k_M^4 k_L^2$ is negative, thus $\partial p_M / \partial \alpha$ is positive.

For $\partial p_H / \partial \alpha$, the numerator is written

$$\alpha^2 (k_H - k_M)(4\alpha^2 k_M^2 k_H (4k_H - k_M) - 8\alpha k_H k_M k_L (2k_M + k_H) + k_L^2 (k_H^2 + 5k_H k_M + 6k_M^2))$$

As the determinant $\Delta = -48k_H k_L^2 (k_H - k_M) k_M^3 (k_H + 2k_M)$ is negative, $\partial p_H / \partial \alpha$ is positive for all α.

Labeling strategy 3: Restrictive labeling – red signal on both the low and intermediate quality products

We only examine the numerator of each partial derivative (the denominator is positive).

For $\partial p_L / \partial \alpha$, the numerator is written $\alpha^2 k_L (k_M - k_L)(\alpha^2 k_M^2 (k_M + 2k_L) - 2\alpha k_M k_H (4k_M - k_L) + k_H^2 (4k_M - k_L))$ and the determinant $\Delta = 12\alpha^2 k_H^2 k_M^2 (k_M - k_L)(4k_M - k_L)$ which is positive, which means there exist two values for α where $\partial p_L / \partial \alpha = 0$, $\alpha_1 = \dfrac{k_H\left(4k_M - k_L - \sqrt{3(k_M - k_L)(4k_M - k_L)}\right)}{k_M (k_M + 2k_L)} > 0$ and $\alpha_2 = \dfrac{k_H\left(4k_M - k_L + \sqrt{3(k_M - k_L)(4k_M - k_L)}\right)}{k_M (k_M + 2k_L)} > 1$. As $\alpha_2 > 1$ for this labeling strategy, we can exclude α_2 from a possible solution. Over the interval $[0, \alpha_1]$, $\partial p_L / \partial \alpha > 0$ and over the interval $[\alpha_1, 1]$, $\partial p_L / \partial \alpha < 0$. We are able to numerically determine α_1 at the equilibrium and it is greater than one.

For $\partial p_M / \partial \alpha$, the numerator is written $\alpha^2 k_M (k_M - k_L)(\alpha^2 k_M^2 (k_M + 2k_L) - 2\alpha k_M k_H (4k_M - k_L) + k_H^2 (4k_M - k_L))$ and as the determinant is the same as for $\partial p_L / \partial \alpha$ there exist the same two values

α where $\partial p_M/\partial\alpha = 0$. As previously, $\alpha_2 > 1$. Over the interval $[0, \alpha_1]$, $\partial p_M/\partial\alpha > 0$ and over the interval $[\alpha_1, 1]$, $\partial p_M/\partial\alpha < 0$. We are able to numerically determine α_1 at the equilibrium and it is greater than one.

For $\partial p_H/\partial\alpha$, the numerator is written $-3\alpha^2 k_M^2 (k_H^2 (4k_M - k_L) - 2k_H k_L (4k_M - k_L)\alpha + \alpha^2 k_M k_L (k_M + 2k_L))$ which is negative for all α.

Labeling strategy 4: Mildly restrictive labeling – red signal on the low quality product

For $\partial p_L/\partial\alpha$, the numerator is written $k_L (k_H - k_M)((4k_H - k_M)k_M^2 - 2\alpha k_L k_M (4k_H - k_M) + \alpha^2 k_L^2 (k_H + 2k_M))$ and the determinant $\Delta = 12k_L^2 k_M^2 (k_H - k_M)(4k_H - k_M)$ is positive which means there exist two values for α where $\partial p_L/\partial\alpha = 0$ $\alpha_1 = \dfrac{k_M\left(4k_H - k_M - \sqrt{3(k_H - k_M)(4k_H - k_M)}\right)}{k_L(k_H + 2k_M)} > 0$ and $\alpha_2 = \dfrac{k_M\left(4k_H - k_M + \sqrt{3(k_H - k_M)(4k_H - k_M)}\right)}{k_L(k_H + 2k_M)} > 1$. As $\alpha_2 > 1$ for this labeling strategy, we can exclude α_2 from a possible solution. Over the interval $[0, \alpha_1]$, $\partial p_L/\partial\alpha > 0$ and over the interval $[\alpha_1, 1]$, $\partial p_L/\partial\alpha < 0$. We are able to numerically determine α_1 at the equilibrium and it is greater than one.

For $\partial p_M/\partial\alpha$, the numerator is written $-3k_M^2 k_L (k_H - k_M)^2$ which is negative for all α.

For $\partial p_H/\partial\alpha$, the numerator is written $3k_M^2 (-k_H + k_M)$ which is negative for all α.

Appendix 3: proof of proposition 2

The expression of the sustainable gains can be written as follows

$$WQ \equiv \sum_{i=L,M,H} k_i D_i$$

$$WQ = \frac{k_H(\alpha_H k_H(4\alpha_M k_M - \alpha_L k_L) - 3\alpha_M k_M \alpha_L k_L) + 2k_M(\alpha_H k_H \alpha_M k_M - \alpha_M k_M \alpha_L k_L) + k_L(\alpha_H k_H \alpha_M k_M - \alpha_M^2 k_M^2)}{2(\alpha_H k_H(4\alpha_M k_M - \alpha_L k_L) - \alpha_M k_M(2\alpha_L k_L + \alpha_M k_M))}$$

For labeling strategies 1 and 2, we examine the sign of $\partial WQ/\partial\alpha$ over the interval $\alpha \in [1, \infty]$, the prescriptive labeling is to put a green signal on the product and as a consequence the regulator improves the quality perception $\alpha > 1$.

Labeling strategy 1: Restrictive labeling – Green signal on the high quality product

$$\frac{\partial WQ_{rg}}{\partial \alpha} = -\frac{k_H k_M (k_L - k_M)(k_H (k_L - 4k_M)) + k_M (5k_L - 2k_M)}{2(\alpha k_H (k_L - 4k_M) + k_M (2k_L + k_M))^2} < 0 \; \forall \; \alpha$$

As the quality perception increases, the sustainable gains deteriorate as compared to the benchmark case.

Labeling strategy 2: Mildly restrictive labeling – Green signal on both the high and intermediate quality product

$$\frac{\partial WQ_{sg}}{\partial \alpha} = \frac{k_M k_L (k_M - k_L)(k_H - k_M)(k_H + 2k_M)}{2(k_H (k_L - 4\alpha k_M) + k_M (2k_L + \alpha k_M))^2} > 0 \; \forall \; \alpha$$

As the quality perception increases, the sustainable gains improve as compared to the benchmark case.

For labeling strategies 3 and 4, we examine the sign of $\partial WQ/\partial \alpha$ over the interval $\alpha \in [0, 1]$, the prescriptive labeling is to put a red signal on the product and as a consequence the regulator deteriorates the quality perception $\alpha < 1$.

Labeling strategy 3: Restrictive labeling – red signal on both the low and intermediate quality product

$$\frac{\partial WQ_{rr}}{\partial \alpha} = \frac{k_H k_M (k_L - k_M)(k_H (k_L - 4k_M) + k_M (5k_L - 2k_M))}{2(k_H (k_L - 4k_M) + \alpha k_M (2k_L + k_M))^2} > \; 0 \; \forall \; \alpha$$

As the quality perception decreases, the sustainable gains deteriorate as compared to the benchmark case.

Labeling strategy 4: Mildly restrictive labeling – red signal on the low quality product

$$\frac{\partial WQ_{sr}}{\partial \alpha} = \frac{k_M k_L (k_H - k_M)(k_L - k_M)(k_H + 2k_M)}{2(k_H (\alpha k_L - 4k_M) + k_M (2\alpha k_L + k_M))^2} < 0 \; \forall \; \alpha$$

As the quality perception decreases, the sustainable gains improve as compared to the benchmark case.

To know which labeling strategies lead to the greatest sustainable gains, we determine the sign of $\left|\frac{\partial WQ_{sg}}{\partial \alpha}\right| - \left|\frac{\partial WQ_{sr}}{\partial \alpha}\right|$ assuming the quality perception

moves by the same proportion α when imposing a green or a red signal that it to say the regulator increases the quality perception by $(1+a)$ in the green labeling strategy and decreases it by $(1-a)$ in the red labeling strategy. As a result, we have the expression

$$\alpha_{sr} k_L < k_L < k_M < \alpha_{sg} k_M \Leftrightarrow (1-a)k_L < k_L < k_M < (1+a)k_M$$

To examine the sign of

$$\left|\frac{\partial WQ_{sg}}{\partial \alpha}\right| - \left|\frac{\partial WQ_{sr}}{\partial \alpha}\right| = \frac{|k_M k_L (k_H - k_M)(k_H + 2k_M)(k_M - k_L)|}{2(k_H(k_L - 4\alpha k_M) + k_M(2k_L + \alpha k_M))^2} - \frac{|k_M k_L (k_H - k_M)(k_H + 2k_M)(k_L - k_M)|}{2(k_H(\alpha k_L - 4k_M) + k_M(2\alpha k_L + k_M))^2},$$

we only have to study the denominator.

$$D_{sg}: |k_H(k_L - 4\alpha_{sg} k_M) + k_M(2k_L + \alpha_{sg} k_M)| \Leftrightarrow |k_H(k_L - 4(1+a)k_M) + k_M(2k_L + (1+a)k_M)|$$

$$D_{sr}: |k_H(\alpha_{sr} k_L - 4k_M) + k_M(2\alpha_{sr} k_L + k_M)| \Leftrightarrow |k_H((1-a)k_L - 4k_M) + k_M(2(1-a)k_L + k_M)|$$

$$|k_H(k_L - 4(1+a)k_M) + k_M(2k_L + (1+a)k_M)| - |k_H((1-a)k_L - 4k_M) + k_M(2(1-a)k_L + k_M)|$$

$$\Leftrightarrow |k_M(2k_L + (1+a)k_M - k_H(4(1+a)k_M - k_L))| - |k_M(2(1-a)k_L + k_M) - k_H(4k_M - (1-a)k_L)|$$

$$\Leftrightarrow k_H(4(1+a)k_M - k_L) - k_M(2k_L + (1+a)k_M) - k_H(4k_M - (1-a)k_L) + k_M(2(1-a)k_L + k_M)$$

$$\Leftrightarrow k_H(4k_M + 4ak_M - k_L) - k_M(2k_L + k_M + ak_M) - k_H(4k_M - k_L + ak_L) + k_M(2k_L - 2ak_L + k_M)$$

$$\Leftrightarrow k_H(4ak_M) - k_M(ak_M) - k_H(ak_L) + k_M(-2ak_L)$$

$$\Leftrightarrow 4k_H k_M - k_M^2 - k_L(k_H + 2k_M) > 0$$

Which means that $D_{sg} > D_{sr}$ and as a result, $\left|\frac{\partial WQ_{sg}}{\partial \alpha}\right| - \left|\frac{\partial WQ_{sr}}{\partial \alpha}\right| < 0$.

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