The Effects of Environmental Quality Misperception on Investments and Regulation

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Abstract

This paper analyses how consumers' environmental quality misperception influences firms' investments in environmental quality. We examine a setup with horizontal and vertical (green) differentiation, where consumers are heterogeneous in the exogenous perception of environmental quality. Demands, true qualities and profits are increasing in the misperception of quality, while the investment in green quality decreases with the degree of product substitutability. We further consider the introduction of either an emission tax or an environmental standard. Both interventions increase the investment in green quality, while the social welfare decreases as a function of environmental damage. In particular, a simple simulation shows that for low marginal damages, the environmental standard increases quality and social welfare, while taxation is more effective when the environmental damage is large.

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1. Introduction

Access to knowledge and innovations in technology have led to increasing awareness of environmental issues. Several studies have shown that world-wide, consumer's appetite for green products has increased significantly in the past years (Chase and Smith, 1992; Reitman, 1992; Kim and Choi, 2005; Chen, 2008, *inter alia*).[1]

Robust empirical finding however suggests that consumers find it difficult to assess the environmental friendliness of a product. The confusion about the greenness of products is reported to be widespread as in Wagner (2002). D'Souza *et al.* (2006) find for instance a negative correlation between individual green quality perception and purchase intention. Consumers thus react by underestimating environmental quality. Barber (2010) instead shows that for a given level of environmental quality, consumers were more likely to pay more for green wine packaging. This result is confirmed by Biswas (2016). In this case, consumers overestimate the environmental quality of the product. Overestimating quality is usually possible in case of eco-labeled products. They are used to certify that a product meets some quality standard, although such product does not fully correspond to eco-friendly materials (Harbaugh *et al.*, 2011, and Brecard, 2014, *inter alia*).[2]

Such result should not come too much as a surprise. A large part of consumers have relatively little knowledge to make an informed decision and traditionally lacked a detailed understanding of green innovation process.

This paper deals with this issue: the effect of a potential misperception of environmental quality. In particular, we want to investigate how consumers' perception influences the firms' investment in environmental quality. This aspect seems relevant in order to design the most

[1]See Kohl (1991) and Chang (2011) about the rise of consciousness and its impact on environmental improvement.

[2]For instance most of the products classified as biodegradable, phosphate and chlorine free may still derive their ingredients from petrochemicals like crude oil or natural gas (which are not renewable). https://www.gmaonline.org/downloads/research-and-reports/greenshopper09.pdf

appropriate environmental regulation. We thus present a model of regulation in the presence of asymmetric information on environmental quality. Our framework is characterised by heterogeneity of consumers due to environmental misperception. We model the differences in consumers' environmental perception as biased signals received by consumers, which are taken as given. This assumption aims to keep the focus on how consumers' perception influences the firms' decisions and regulation rather than on the direct determination of consumers' perception.

In the baseline model, we evaluate the results when no regulatory policies occur. Demand, true environmental quality and profits are increasing in the perceived quality, while, the investment in green quality decreases. Indeed, a higher degree of substitutability implies higher competition among companies that react by softening their investment in environmental quality.

The paper considers next two government interventions. First, we investigate the effects of a tax on polluting emissions. This policy increases the investment in environmental quality due to changes of firms' incentives. A company thus invests in green quality not only to acquire green consumers but also to reduce the tax burden. We investigate further the introduction of an endogenous tax. The level of optimal taxation increases with the quality misperception if the marginal damage of emissions is sufficiently high. This result can be explained as follows. A higher perception of environmental quality raises the demand. If the marginal damage of emission is high, then the increase in demand needs to be compensated by a tax increase. The second intervention evaluates the introduction of an environmental standard. This policy increases the perceived quality even for consumers who underestimate quality and also their willingness to pay for the goods, while increasing firms' profits. Instead, an endogenous environmental standard *bites* if the overestimation of environmental quality of some consumers is high, leading firms to invest more in quality. If the marginal damage is relatively large, then the optimal environmental standard decreases with the level of quality overestimation. This is due to the fact that a relatively large demand would harm considerably the environment as the marginal damage increases.

We compare these two interventions in a numerical simulation both in terms of environmental quality and social welfare. For lower levels of marginal damage, the environmental standard increases the levels of both quality and welfare with respect to the case of taxation, while when marginal damage is relatively large, emission tax seems to be more effective. Intuitively, this result can be easily explained by the incentives that the tax imposes on firms' profits when damage increases. When damage is lower, an environmental standard rapidly increases quality and social welfare since it requires an immediate application of a minimum threshold. Instead, when the damage is larger, taxation is more effective due to incentives pressure received by firms.

The economic literature has recently analysed the presence of green consumers. A first group of papers focused on the impact of higher consumers' consciousness on the market equilibrium and the associated social welfare (Eriksson, 2004; Conrad, 2005). A second group dealt with the presence of green consumers interacts with the optimal environmental policy (Arora and Gangopadhyay, 1995; Cremer and Thisse, 1999; Moraga-Gonzàlez and Padron-Fumero, 2002; Lombardini-Riipen, 2005). The presence of green consumers has been examined in relation with socially responsible firms (Rodriguez-Ibeas, 2007; Garcia-Gallego and Georgantzis, 2009; Doni and Ricchiuti, 2013), or in determining the validity of the Porter hypothesis (Andrè *et al.*, 2009; Lambertini and Tampieri, 2012). Liu *et al.* (2012) for instance examine the impact of consumers' environmental awareness on competition among the supply chain players exploiting a two-stage Stackelberg game in three supply chain network structures. They find that, when consumers' environmental awareness increases, retailers and manufacturers with superior eco-friendly operations will benefit, while interestingly, higher levels of retail competition may make manufacturers with low eco-friendly operations benefit from the increase of consumers' environmental awareness. The most common framework of these contributions is a pure vertically differentiated duopoly. In order to treat quality misperception, we extend such a framework considering both horizontal and vertical differentiation, while goods differ in the degree of substitutability and in (environmental) quality. Introducing the misperception of green consumers and its effects in the private and regulated equilibrium is the contribution of the present analysis.

One of the most related contributions is Hattori and Higashida (2012). They focus on endogenous misleading advertising in duopolistic markets with horizontal product differentiation and an externalities effect in firms' optimal advertising with welfare implications. The effect of misperception on environmental quality in our model follows this line of research although we intentionally leave the signals perceived by consumers as exogenous in order to avoid any strategic behaviour of firms in the quality misperception of consumers.

The remainder of the paper is organised as follows. Section 2 introduces the model. Section 3 shows the baseline results. Section 4 considers the regulated equilibrium through the two interventions. These are developed and compared in Subsection 4.1, 4.2 and 4.3, respectively. Concluding remarks follows in Section 5.

2. The model

In the spirit of Garella and Petrakis (2008), we consider a market for differentiated goods with two firms, 1 and 2, and a continuum of consumers with total mass normalised to 1. In case of perfect information on environmental quality, a consumer's gross utility is:[3]

$$U\left(x_1, x_2\right) = \left(\alpha + e_1\right) x_1 + \left(\alpha + e_2\right) x_2 - \frac{x_1^2 + 2\beta x_1 x_2 + x_2^2}{2} + c_0, \tag{1}$$

where $\alpha + e_i$ identifies the environmental quality of good i, $i \in \{1, 2\}$. In particular, α is the minimum level of quality (exogenously taken) and e_i is the quality chosen by firm i. The

[3]See Häckner (2000).

quantity of good i bought by the representative consumer is x_i, while $\beta \in [0,1]$ is the degree of substitutability between the two goods. When $\beta = 0$, the goods are independent, and when $\beta = 1$, the goods are perfect substitutes.

Under perfect information, utility maximisation of the representative consumer with respect to x_i, $\forall i \in \{1,2\}$ determines the demand functions,

$$x_i\left(p_i, p_j, e_i, e_j\right) = \frac{\alpha\left(1-\beta\right) + \left(e_i - \beta e_j\right) - p_i + \beta p_j}{1-\beta^2} \qquad j \in \{1,2\}, j \neq i. \tag{2}$$

Consumers have recently increased their attention toward environmental friendly products. Consumers' preferences, thus, include a psychological aspect towards green purchase intention captured by the perception of quality: the higher the quality of the product, the higher the value of the individual utility. In turn, due to the general difficulty of observing green quality, many companies are marketing their products with eco-labels, see Harbaugh *et al.* (2011). More in general, they spend money for false advertisements trying to persuade consumers on the potential quality of the products.[4] This confusion may induce some consumers to overestimate the quality of the product. However, some consumers, who are unsure of the exact standard that the label represents, may instead underestimate the quality. For these reasons, consumers may not have the right perception of green characteristics of products. Our framework allows some of these consumers to overestimate (or underestimate) at least partially the true quality of both goods as in a real-world case.[5]

[4]As mentioned above, we do not study firms' potential choice of eco-labels or *false* advertising. In principle, this additional analysis would require another stage of optimization and a learning structure of consumers' choice and it is outside the scope of this paper.

[5]There are several implications in case of exogenous consumers' perception of quality. First, there is no communication between consumers differing in perception of environmental quality. Indeed, the actual fractions of consumers could be in principle the result of previous communications among consumers. Second, there is no credible third party certification available or credible for every consumer. This implicit assumption may be interpreted as some consumers being sceptical towards some type of certification. Third, informed consumers do not incur any cost to be informed. The reason could be motivated by idiosyncratic preferences towards environmental awareness. Some consumers intrinsically care for environment and enjoy to keep themselves informed without any cost.

Following the tradition of learning literature,[6] each individual capture an exogenous informative signal $s_i \in \{e_{i\in\{1,2\}}; e_0; e_m\}$, where signals are independent draws by firms' optimization. Asymmetric information is identified by two of these signals as proxies of quality misperception perceived by consumers. These signals can be, respectively, higher ($s_i = e_m > e_i$) or lower ($s_i = e_0 < e_i$) than the true quality, e_i. Consumers in proportion $\lambda \in (0,1)$ recognise the true quality e_i, i.e., $s_i = e_i$, $\forall i \in \{1,2\}$, while a proportion $(1-\lambda)$ of them cannot observe, e_i, and receives the wrong signal, s_i, with equal probability, i.e., $\Pr(s_i = e_0)|_{(1-\lambda)} = \Pr(s_i = e_m)|_{(1-\lambda)}$. Thus four equiprobable pairs of perceived qualities are realized, i.e., (e_0, e_0), (e_m, e_m), $(e_{0,}e_m)$ and (e_m, e_0), for consumers that misperceive the true quality of both goods. There are also two equiprobable realisations for consumers with misperception of good 1, namely $(e_{0,}e_2)$, and (e_m, e_2). Similar results for good 2. The expected proportion of consumers that receive the correct information about the environmental quality of both goods is λ^2. Then, $(1-\lambda)^2$ consumers expect to receive wrong information about both goods, whereas $2\lambda(1-\lambda)$ consumers expect to receive wrong information about at most one of the goods.[7] The demand for good 1 is given by:

$$\begin{gathered} q_1 = \lambda^2 x_1(e_1, e_2) + \\ \frac{\lambda(1-\lambda)}{2}\left[x_1(e_1, e_m) + x_1(e_0, e_2) + x_1(e_1, e_0) + x_1(e_m, e_2)\right] + \\ \frac{(1-\lambda)^2}{4}\left[x_1(e_0, e_0) + x_1(e_m, e_0) + x_1(e_0, e_m) + x_1(e_m, e_m)\right]. \end{gathered} \tag{3}$$

We thus identify nine types of consumers according to the received signals: a fraction of fully aware consumers, four groups of partially aware consumers and four groups of consumers

[6]See among others, Banerjee (1992) and Bikhchandani et al. (1992) as important contributions in this literature.

[7]We develop an alternative model in AppendixA.16 using noisy signals. We show how the results qualitatively correspond to those proposed in Section 2 and 3.

with wrong signals in both goods. Substituting the demands (2) of each type into (3) yields:

$$q_i\left(p_i, p_j, e_i, e_j\right) = \frac{(1-\beta)\left[\alpha + \overline{e}\right] + \lambda\left(e_i - \beta e_j\right) - p_i + \beta p_j}{1-\beta^2}. \tag{4}$$

where $\overline{e} = \frac{1}{2}\left(e_m + e_0\right)$ denotes the average value of quality misperception. The demand function of firm i always increases when the average value, $\overline{e}$, rises. This is motivated by consumers' potential appetite for green product. For instance, the net utility of consumers, fully aware of the quality of goods 1 and 2, is given by:

$$U\left(x_1, x_2\right) = \left(\alpha + e_1^*\right) x_1 + \left(\alpha + e_2^*\right) x_2 - \frac{\left(x_1^2 + x_2^2 + 2\beta x_1 x_2\right)}{2} - p_1^* x_1 - p_2^* x_2. \tag{5}$$

Similar for the other fractions. Therefore, consumer surplus CS is represented by the weighted average of the aggregate utility of consumers' profiles. AppendixA.1 proposes a complete definition of Consumer Surplus and related computations.

The supply side is rather standard. Competition between firms is based on the choice of the environmental quality level, e_i and their prices.[8] We normalise marginal costs of production to zero, while fixed costs rise in quality:

$$C_i = e_i^2 \quad \forall i \in \{1, 2\} \tag{6}$$

Thus the profit of firm i is:

$$\pi_i = p_i q_i\left(p_i, p_j, e_i, e_j\right) - C_i. \tag{7}$$

According to Arora and Gangopadhyay (1995) and Bansal and Gangopadhyay (2003), we model a typical emission standard as the maximum level of emissions that is legally allowed

[8] Note that demand function takes into account both horizontal and vertical differentiation, while, the information technology is the same between firms.

to be produced by firms, i.e., $\overline{E} = \overline{E}_1 + \overline{E}_2$, where $\overline{E}_i = \overline{E}/2 > e_i$, $i \in \{1, 2\}$. Each firm i investing in environmental quality reduces total emissions of an amount, e_i, such that the *net* level of emission is $E = \overline{E} - (e_1 + e_2)$. Further, we assume $E > 0$. This assumption rules out the unrealistic case in which investing in green quality more than offsets pollution. Indeed although new technologies and cleaner fuel can help cut down emissions of pollutants into the atmosphere, in reality they do not eliminate completely the environmental damage.

This type of abatement technology is called *end-of-pipe* emissions. This technology limits emissions at the end of the manufacturing plants without modifying the main production process. Waste and emissions, for instance, are limited through filters and treatment units avoiding part of the potentially toxic processes and materials in the air.[9] An alternative approach to model abatement technology is called *cleaner production*, which entails an emissions reduction per-unit of output. In AppendixA.2, we show that our results, proposed here and in the next Section, are consistent with the alternative approach with a cleaner production technology. As standard in the literature, the environmental damage is assumed as a quadratic function of emissions, $D = dE^2$, where $d > 0$ represents the severity of damage.[10]

Thus social welfare is given by:

$$SW = \sum_{i}^{1,2} \pi_i + CS - D.$$

The timing of the game is as follows. In the first stage, firms choose the level of environmental quality. In the second stage, firms compete in prices.[11] The equilibrium concept is the subgame perfect equilibrium computed by backward induction.

[9]See, *inter alia*, Clemenz (2010), Christin *et al.* (2014) and Meunier and Nicolai (2013) for different applications of this procedure.

[10]For simplicity, we abstract away from spillovers in the industry.

[11]In AppendixA.15, we model an identical environment in the alternative case of Cournot competition confirming the results proposed in Section 3.

3. Baseline results

In the market stage, each firm i maximises profits with respect to p_i. By solving the system of first order conditions, we obtain the following equilibrium price,

$$p_i^*(e_i, e_j) = \frac{\left(2-\beta-\beta^2\right)\left[\alpha+\overline{e}\left(1-\lambda\right)\right]+\lambda\left[e_i\left(2-\beta^2\right)-\beta e_j\right]}{4-\beta^2}, \tag{8}$$

where $p_1^* = p_2^*$ if and only if $e_1 = e_2$. Eq. (8) is relevant in two respects. First, by looking at eq. (5), an increase in the perceived quality due to at least one of the signals, e_0 or e_m, positively influences consumer's willingness to pay for environmental quality and reflects higher marginal utility when she buys a green product. Indeed, through eq. (8), the larger is the quality misperception proxied by the average signal $\overline{e}$, the higher is the price that a firm can impose. This means that the average signal is characterized as a shifter raising the demand of each product. Second, eq. (8) even shows that the equilibrium price of firm i is decreasing in the quality level chosen by its rival e_j. In detail, when the rival's quality e_j increases the price p_i determined by quality e_i is monotonically reduced at equilibrium and the demand function of firm i is shifted down. This negative effect is higher, the larger the degree of the substitutability between the two goods, β. Equilibrium quantities, derived by the first order conditions of eq. (7), are consequently given by:

$$q_i^*\left(p_i^*(e_i, e_j), p_j^*(e_i, e_j)\right) = \frac{p_i^*}{1-\beta^2}. \tag{9}$$

Thus they have the same properties of prices with respect to e_j and $\overline{e}$. In the first stage, each firm i maximises its profit with respect to its environmental quality, e_i:

$$\max_{e_i} \pi_i = \frac{\left[p_i^*(e_i, e_j)\right]^2}{1-\beta^2} - C_i(e_i). \tag{10}$$

The first order condition yields the best reply function for firm i:

$$e_i\left(e_j\right) = e\left(0\right) - \frac{\lambda^2 \beta\left(2-\beta^2\right)}{\left(4-\beta^2\right)^2\left(1-\beta^2\right) - \lambda^2\left(2-\beta^2\right)^2} e_j, \tag{11}$$

where the denominator is always positive, while $e\left(0\right)$ is a constant function of the average signal of quality mispercetion $\overline{e}$ as follows:

$$e\left(0\right) = \frac{\lambda\left(2-\beta^2\right)\left(1+\beta\right)\left(1-\beta\right)\left[\left(1-\lambda\right)\overline{e}+\alpha\right]}{\left(4-\beta^2\right)^2\left(1-\beta^2\right) - \lambda^2\left(2-\beta^2\right)^2}, \tag{12}$$

Examining (10) reveals some comparative statics that are summarized in the following Lemma:

Lemma 1. $\forall\ \lambda^2 < \widehat{\lambda}^2$, *i) the problem of eq. (10) admits a maximum and ii)* $\frac{\partial e_i^*}{\partial e_j} < 0$, *such that green qualities are strategic substitutes.*

Proof. See AppendixA.3 for the definition of $\widehat{\lambda}^2$ and the proofs of point (i) and (ii). ■

Lemma 1 shows that when the group of perfectly informed consumers is not too large, i.e., $\lambda^2 < \widehat{\lambda}^2$, the second order condition of eq. (10) is negative, and therefore the concavity of the profit function is ensured. Further the same condition guarantees that $\frac{\partial e_i^*}{\partial e_j} < 0$ such that the environmental qualities are strategic substitutes. Interestingly, the marginal revenue of firm i decreases when the quality of firm j, e_j, increases. Given the values of λ and β, the difference in qualities, e_i and e_j, is a measure of the degree of product differentiation perceived by consumers, and meanwhile, it can also reveal how close substitute products are from firms' perspectives. Thus an increase of the environmental quality of the competitor decreases the marginal return of each firm in quality investment. Moreover, when the degree of substitutability β increases, the two products became more homogeneous and firms' profits necessarily decrease. Solving the system of (11), the equilibrium qualities, e_i^*, $\forall i \in \{1,2\}$, are symmetric:

$$e_i^* = \frac{\lambda\left(2-\beta^2\right)\left[\alpha + \overline{e}\,(1-\lambda)\right]}{(2-\beta)^2\,(1+\beta)\,(2+\beta) - \lambda^2\left(2-\beta^2\right)^2}. \tag{13}$$

As underlined in Section 2, the lower bound signal e_0 should be lower than the true quality signal, i.e., $e_i^* > e_0$ and this is possible if and only if,

$$e_0 < \widetilde{e}_0 \equiv \frac{\lambda\left(2-\beta^2\right)\left[e_m\,(1-\lambda) + 2\alpha\right]}{2\,(2-\beta)^2\,(1+\beta)\,(2+\beta) + \lambda\,(1+\lambda)\left(2-\beta^2\right)}. \tag{14}$$

Eq. (14) suggests that for any upper bound signal e_m, lower bound signal e_0 received by some uniformed consumers should not be too high. In particular, the difference between signals ranges within a certain threshold to guarantee that $e_i^* > e_0$. Note that consumers' perception of low environmental quality through e_0 still depends on the potential variation of the upper bound. Indeed, a further increase in the upper bound e_m rises the range of values of lower bound e_0 that satisfy eq. (14). Instead, according to eq. (13), we show that the symmetric outcome arises when the degree of substitution β is not too high. Note that the equilibrium outcome of a pure vertically differentiated duopoly model cannot realise as a limiting case of our model when β tends to 1. The demand systems are quite distinct to the case with only vertical differentiation. In our system, each consumer buys a variable quantity of both goods, whereas she buys a single unit of one good in the standard vertical differentiation models.[12] In equilibrium, firm i's prices and profits are respectively,

$$p_i^* = \frac{\left(1-\beta^2\right)\left(4-\beta^2\right)}{\lambda\left(2-\beta^2\right)} e_i^*, \tag{15}$$

and

$$\pi_i^* = \frac{\left(1-\beta^2\right)\left(4-\beta^2\right)^2 - \lambda\left(2-\beta^2\right)^2}{\lambda^2\left(2-\beta^2\right)^2} e_i^{*2}. \tag{16}$$

[12] See Gabszewicz and Thisse (1979, 1980) and Shaked and Sutton (1982), *inter alia*.

We are now in a position to examine the characteristics of the equilibrium. Let us begin the comparative statics by evaluating how a variation in the degree of substitutability influences the equilibrium quality. The following Lemma suggests that the equilibrium quality is inversely related to the degree of product substitutability,

Lemma 2. *The equilibrium level of environmental quality decreases with the degree of product substitutability.*

Proof. See AppendixA.4 ■

This means that an increase of product differentiation increases the level of environmental quality. The reason is that whether product differentiation increases, this rises consumers' gross utility and product demands with a positive effect on profits and quality.

Consider next the analysis of a variation in the average signal, $\bar{e}$. Differentiating the equilibrium qualities yields,

$$\frac{\partial e_i^*}{\partial \overline{e}} = \frac{\lambda (1-\lambda) \left(2-\beta^2\right)}{(2-\beta)^2 (1+\beta)(2+\beta) - \lambda^2 (2-\beta^2)} > 0. \tag{17}$$

The uncertainty about the value of the quality of a good has directly implications with personal misperception. In particular, given (17) together with (9), (15) and (16), it follows that:

Proposition 1. *Qualities, prices, quantities and profits in equilibrium increase in the average signal $\bar{e}$.*

Proof. See AppendixA.5 ■

Proposition 1 states that the higher the average signal received by consumers, the higher is the quality misperception they perceive. This rises the demand for firm's product and consequently firms' incentives to invest in environmental quality due to a positive shift in price at the equilibrium. In this case firms exploiting such wrong signals charge higher price to consumers, sell more and consequently make higher profits.

Let us consider also the particular case in which the average signal of quality misperception $\overline{e}$ coincides with the true quality, e_i^*, i.e., $\overline{e} = e_i^*$. We thus want to investigate the impact of misperception of quality whenever uniformed consumers have on average a correct perception of the true quality. This may be interpreted as a case of *partial* imperfect information rather different from the previous case of imperfect information in which uniformed consumers do not perceive on average the true quality, i.e., $\overline{e} \neq e_i^*$. The latter corresponds to the solution of eqs. (9), (15) and 16 in this Section. Formally, substituting $\overline{e}$ into (13), and solving for e_i^* yields,

$$e_i^{True} = \frac{\alpha\lambda\left(2-\beta^2\right)}{(1+\beta)(2+\beta)(2-\beta)^2 - (2-\beta^2)\,\lambda}. \tag{18}$$

Comparing eq. (13), e_i, with eq. (18), e_i^{True} and observing changes in profits, prices and quantity, we may show that,

Lemma 3. *Prices, quantities and profits are higher in case of full imperfect information if and only if* $\overline{e} > e_i^{True}$.

Proof. See AppendixA.6 ■

Under a certain condition, prices, quantities and profits are higher when imperfect information is totally in place, with respect to the case in which people receive on average the true signal, i.e., $\overline{e} = e_i^*$. This is possible whenever the average signal under *full* imperfect information, $\overline{e}$, is higher than the optimal quality chosen by firms in case of *partial*imperfect information, i.e., $\overline{e} > e_i^{True}$. This is the sufficient condition to ensure that the average signal acts as a complete demand shifter in consumers' utility function. This result is even confirmed by an alternative structure based on noisy signals, see in particular Lemma 6 of AppendixA.16. Intuitively, the result summarized in Lemma 3 suggests an interesting channel of modeling asymmetric information through signal process. As previously mentioned, firms exploit the potential misperception caused by not correct signals and charge higher price to consumers gaining larger profits. Firms take advantage from imperfect information, and in particular, the higher the quality misperception through $\overline{e}$, the larger the potential gains that each firm may have in terms of profits.

We are now ready to observe and compare the potential impact of regulatory interventions by taking into account some of the most important instruments used in environmental policy.

4. Regulatory interventions

As the literature suggests (e.g., *inter alia*, Frey *et al.*, 1985; Ulph, 1996; and Requate, 2005), the pool of environmental policy is rather extensive and includes several instruments from emissions taxes to tradable emissions. In a model of asymmetric information through signals, we focus on the potential impact of incentive-based instruments since they are the most interesting tools in a framework characterized by quality misperception. In particular, emission taxes and quality standards are widely considered as the most common policy instruments for regulation of environmental externalities.[13] We assume that the government cannot solve the consumers' information problem, but it is aware of the size and the composition of social welfare and it is able to enforce the standard.

4.1. Emissions Tax

We analyse the effect of introducing an emissions tax according to Chiou and Hu (2001), Petrakis and Xepapadeas (2001, 2003), Poyago-Theotoky (2007) and McDonald and Poyago-Theotoky (2016). In this view, a tax provides an incentive in abating polluting emissions in

[13]See Holland (2012) for some details on the role of these instruments.

order to reduce the tax burden. Both firms are rewarded by paying less when the optimal quality increases below the maximum level of emissions, E.

As a first step, let us observe the effect of exogenous emission tax and its effect on profits and qualities. Firm i's profit function is given by:

$$\pi_i = p_i q_i \left(p_i, p_j\right) - C_i - tE, \tag{19}$$

where taxation is a linear function of emissions E, and $t > 0$ is the unit tax. In turn, social welfare can be derived as follows,

$$SW = \sum\nolimits_{i}^{1,2} \pi_i + CS - D + T,$$

where $T = 2tE$ denotes total tax revenue. The market stage remains unchanged compared to the unregulated case. In the first stage, equilibrium qualities are:

$$e_i^{t*} = \frac{t\left(2-\beta\right)^2\left(1+\beta\right)\left(2+\beta\right) + 2\lambda\left(2-\beta^2\right)\left[\overline{e}\left(1-\lambda\right)+\alpha\right]}{2\left[\left(2-\beta\right)^2\left(1+\beta\right)\left(2+\beta\right) - \left(2-\beta^2\right)\lambda^2\right]}. \tag{20}$$

As expected, eq. (20) shows that an increase in emissions tax positively influences the optimal quality chosen by each firm. Further, a simple comparison with the previous unregulated case shows that,

$$e_i^* - e_i^{t*} = -\frac{t\left(2-\beta\right)^2\left(1+\beta\right)\left(2+\beta\right)}{2\left(2-\beta\right)^2\left(1+\beta\right)\left(2+\beta\right) - 2\lambda^2\left(2-\beta^2\right)} < 0. \tag{21}$$

The environmental quality is clearly higher in the regulated case compared to unregulated one proposed in the previous section, eq. (13). It follows that:

Proposition 2. *Qualities, prices, and quantities rise in equilibrium after the introduction of an emissions tax t.*

Proof. See AppendixA.7 ■

Interestingly, in accordance with Proposition 2, the primary result of introducing an emissions tax is the rise of the environmental quality optimally chosen by firms. This of course is the first natural effect of implementing such instruments. Note that there is also a secondary effect passing through consumers' welfare. Indeed, a rise in quality is associated to an increase in consumers' demand and this necessarily rises price and quantity at the equilibrium. The effect on profits are relatively different with respect to the unregulated case. In principle, we would expect a net reduction in profits after the introduction of the tax. Instead, we may observe that the profit levels are not monotonically decreasing in tax variations and an increasing margin of profit is possible if the maximum level of emissions legally allowed to be produced by firms, i.e., $\overline{E}$, is not too large. In particular,

Proposition 3. *Profits rise in equilibrium after the introduction of an emissions tax t if and only if $\overline{E} \leq \Xi$ where Ξ is defined in AppendixA.8.*

Proof. See AppendixA.8 ■

Intuitively, Proposition 3 suggests that the secondary effect that increases consumers' demand positively impact on firms' profits, whenever the maximum level of emissions exogenously taken is relatively low. This is no longer valid instead when the level of emission is higher than a certain level, Ξ. In this case the tax burden is so heavy, and consequently even the cost for unit of emission, that the profits start to decrease.

Next, we assume the introduction of an endogenous optimal tax. Suppose that there is a pre-stage where the government sets a Pigouvian tax with the aim to maximise social welfare. The first order condition of Social Welfare, SW, with respect to t yields the socially optimal tax t^*:

$$t^* = A + B\overline{e},$$

where A and B are defined in AppendixA.9, with $B > 0$ for $d \in \left(0, \widetilde{d}\right)$, where

$$\widetilde{d} \equiv \frac{\lambda\left[4-\lambda-\beta\left(4+\lambda-\beta\left(1+\lambda\right)\right)\right]}{4\left(2-\beta\right)^{2}\left(1-\beta^{2}\right)}-\frac{1}{2}.$$

Hence it follows that,

Proposition 4. *The level of optimal taxation increases with the average signal of environmental quality, $\overline{e}$, when $d < \widetilde{d}$.*

Proof. See AppendixA.9. ■

The results of Proposition 4 can be explained as follows. The effect of quality misperception through signal $\overline{e}$ on the optimal tax depends on the marginal damage of emissions and its impact on the demand function. In particular a large damage $d > \widetilde{d}$ negatively influences the demand through the endogenous tax rate. When the damage is not so high, i.e., $d \in \left(0, \widetilde{d}\right)$, then a higher level of misperception $\overline{e}$ increases the tax rate in order to ensure higher level of aggregate taxation. In the similar case with damage below $\widetilde{d}$ and a lower level of misperception $\overline{e}$, then a lower tax rate is necessarily required. Instead, in case of larger damage $d > \widetilde{d}$, a lower level of misperception $\overline{e}$ requires a higher tax rate in order to compensate the fall in aggregate taxation, due to the lower demand. Finally, $d > \widetilde{d}$ with a higher level of misperception $\overline{e}$ allows for a lower optimal taxation due to the higher demand.

4.2. Environmental standard

In this section, we introduce an environmental standard in the spirit of Motta and Thisse (1999) and Moraga-González and Padrón-Fumero (2002). The main purpose of this instrument is to set a minimum level of environmental quality requiring that a firm's output meet certain conditions, e. g., maximum emission rates or efficiency standards. We denote it as $\widehat{e} > e_0$, i.e., a predetermined value higher than the lower bound in misperception.[14] Whenever $\widehat{e} > e_0$, uninformed consumers who receive low quality information for good i revise

[14]This procedure is borrowed from Garella and Petrakis (2008).

their beliefs and update it to $e_0 = \widehat{e}$. This increases their willingness to pay for that product. Begin by evaluating how this influences the quality investment in equilibrium. Differentiating e_i^* with respect to e_0, it yields:

$$\frac{\partial e_i^*}{\partial e_0} = \frac{\lambda\left(2-\beta^2\right)(1-\lambda)}{2\left(2-\beta\right)^2\left[(1+\beta)(2+\beta)-2\lambda^2\right]} > 0. \tag{22}$$

This result implies that the environmental standard has a positive impact on firms' qualities satisfying the higher necessity of green products.

Proposition 5. *Introducing an environmental standard increases the quality investment of both firms.*

Proof. See AppendixA.10 ■

A larger willingness to pay of consumers influences in turn firms' incentives to invest in environmental quality. The implementation of a standard guarantees a large level of green type due to the exogenous threshold. With regards to the effect of substitutability among goods, we differentiate with respect to β as follows,

$$\frac{\partial e_i^*}{\partial e_0 \partial \beta} = -\frac{\lambda\left(8-8\beta-2\beta^2+8\beta^3+\beta^4-2\beta^5\right)(1-\lambda)}{2\left[8+4\beta-\beta^3+\beta^4-2\lambda^2-\beta^2\left(6-\lambda^2\right)\right]^2} < 0. \tag{23}$$

Eq. (23) suggests that the substitutability among goods β reduces the impact of this policy in the market. The lack of strategic effects implies that, even if the environmental standard succeeds in inducing cleaner products, its efficacy depends on the substitutability of products. Moreover, looking at eqs. (22) and (23), a higher willingness to pay for green products induces firms to invest in a higher level of quality. Let us evaluate next how the impact of the environmental standard influences qualities, prices, quantities and profits. Observing the role of the standard, it follows that:

Proposition 6. *Qualities, prices, quantities and profits rise in equilibrium if an environmental standard, $\widehat{e}$, is introduced such that $\widehat{e} > e_0$.*

Proof. See AppendixA.11. ■

Since the consumers' willingness to pay is higher in the regulated case compared to the unregulated one, their demand for both goods shifts up. Firms offer goods of higher quality, so that they can also charge higher prices. In turn profits increase.

Consider next the introduction of an endogenous environmental standard.[15] Suppose that there is a pre-stage in which the government sets an environmental standard $\widehat{e} > e_0$ so as to maximise social welfare. Consumers will update their evaluation of the lower bound of environmental quality, so that $e_0^* = \widehat{e}$ (see AppendixA.12 for the explicit derivation or e_0^*).

The first question is whether or not the introduction of an optimal environmental standard would *bite*, i.e., if it would influence the level of investment in environmental quality of the firm or not. In particular, the environmental standard bites if it is set at a higher quality level than the equilibrium quality adopted by firms in the unregulated case.

Comparing $\widehat{e}$ with e_i^*, i.e., the equilibrium quality in the unregulated case yields $\widehat{e} - e_i^* > 0$, for $e_m > \widetilde{e}_m$, where $\widetilde{e}_m$ is defined in AppendixA.12. Hence,

Proposition 7. *An optimal environmental standard bites only if the upper bound signal, e_m, is sufficiently high.*

Proof. See AppendixA.13. ■

Proposition 7 shows how the perception of environmental quality may influence the effectiveness of a policy based on environmental standards. In particular, when consumers' upper

[15] See Ecchia and Lambertini (1997) for an analysis of endogenous minimum quality standard.

bound, e_m, is high, then firms are willing to invest less in environmental quality. Finally, note that there is no trade-off between consumer surplus and damage function. This is due to the fact that the quality is green and consumers internalise its benefit in their utility function, so that incentives are aligned. This trade-off emerges in situations where quality is hedonistic rather than green. In this case, an increase in consumer surplus would imply higher emissions (Lambertini and Tampieri, 2012 and Ecchia *et al.*, 2013).

We then examine the introduction of an optimal environmental standard on the average signal, $\overline{e}$. Differentiating e_0^* with respect to $\overline{e}$ yields:

$$\frac{\partial \widehat{e}}{\partial \overline{e}} > 0, \tag{24}$$

for $d < \widehat{d}$ (see AppendixA.14 for the proof of eq. (24) and the definition of $\widehat{d}$). Equation (24) suggests that, if the marginal damage is relatively low, then the average misperception of the environmental quality increases the level of the optimal environmental standard. This also guarantees an effective policy by the government, since the optimal standard reacts to the level of misperception. The effect emerges only if the emissions are not so harmful. When $d > \widehat{d}$, the optimal standard is lower in order to keep the demand low. Indeed in case of large demand, it would harm considerably the environment due to higher marginal damage.

4.3. Tax vs standard

We now propose a simple simulation just to provide an example of the impact that the two policies may have on environmental quality. Unlike the case of perfect information, where the effect on qualities is analogous between the interventions (Holland, 2012), we show that misperception in qualities determines a different effect implementing an emission tax or a standard.

We compare the equilibrium qualities when either the optimal tax or the optimal environmental standard are applied. We allow the quality levels to change according to the marginal damage of emission d.[16] We assume generic values of parameters of the model: the proportion of consumers that recognise the quality of one good (λ) is equal to 0.3; the substitutability among goods, β, is assumed to be 0.2; while, the constant coefficient α is 10. Finally, since introducing the emission standard does not affect qualities whenever the overestimation is relatively low (see Proposition 7), we set the conditions on e_m such that the environmental standard is biting.

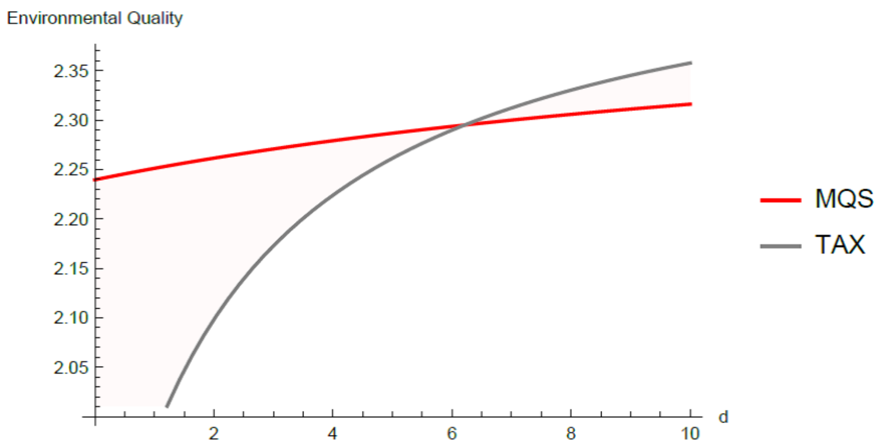

Figure 1: Tax vs Emission Standard - The effect on environmental quality

Figure 1 compares the effects of optimal tax rate and emission standard on environmental quality. Environmental quality is an increasing and concave function of marginal damage, d, in both cases. This means that both interventions exert an ongoing pressure on price competition and reduce the emissions of not eco-friendly products. However, we may observe that for lower level of damage, environmental standard ensures higher level of quality in case of misperception. Results changes for larger values of d while the emission tax guarantees higher level of environmental quality. This is clearly related on incentives that taxation imposes on firms' profits when damage increases. More in details, a standard rapidly rises

[16]Note that the simulation is valid for a given average level of quality misperception, $\bar{e}$.

the level of environmental quality and social welfare due to the application of a minimum threshold. This effect is relatively efficient when the damage is relatively low. When the damage is larger, the effect of a standard is reduced, while an emission tax becomes more effective due to positive incentives of increasing qualities received by firms. Similar analysis can be observed for social welfare. In figure 2, indeed, social welfare is a decreasing function of marginal damage in both cases. This is highly intuitive since communities suffer for the increasing environmental damage even in case of policy interventions. Note that social welfare is higher for a lower level of damage in case of environmental standard. Instead, when the level of damage is larger, social welfare is higher in case of taxation.

Interestingly, these results suggest a positive relationship between environmental quality and social welfare according to the regulating tool adopted. Note that for larger value of damage, quality increases in case of taxation and consequently social welfare is higher in this case with respect to the standard.

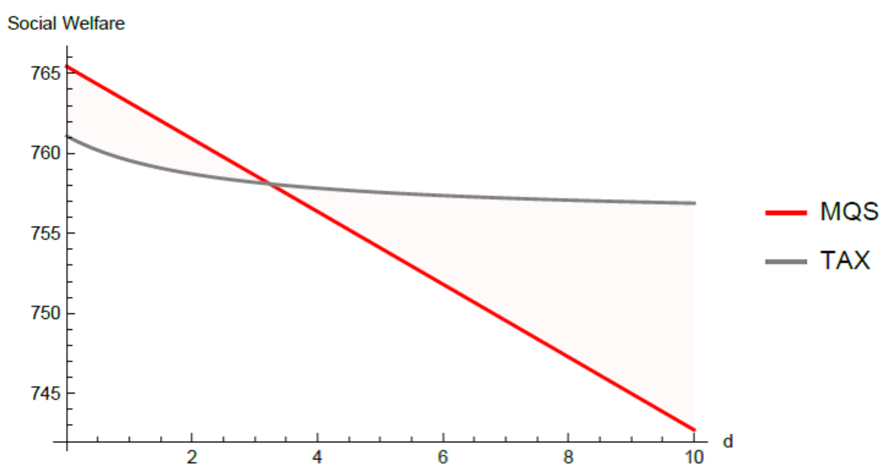

Figure 2: Tax vs Emission Standard - The effect on Social Welfare

5. Concluding remarks

We have analysed how environmental quality misperception influences the incentive to invest in cleaner production as regulatory interventions. Quality misperception is positively related to demands, true environmental qualities and profits. On the other hand equilibrium qualities decrease the more the goods are substitutes. The introduction of either a tax on emissions or an environmental standard raises the equilibrium quality. A simple simulation suggests that when the marginal damage is relatively lower, environmental standard ensures higher level of quality and social welfare. In case of larger damage, instead, emission tax seems to guarantee higher level of quality and welfare.

An important extension of the present analysis may take into account asymmetric technologies among firms. Our idea is that the importance of environmental perception is reduced whenever one firm is more efficient than the competitor. This proxies the market power of the efficient firm with higher profits as quality increases. Accordingly, the weight of overestimation in determining quality is relatively lower than in the symmetric case, since efficient firms may have higher profits than the one of its competitor. By the same token, the level of the average value of quality misperception has a lower weight for the efficient firm than for the inefficient one. It is higher in the presence of an environmental standard rather than with a tax on emission, since the former policy does not affect production costs. The analysis with asymmetric technology among firms may constitute a fertile ground for future research.

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AppendixA. Appendix

AppendixA.1. Consumer surplus

Consumer surplus is determined by evaluating the sum of utilities:

$$\begin{aligned} CS &= \frac{1}{1-\beta^2}\left[2\left(p_1^{*2}+p_2^{*2}+e_m^2\right)+4\alpha\left(1-\beta\right)\left(\alpha+e_m+e_0\right)-2p_2^*\left(2\alpha+e_m+e_0\right)\left(1-\beta\right)+\right. \\ & -\beta\left(e_0+e_m\right)^2-2p_2^*\lambda\left(2e_2^*-\left(e_m+e_0\right)\left(1-\beta\right)-2e_1\beta\right)+ \\ & -2\lambda\left(\left(e_m+e_0-e_1^*-e_2^*\right)\left(e_m+e_0-e_1^*-e_2^*-\beta\left(2\alpha+e_m+e_0\right)-2\alpha\right)\right)+ \\ & -\lambda^2\beta\left(e_m+e_0-2e_1^*\right)\left(e_m+e_0-2e_2^*\right) \\ & \left.-2p_1^*\left(\left(e_m+e_0\right)\left(1-\beta\right)\left(1-\lambda\right)+2\left(\alpha+p_2^*\beta+e_1^*\lambda-\alpha\beta-e_2^*\lambda\beta\right)\right)\right]. \end{aligned}$$

AppendixA.2. Cleaner production technology

In this appendix, we examine the baseline results when the technology of abatement entails a per-unit of output reduction emission. Due to cleaner technology, the firm i abatement cost is $C_i^{cl}\left(e_i\right)=q_i e_i^2$, where superscript *cl* stands for *cleaner* production. Market competition in the second stage yields,

$$p_i^{cl}=\frac{\left[\alpha+\overline{e}(1-\lambda)\right]\left(2-\beta^2-\beta\right)+e_1\left[2e_1+\left(2-\beta^2\right)\lambda\right]-e_2\beta\left(e_2+\lambda\right)}{4-\beta^2}.$$

In the first stage, each firm i maximises its profit with respect to its environmental quality e_i,

$$\max_{e_i}\pi_i=\frac{\left[q_i^*\left(e_i,e_j\right)\right]^2}{1-\beta^2}-C_i^{cl}\left(e_i\right).$$

The first order condition of π_i with respect to e_i yields:

$$\frac{\partial \pi_i}{\partial e_j} = \frac{2\left(2-\beta^2\right)\left(2e_i-\lambda\right)}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)} \times \tag{A.1}$$

$$\left[-\alpha\beta^2-\alpha\beta+2\alpha+\left(\beta^2-2\right)e_i^2-\left(\beta^2-2\right)e_i\lambda+\beta e_j^2-\beta e_2\lambda+\left(2-\beta-\beta^2\right)\overline{e}(1-\lambda)\right]=0.$$

The second order conditions of π_i with respect to e_i yields:

$$\frac{\partial^2 \pi_i}{\partial e_j^2} = \frac{2\left(\beta^2-2\right)\left(-2\alpha\beta^2-2\alpha\beta+4\alpha+\beta^2\lambda^2+6\left(\beta^2-2\right)e_i^2\right)}{\left(\beta^2-4\right)^2\left(1-\beta^2\right)}+$$

$$\frac{2\left(\beta^2-2\right)\left(6\left(2-\beta^2 2\right)e_i\lambda+2\beta e_j^2-2\beta e_i\lambda+2\left(\beta^2+\beta-2\right)\overline{e}(\lambda-1)-2\lambda^2\right)}{\left(\beta^2-4\right)^2\left(1-\beta^2\right)}<0,$$

for $e_i \in \left(e_i^b, e_i^a\right)$, where

$$e_i^a \equiv \left.\frac{6\lambda-3\beta^2\lambda+\sqrt{3}\sqrt{\left(\beta^2-2\right)\left(4\alpha\left(\beta^2+\beta-2\right)+\beta^2\lambda^2-4\beta e_j^2+4\beta e_j\lambda-4\left(\beta^2+\beta-2\right)\overline{e}(\lambda-1)-2\lambda^2\right)}}{6\left(2-\beta^2\right)}\right|_{e_j=e_j^{cl}},$$

$$e_i^b \equiv \left.\frac{6\lambda-3\beta^2\lambda-\sqrt{3}\sqrt{\left(\beta^2-2\right)\left(4\alpha\left(\beta^2+\beta-2\right)+\beta^2\lambda^2-4\beta e_j^2+4\beta e_j\lambda-4\left(\beta^2+\beta-2\right)\overline{e}(\lambda-1)-2\lambda^2\right)}}{6\left(2-\beta^2\right)}\right|_{e_j=e_j^{cl}},$$

and e_j^{cl} is firm j's optimal investment in green quality (see below).

As in the baseline model we investigate the solution of the green quality by studying the map of the reaction functions. Following Bulow *et al.* (1985), we know that the nature of strategic interaction is entirely determined by the sign of the partial derivatives of FOCs with respect to the competitor's green quality, which ultimately yields the slopes of reaction functions $e_i^*(e_j)$. These derivatives are:

$$\frac{\partial e_i^*(e_j)}{\partial q_j} \propto \frac{\partial^2 \pi_i}{\partial e_i \partial e_j} = \frac{2\beta\left(\beta^2-2\right)(2e_i-\lambda)(\lambda-2e_j)}{\left(4-\beta^2\right)^2(1-\beta^2)},$$

which is always positive as in the symmetric equilibrium, $e_i = e_j$. Hence the strategic nature of environmental quality with cleaner production is qualitatively similar to the case with end-of-pipe production.

Lemma 4. *Suppose that firms adopt a cleaner production technology. Then green qualities are strategic substitutes.*

Solving the system of FOCs given by (A.1), the equilibrium qualities are:

$$e_i^{cl} = \frac{1}{2}\left(\sqrt{4(\alpha+\overline{e})-4\overline{e}\lambda+\lambda^2}+\lambda\right).$$

An alternative equilibrium result is $e_i^{cl} = \lambda/2$ which entails non-strategic interaction among firms and it is thus set aside. Condition $e_i^{cl} > e_0$ holds for

$$e_0 < e_0^{cl} \equiv \frac{1}{4}\left(1+\lambda+\sqrt{16\alpha-8e_m(\lambda-1)+(\lambda+1)^2}\right).$$

Let us turn now on the comparative statics of e_i^{cl}. Unlike the case with the end-of-pipe production, differentiation of e_i^{cl} with respect to β yields $\partial e_i^{cl}/\partial\beta = 0$ such that optimal investment in green quality is insensitive to horizontal product differentiation with cleaner production. Conversely, differentiating the equilibrium qualities yields

$$\frac{\partial e_i^{cl}}{\partial \overline{e}} = \frac{1-\lambda}{\sqrt{4\alpha+4\overline{e}(1-\lambda)+\lambda^2}} > 0,$$

which exhibits the same sign as in the baseline case of end of pipe emissions. Therefore the results in Proposition 1 in the main text are confirmed also in case of cleaner production.

AppendixA.3. Proof of Lemma 1

The second order conditions of π_i with respect to e_i yields:

$$\frac{\partial^2 \pi_i}{\partial e_i^2} = \frac{2\lambda^2 \left(2-\beta^2\right)^2}{\left(4-\beta^2\right)^2 \left(1-\beta^2\right)} - 2 < 0, \tag{A.2}$$

while the derivative of the optimal quality, e_i^*, with respect to e_j,

$$\frac{\partial e_i^*}{\partial e_j} = \frac{\lambda^2 \beta \left(2-\beta^2\right)}{\left(4-\beta^2\right)^2 \left(1-\beta^2\right) - \lambda^2 \left(2-\beta^2\right)^2} < 0 \tag{A.3}$$

if and only if,

$$\lambda^2 < \widehat{\lambda}^2 \equiv \frac{\left(4-\beta^2\right)^2 \left(1-\beta^2\right)}{\left(2-\beta^2\right)^2}. \tag{A.4}$$

The problem admits a maximum when the group of consumers who perfectly receive the signal, e_i, is not too large. This means that condition (A.4) ensures the second order condition of eq. (10) is negative and concavity of the profit function is satisfied. Moreover, condition (A.4) guarantees downward sloping best replies such that the qualities are strategic substitutes. Note however that $\widehat{\lambda}^2|_{\beta \to 1} = 0$ means that eq. (A.4) is not more satisfied and consequently even eqs. (A.2) and (A.3) do not hold.

AppendixA.4. Proof of Lemma 2

Differentiating e_i^* with respect to β yields:

$$\frac{\partial e_i^*}{\partial \beta} = \frac{\lambda \left(8 - 8\beta - 2\beta^2 + 8\beta^3 + \beta^4 - 2\beta^5\right) \left[\left(e_m + e_0\right)\left(1-\lambda\right)/2 + 2\alpha\right]}{2\left[8 + 4\beta - \beta^3 + \beta^4 - 2\lambda^2 - \beta^2\left(6 - 2\lambda^2\right)\right]^2} < 0.$$

This means that an increase in product differention, i.e., $\beta \to 0$, increases the environmental quality optimally chosen by firms. In other words, environmental quality decreases with the degree of substitutability.

AppendixA.5. Proof of Proposition 1

Looking at eqs. (9), (15) and (16), we note that prices, quantities and profits at the equilibrium are increasing in signal e_i^*. Then since eq. (15) is always satisfied, this proves the last part of Proposition.

AppendixA.6. Proof of Lemma 3

Let us first denote, respectively, prices, quantities and profits when $\overline{e} = e_i^*$. Note that in this particular case, uniformed consumers capture on average the correct quality signal, e_i^*. The environmental quality optimally chosen by firm i, is e_i^{True}, as proposed in eq. (18). Hence, it follows that,

$$\begin{aligned} p_i^{True} &= p_i^*|_{e_i^{True}} , \\ q_i^{True} &= q_i^*|_{e_i^{True}} , \\ \pi_i^{True} &= \pi_i^*|_{e_i^{True}} , \end{aligned}$$

We compare these values of price, quantity and profit of firm i with respect to the values of price, quantity and profit of firm i when $\overline{e} \neq e_i^*$, as proposed in eqs. (15), (9) and (16). It follows that if $\overline{e} > e_i^{True}$, then

$$p_i^* - p_i^{True} = \frac{(1-\beta)(1-\lambda)\left[\left(\beta^2-2\right)\lambda(\alpha+\overline{e}) + (\beta+1)(\beta+2)(\beta-2)^2\overline{e}\right]}{(2-\beta)\left[\left(\beta^2-2\right)\lambda + (\beta+1)(\beta+2)(\beta-2)^2\right]} > 0$$

and,

$$q_i^* - q_i^{True} = \frac{(\lambda-1)\left(\left(\beta^2-2\right)\lambda(\alpha+\overline{e}) + (\beta+1)(\beta+2)(\beta-2)^2\overline{e}\right)}{(\beta-2)(\beta+1)\left(\left(\beta^2-2\right)\lambda + (\beta+1)(\beta+2)(\beta-2)^2\right)} > 0$$

and finally,

$$\pi_i^* - \pi_i^{True} = -\frac{(\lambda-1)\left(\left(\beta^2-2\right)^2\lambda^2+\left(\beta^2-1\right)\left(\beta^2-4\right)^2\right)\left(\left(\beta^2-2\right)\lambda(\alpha+\overline{e})+(\beta+1)(\beta+2)(\beta-2)^2\overline{e}\right)}{\left(\left(\beta^2-2\right)\lambda+(\beta+1)(\beta+2)(\beta-2)^2\right)^2\left(\left(\beta^2-2\right)\lambda^2+(\beta+1)(\beta+2)(\beta-2)^2\right)}\times$$

$$\frac{\left(\alpha\left(-2\beta^4+2\beta^3-\beta^2(\lambda-3)(\lambda+4)-8\beta+2\left(\lambda^2+\lambda-8\right)\right)+\overline{e}(\lambda-1)\left(\left(\beta^2-2\right)\lambda+(\beta+1)(\beta+2)(\beta-2)^2\right)\right)}{\left(\left(\beta^2-2\right)\lambda+(\beta+1)(\beta+2)(\beta-2)^2\right)^2\left(\left(\beta^2-2\right)\lambda^2+(\beta+1)(\beta+2)(\beta-2)^2\right)} > 0$$

The results suggest that prices, quantities and profits are higher when imperfect information is totally in place, i.e., $\overline{e} \neq e_i^*$ if and only if the average quality signal, $\overline{e}$, in case of a *full* imperfect information, $\overline{e} \neq e_i^*$, is higher than the optimal quality in case of *partial* imperfect information, $\overline{e} = e_i^*$, in which consumers on average correctly identify the true quality.

AppendixA.7. Proof of Proposition 2

The proof is easily derived by combining the effects of eqs. (17) and (21) on eqs. (9), (15).

AppendixA.8. Proof of Proposition 3

We now discover that it exists a threshold such that the profits may increase if the maximum level of emission is relatively low. By differentiating profits with respect to t yields

$$\frac{\partial \pi_i^*}{\partial t} = \frac{2(1+\beta)(2+\beta)(2-\beta)^2 t\left[3(1+\beta)(2+\beta)(2-\beta)^2-\left(6+\beta-3\beta^2\right)\lambda^2\right]}{4\left[\left(\beta^2-2\right)\lambda^2+(\beta+1)(\beta+2)(\beta-2)^2\right]^2}+$$

$$-\frac{4\lambda\left[2\left(2-\beta^2\right)^2\lambda^2+(\beta+1)(\beta+2)\left(2\beta^2+\beta-4\right)(\beta-2)^2\right]\left[\overline{e}(1-\lambda)+\alpha\right]}{4\left[\left(\beta^2-2\right)\lambda^2+(\beta+1)(\beta+2)(\beta-2)^2\right]^2}+$$

$$-\frac{4\overline{E}\left[(1+\beta)(2+\beta)(2-\beta)^2-\left(2-\beta^2\right)\lambda^2\right]^2}{4\left[\left(\beta^2-2\right)\lambda^2+(\beta+1)(\beta+2)(\beta-2)^2\right]^2} > 0, \tag{A.5}$$

for $\overline{E} \leq \Xi$ where

$$\Xi \equiv \frac{(\beta+1)(\beta+2)(\beta-2)^2 t\left[(\beta(3\beta-1)-6)\lambda^2+3(\beta+1)(\beta+2)(\beta-2)^2\right]}{2\left[(\beta+1)(\beta+2)(\beta-2)^2-\left(2-\beta^2\right)\lambda^2\right]^2}+$$

$$-\frac{2\lambda\left[2\left(\beta^2-2\right)^2\lambda^2+(\beta+1)(\beta+2)\left(2\beta^2+\beta-4\right)(2-\beta)^2\right](\overline{e}(1-\lambda)+\alpha)}{2\left[(\beta+1)(\beta+2)(\beta-2)^2-\left(2-\beta^2\right)\lambda^2\right]^2}.$$

such that this threshold is the maximum level of emission to ensure the positivity of eq. (A.5).

AppendixA.9. Proof of Proposition 4

By computing the first order condition of the social welfare function SW with respect to t yields,

$$t^* = A + \overline{e}B,$$

which is a linear form describing the optimal level of taxation, In particular, note that it is composed by two parts where the first part, A, is independent by $\overline{e}$. It follows that:

$$A = \frac{4d\overline{E}\left(2+\beta-\beta^2\right)^2\left(2-\beta-\beta^2\right)+2\alpha\lambda\left(1-\beta^2\right)\left[2-\beta-4d\left(2-\beta^2\right)\right]+2\lambda^2\left(2-\beta^2\right)\left[\alpha-2d\overline{E}\left(1-\beta^2\right)\right]+2\alpha\lambda^3}{2\left(1+2d\right)\left(2+\beta-\beta^2\right)^2\left(2-\beta-\beta^2\right)-\lambda\left(2-\beta\right)^2\left(1+\beta\right)\left(2+\beta\right)+\lambda^2\left(1+\beta\right)\left(2+\beta\right)\left[1+\beta\left(1-\beta\right)\right]},$$

$$B = \frac{2\lambda\left(1-\lambda\right)\left[6+4d\left(2-3\beta^2+\beta^4\right)-2\lambda+\beta\left(5-\beta\left(4+\beta\left(2-\beta\right)-\lambda\right)\right)\right]}{2\left(1+2d\right)\left(2+\beta-\beta^2\right)^2\left(2-\beta-\beta^2\right)-\lambda\left(2-\beta\right)^2\left(1+\beta\right)\left(2+\beta\right)+\lambda^2\left(1+\beta\right)\left(2+\beta\right)\left[1+\beta\left(1-\beta\right)\right]}.$$

We then investigate how a change in the perception of environmental quality would influence the optimal level of taxation. By differentiating t^* with respect to the average signal $\overline{e}$, it yields $\partial t^*/\partial \overline{e} = B > 0$ if and only if,

$$d < \widetilde{d} \equiv \frac{\lambda \left[4 - \lambda - \beta \left(4 + \lambda - \beta \left(1 + \lambda\right)\right)\right]}{4 \left(2 - \beta\right)^2 \left(1 - \beta^2\right)} - \frac{1}{2}.$$

AppendixA.10. Proof of Proposition 5

The result is easily derived by looking at the comparative statics of eq. (22).

AppendixA.11. Proof of Proposition 6

The proof is easily derived by combining the effects of eqs. (17) and (22) on eqs. (9), (15) and (16).

AppendixA.12. Characterization of the Endogenous Standard

A similar approach to the one proposed in Proposition 4 shows that the first order condition of SW with respect to e_0 yields:

$$e_0^* = C + e_m F, \tag{A.6}$$

which is a linear form describing the optimal level of quality. In particular, note that it is composed by two parts where the first part, C, is independent by e_m. It follows that:

$$C = \frac{2}{(2 - \beta^2)} \frac{\Phi - \Psi}{\Lambda - \Gamma} \quad \text{and} \quad F = \frac{1}{(2 - \beta^2)} \frac{F}{\Lambda - \Gamma}$$

where variables Φ, Ψ, Λ, Γ, $\digamma$ respectively indicating,

$$
\begin{aligned}
\Phi &= 2d\lambda\bar{e}\left(1-\beta\right)\left(2-\beta^2\right)\left(2+\beta\right)\left(2+\beta-\beta^2\right)^2\left(2-\beta^2\right)-\alpha\left(2-\beta\right)^2\left(1-\beta\right)\left(1+\beta\right)^2\left(2+\beta\right)^2\left(3-2\beta\right)\\
\Psi &= \alpha\lambda^2\left(1+\beta\right)\left(2-\beta^2\right)\left[12+4d\left(1-\beta\right)\left(2-\beta^2\right)-\beta\left(8-\beta\left(4-3\beta\right)\right)\right]-\lambda^3\left(2-\beta^2\right)^2\left[\alpha-2d\bar{e}\left(1-\beta^3\right)\right]\\
\Lambda &= 2\lambda^2\left(1+\beta\right)\left[18+2d\left(1-\beta\right)\left(2-\beta^2\right)-\beta\left(10-\beta\left(5-3\beta\right)\right)\right]-\left(1+\beta\right)^2\left[7-3\beta\left(3-\beta\right)+\lambda\left(1+\beta\left(1-\beta\right)\right)\right]\\
\Gamma &= \lambda^3\left[3-2\beta^2+4d\left(1-\beta^2\right)\right]+\lambda^4\\
\digamma &= 2\lambda^2\left(1+2d\right)\left(2-\beta\right)^2\left(1-\beta^2\right)-\left(1-\lambda\right)\left[\left(2-\beta\right)^2\left(1+\beta\right)^2\left(2+\beta\right)^2\left(1+\beta\left(1-\beta\right)\right)\right]-\lambda^3\left(2-\beta^2\right)^2 \qquad \text{(A.7)}
\end{aligned}
$$

AppendixA.13. Proof of Proposition 7

As mentioned in the main text, introducing an endogenous standard requires that consumers update their evaluation of lower bound such that $\widehat{e}=e_0^*$ as shown in eq. (A.6). Then, comparing $\widehat{e}$ with e_i^*, i.e., the equilibrium quality in the unregulated case yields $\widehat{e}-e_i^*>0$, for $e_m>\widetilde{e}_m$, where $\widetilde{e}_m$ is defined as follows,

$$\widetilde{e}_m \equiv \frac{\chi+\psi}{\varrho+\vartheta}$$

Note that all variables χ,ψ, ϱ,ϑ respectively indicate

$$
\begin{aligned}
\chi &= 2\alpha\left(1-\beta\right)\left(1+\beta\right)\left(3-2\beta\right)\left(4-\beta^2\right)^2+\lambda\left(2-\beta\right)^2\left(2+\beta\right)\left(2-\beta^2\right)\left[\alpha+4d\bar{e}\left(1-\beta^2\right)\right]\\
\psi &= \lambda^2\left(2-\beta^2\right)\left[2d\left(\bar{e}+4\alpha\right)\left(1-\beta\right)\left(2-\beta^2\right)+\alpha\left[16-\beta\left(12-\beta\left(6-5\beta\right)\right)\right]\right]-2d\bar{e}\lambda^3\left(1-\beta\right)\left(2-\beta^2\right)^2\\
\varrho &= \left(1+2\beta-\beta^3\right)\left(4-\beta^2\right)^2-\lambda^2\left(2-\beta\right)^2\left(2+\beta\right)\left[4+\beta\left(5-\beta\left(1-\beta\left(2+\beta\right)\right)\right)\right]\\
\vartheta &= \lambda^2\left(2-\beta^2\right)\left[12+4d\left(1-\beta\right)\left(2-\beta^2\right)-\beta\left[8-\beta\left(4-3\beta\right)\right]\right]-2\lambda^3\left(1+2d\right)\left(1-\beta\right)\left(2-\beta^2\right)^2 \qquad \text{(A.8)}
\end{aligned}
$$

AppendixA.14. Proof of eq. (24)

Given eq. (A.6), it can be easily shown that $\frac{\partial e_0^*}{\partial e_m} = F$. Note that this is positive if and only if $d < \widehat{d}$ where,

$$\widehat{d} \equiv \frac{(2-\beta)^2(1+\beta)^2(2+\beta)^2\left[7-3\beta(3-\beta)+\lambda(1+\beta(1-\beta))\right]}{4\lambda^2(2-\beta^2)^2(1-\beta^2)(1-\lambda)} + \tag{A.9}$$

$$+\frac{\lambda^3\left(3-2\beta^2\right)\left(2-\beta^2\right)^2-2\lambda^2(1+\beta)\left(2-\beta^2\right)\left[18-\beta(10+\beta(5-3\beta))\right]}{4\lambda^2(2-\beta^2)^2(1-\beta^2)(1-\lambda)}$$

AppendixA.15. Quantity competition

In this section we consider how the type of competition affects the baseline results by assuming Cournot competition. By (4), the i's inverse demand function is,

$$p_i = \frac{1}{2}\left[2\alpha - \lambda(e_0 - 2e_i + e_m) + e_0 + e_m - 2q_i - 2\beta q_j\right].$$

In the second stage, maximising profits with respect to q_i and using $\overline{e} = \frac{1}{2}(e_m + e_0)$ yields,

$$q_i^* = \frac{2(2-\beta)\left[\alpha + \overline{e}(1-\lambda)\right] + 2\lambda(2e_i - \beta e_j) + (2-\beta)}{2(4-\beta^2)}$$

In the first stage, each firm i maximises its profit with respect to its environmental quality e_i such that,

$$\max_{e_i} \pi_i = \frac{\left[q_i^*(e_i, e_j)\right]^2}{1-\beta^2} - C_i(e_i, e_j).$$

The first order condition yields the best reply function for firm i:

$$e_i(e_j) = e_c(0) - \frac{2\lambda^2\beta}{(4-\beta^2)^2 - 4\lambda^2} e_j,$$

where

$$e_c(0) = \frac{\lambda(2-\beta)(2\alpha + (e_0 + e_m)(1-\lambda))}{(4-\beta^2)^2 - 4\lambda^2}. \tag{A.10}$$

The second order conditions of π_i with respect to e_i yields:

$$\frac{\partial^2 \pi_i}{\partial e_i^2} = \frac{8\lambda^2}{(4-\beta^2)^2} - 2 < 0,$$

for

$$\lambda^2 < \widehat{\lambda}_c^2 \equiv \frac{(4-\beta^2)^2}{4},$$

implying that (A.10) is positive. Following a similar reasoning as in the case with price competition we get,

Lemma 5. *Suppose that firms compete in quantities. Then green qualities are strategic substitutes.*

Solving the system of (11), the equilibrium qualities are:

$$e_i^* = \frac{\lambda^2(e_0 + e_m) - \lambda(2\alpha + e_0 + e_m)}{(\beta-2)(\beta+2)^2 + 2\lambda^2}.$$

Condition $e_i^* > e_0$ holds for,

$$e_0 < \widetilde{e}_0 \equiv \frac{\lambda(e_m(\lambda - 1) - 2\alpha)}{(\beta-2)(\beta+2)^2 + \lambda^2 + \lambda}.$$

Differentiating e_i^* with respect to β yields,

$$\frac{\partial e_i^*}{\partial \beta} = \frac{2(\beta+2)(3\beta-2)\lambda\left[\alpha + (e_0 + e_m)(1-\lambda)\right]}{\left[2\lambda^2 - (2-\beta)(\beta+2)^2\right]^2} > 0,$$

for $\beta > 2/3$. When substitution is sufficiently high the investment in quality increases compared to the case of price competition.

Consider next the analysis of a variation in the average perception of environmental quality. Differentiating the equilibrium qualities,

$$\frac{\partial e_i^*}{\partial \overline{e}} = \frac{2(1-\lambda)\lambda^2}{(2+\beta)\left[(2-\beta)(2+\beta)^2 - 2\lambda^2\right]} > 0.$$

The results in Proposition 1 are then confirmed even in an environment with quantity competititon.

AppendixA.16. An alternative framework for quality misperception

Here, we propose a similar model to the one proposed in Sections 2 and 3 with an alternative structure of signals. The aim is to show the relative robustness of our analysis about quality misperceptions, their relation and the effect on demands and consequently on prices, quantity and profits.

Let us consider a market for differentiated goods with two firms, 1 and 2, and a continuum of consumers indexed by the unit interval $[0,1]$. A consumer's consumption profile $\mathbf{x} = (x_1, x_2)$ yields gross utility $U(\mathbf{x}) = \sum_i^{1,2} u_i(\mathbf{x})$ where for each product $i \in \{1,2\}$,

$$u_i(\mathbf{x}) = x_i \left(e_i - \frac{x_i + \beta x_j}{2} \right) \tag{A.11}$$

where e_i identifies the environmental quality of good i and, $\beta \in [0,1]$ is the degree of product differentiation between the two goods. When $\beta = 0$, the goods are independent, and when $\beta = 1$, the goods are perfect substitutes. Facing a consumption profile $\mathbf{p} = (p_1, p_2)$**,** the representative consumers maximizes consumer surplus, $U(\mathbf{x}) - \sum_i^{1,2} p_i x_i$. Solving this problem we determine the demand functions for both goods, x_i, $\forall i \in \{1,2\}$, as follows:

$$x_i(p_i, p_j, e_i, e_j) = \frac{(e_i - p_i) - \beta(e_j - p_j)}{1-\beta^2}, \quad j \in \{1,2\}, \quad j \neq i. \tag{A.12}$$

Market conditions are determined by the environmental quality of each product, e_i, $\forall i \in$

$\{1,2\}$. Without loss of generality, we assume that a share of consumers $\zeta \in [0,\lambda]$ receives a perfect signal $s_i = e_i \; \forall i \in \{1,2\}$ of the environmental quality, while the remaining consumers $\zeta \in (\lambda, 1]$ shares a common prior $e_i \sim N\left(\bar{e}, \sigma_e^2\right)$ and must rely on a imperfect signal of environmental quality for each product,[17]

$$s_i = e_i + \varepsilon \qquad \text{where } \varepsilon \sim N(0, \sigma_\varepsilon^2)$$

Signals of distinctive qualities are independent and the distribution of such signals is exogenously given. Observe that each signal s_i deviates from the true quality e_i by an independent error term with normal distribution. Parameters σ_e^2 and σ_ε^2 are the variances of the common prior and the noise. The demand for good $i \in \{1,2\}$ is thus given by:

$$q_i = \lambda x_i\left(e_i, e_j\right) + (1-\lambda) x_i\left(s_i, s_j\right) \tag{A.13}$$

Substituting the demands (A.12) of both informed and uniformed consumers into (A.13) yields:

$$q_i\left(p_i, p_j, e_i, e_j, s_i, s_j\right) = \frac{\lambda\left(e_i - \beta e_j\right) + (1-\lambda)\left[s_i - \beta s_j\right] - p_i + \beta p_j}{1-\beta^2} \tag{A.14}$$

where $s_i - \beta s_j$ denotes the difference in misperceptions between products. The demand function of firm i is influenced by the vector of signals $\mathbf{s} = \left(s_i, s_j\right)$ and can be higher or lower than the case of perfect information. This effect depends on the value of common prior position. When uniformed consumers have a prior on average higher than the true quality e_i, then the misperception on environmental quality acts as a demand shifter at the equilibrium creating incentives to consumers to buy green products.

Lemma 6. *Quality misperceptions originated by signals vector* $\mathbf{s} = \left(s_i, s_j\right)$ *increase demand*

[17] See Morris and Shin (2002).

functions when $\bar{e} \geq e_i$

Proof. The aim of the proof is to observe the potential increase in demand of good i since some consumers misperceive the true quality through noise signal. The simplest way to observe this effect is to compare the demand shifter in case of imperfect information comparing it to the case of perfect information at the equilibrium. In particular, eq. (A.12) shows on the left hand side the demand shifter when some consumers are uniformed, i.e., $\zeta \in (\lambda, 1]$, and perceive signals on products, while the right hand side refers to the case of perfect information where all consumers observe the true qualities. It follows that misperception increases demand when,

$$\lambda\left(e_i - \beta e_j\right) + (1-\lambda)\left[s_i - \beta s_j\right] \geq \left(e_i - \beta e_j\right) \tag{A.15}$$

while rearranging,

$$\left[s_i - \beta s_j\right] \geq \left(e_i - \beta e_j\right)$$

Let us compute the expectations and variances for the two cases:

$$\mathbb{E}_i\left[e_i - \beta e_j + (1-\beta)\varepsilon\right] \geq \mathbb{E}_i\left[e_i - \beta e_j\right]$$

such that:

$$\mathbb{E}_i\left[e_i\right] - \beta\mathbb{E}_i\left[e_j\right] + (1-\beta)\mathbb{E}_i\left[\varepsilon\right] \geq e_i - \beta e_j$$

where $\mathbb{E}_i\left[e_j\right] = \mathbb{E}_i\left[e_i\right]$ for the common prior $e_i \sim N\left(\bar{e}, \sigma_e^2\right)$. Further,

$$(1-\beta)\bar{e} \geq e_i - \beta e_j$$

and at the symmetric equilibrium in the first stage, i.e., $e_i = e_j$,

$$\bar{e} \geq e_i$$

which is the sufficient condition to obtain an increase in demand function due to misperception on quality. Moreover, it can be easily observable that the variance is higher when consumers misperceive environmental quality,

$$var\left[e_i - \beta e_j + (1-\beta)\varepsilon\right] \geq 0$$

and simplifying,

$$(1-\beta)(\sigma_e^2 + \sigma_\varepsilon^2) \geq 0$$

naturally the variance in case of imperfect information is positive. ■

This result is similar to the one proposed in the main text as a function of the average signal, $\bar{e}$ (see Section 2 for further details). In particular, it is confirmed by the analysis proposed in the main text when uniformed consumers have on average a correct perception of the true quality, see eq. (18) and the related Lemma 3. This structure specifies that the formation process of the demand does not simply depend on the increase in the average quality, but requires that consumers' prior must be on average higher than the true quality, e_i. This is the sufficient condition to obtain an increase in demand. Such result is motivated again by consumers' appreciation of green product and the impossibility to perceive a correct signal at least for a part of them. The higher the quality misperception, the larger the amount of goods required by consumers.

Moreover, consumer surplus CS is represented by the weighted average of the aggregate utility of consumers' profiles,

$$\begin{aligned} CS &= \sum\nolimits_i^{1,2} \left(p_i^2 + (1-\lambda)s_i^2 + \lambda e_i^2\right) + \\ &\quad -2(1-\lambda)\sum\nolimits_i^{1,2} p_i(s_i + \beta s_j) \\ &\quad -2\lambda \sum\nolimits_i^{1,2} p_i(e_i - \beta e_j) \\ &\quad -\beta \sum\nolimits_i^{1,2} (\lambda e_i e_j + (1-\lambda)s_i s_j + p_i p_j) \end{aligned}$$

The supply side is rather standard and it is identical to the framework proposed in the main text. Therefore, marginal costs of production to zero, while fixed costs rise in quality:

$$C_1 = e_1^2, \quad C_2 = e_2^2.$$

Thus the profit of firm i is:

$$\pi_i = p_i q_i \left(p_i, p_j, e_i, e_j, s_i, s_j\right) - C_i. \tag{A.16}$$

The timing of the game is as follows:

- First, firms choose the level of environmental quality.
- Second, they compete in prices.

The equilibrium concept is the subgame perfect equilibrium computed by backward induction.

$$p_i^* \left(e_i, e_j\right) = \frac{\lambda \left[e_i \left(2-\beta^2\right) - \beta e_j\right] + (1-\lambda)\left[s_i \left(2-\beta^2\right) - \beta s_j\right]}{4-\beta^2}, \tag{A.17}$$

It is worthwhile to note that the prices of firms at the optimal level are equal, i.e., $p_1^* = p_2^*$, if and only if the environmental quality of each firm coincides, i.e., $e_1 = e_2$. Note that s_i and s_j are signals perceived by consumers as a function of the quality of the product, e_i, $i \in \{1, 2\}$

plus a common shock, ε, which is a noise exogenously taken and not attributable to the firms. Here signals create misperception on quality and positively influences consumer's willingness to pay for environmental quality.

Eq. (A.17) even shows that the equilibrium price of firm i is decreasing in the quality level chosen by its rival, e_j, and even by its misperception, s_j, captured by consumers. Equilibrium quantities, derived by the first order conditions of eq. (A.16), are,

$$q_i^* \left(p_i^* \left(e_i, e_j\right), p_j^* \left(e_i, e_j\right)\right) = \frac{p_i^*}{1-\beta^2}.$$

with similar properties on prices. In the first stage, each firm i maximises its profit with respect to its environmental quality, e_i:

$$\max_{e_i} \pi_i = \frac{\left[p_i^* \left(e_i, e_j\right)\right]^2}{1-\beta^2} - C_i \left(e_i\right). \tag{A.18}$$

The first order condition yields the best reply function for firm i:

$$e_i \left(e_j\right) = e_i \left(0\right) - \frac{\lambda^2 \beta \left(2-\beta^2\right)}{\left(4-\beta^2\right)^2 \left(1-\beta^2\right) - \lambda^2 \left(2-\beta^2\right)^2} e_j, \tag{A.19}$$

where the denominator is always positive, while $e_i(0)$ is:

$$e_i \left(0\right) = \frac{\lambda \left(2-\beta^2\right) \left[\left(1-\lambda\right) \left(s_i \left(2-\beta^2\right) - s_j \beta\right)\right]}{\left(4-\beta^2\right)^2 \left(1-\beta^2\right) - \lambda^2 \left(2-\beta^2\right)^2}. \tag{A.20}$$

Our framework considers symmetric technology for both firms which entails, in equilibrium, a symmetric quality choice. Moreover, note that s_i and s_j are imperfect signals of the true quality e_i and e_j, plus a common noise, ε. Thus in equilibrium, a symmetric equilibrium arises between signals, $s_i = s_j = s$, so that (A.20) becomes

$$e_i \left(0\right) = \frac{\left(2-\beta^2\right) \left(2-\beta-\beta^2\right) \left(1-\lambda\right) \lambda s}{\left(4-\beta^2\right)^2 \left(1-\beta^2\right) - \lambda^2 \left(2-\beta^2\right)^2}. \tag{A.21}$$

As in the baseline case, the second order conditions of π_i with respect to e_i yields:

$$\frac{\partial^2 \pi_i}{\partial e_i^2} = \frac{2\lambda^2 \left(2-\beta^2\right)^2}{\left(4-\beta^2\right)^2 \left(1-\beta^2\right)} - 2 < 0,$$

for,

$$\lambda^2 < \widehat{\lambda}^2 \equiv \frac{\left(4-\beta^2\right)^2 \left(1-\beta^2\right)}{\left(2-\beta^2\right)^2}.$$

Even in this case examining eqs. (A.19) and (A.21), it can be easily derived that green quality are strategic substitutes. An increase of the environmental quality of the competitor decreases the marginal return of the firm of investing in the own quality. Results proposed by Lemma 1 are therefore confirmed by this model such that,

Lemma 7. *Green qualities are strategic substitutes.*

Proof. As in the baseline case, the second order conditions of π_i with respect to e_i yields:

$$\frac{\partial^2 \pi_i}{\partial e_i^2} = \frac{2\lambda^2 \left(2-\beta^2\right)^2}{\left(4-\beta^2\right)^2 \left(1-\beta^2\right)} - 2 < 0,$$

for

$$\lambda^2 < \widehat{\lambda}^2 \equiv \frac{\left(4-\beta^2\right)^2 \left(1-\beta^2\right)}{\left(2-\beta^2\right)^2}.$$

■

Moreover, solving the system of (A.19), the equilibrium qualities, $e_i^* \ \forall i \in \{1,2\}$, are symmetric:

$$e_i^* = \frac{\left(2-\beta^2\right)(1-\lambda)\lambda s}{(\beta+1)(\beta+2)(2-\beta)^2 - \left(2-\beta^2\right)\lambda^2}, \tag{A.22}$$

which is clearly increasing in signal s. This is consistent with the baseline results, in particular with equation (17), where the equilibrium quality is increasing in the average misperception $\bar{e}$. In what follows, we mirror the analysis of the baseline results. Differentiating

(A.22) with respect to β yields:

$$\frac{\partial e_i^*}{\partial \beta} = -\frac{(2-\beta)\left[\beta(\beta(\beta+2)(2\beta-1)-2)+4\right](1-\lambda)\lambda s}{\left[(\beta+1)(\beta+2)(2-\beta)^2-\left(2-\beta^2\right)\lambda^2\right]^2} < 0,$$

which is in line with the result in Lemma 2.

Finally, differentiating p_i^* with respect to s yields:

$$\frac{\partial p_i^*}{\partial s} = \frac{\left(4-\beta^2\right)\left(1-\beta^2\right)(1-\lambda)}{(\beta+1)(\beta+2)(2-\beta)^2-\left(2-\beta^2\right)\lambda^2} > 0, \tag{A.23}$$

and differentiating π_i^* with respect to s yields:

$$\frac{\partial \pi_i^*}{\partial s} = \frac{\left(4-\beta^2\right)^2\left(1-\beta^2\right)-\lambda^2\left(2-\beta^2\right)^2}{\left[(\beta+1)(\beta+2)(2-\beta)^2-\left(2-\beta^2\right)\lambda^2\right]^2} > 0, \tag{A.24}$$

for $\lambda^2 < \widehat{\lambda}^2$, we obtain the results coherent with Proposition 1.