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The Effects of Environmental Quality Misperception on Investments and Regulation

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Abstract

This paper analyses whether consumers' misperception on the quality of the product influences firms' investment choices. 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 perception of higher quality, while the investment in green quality is high for high and low degrees 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. We show that for low marginal damages, the environmental standard increases quality, while taxation is more effective when the environmental damage is large.

Keywords: Green quality, Misperception, Pigouvian, taxation, Environmental Standard

JEL codes: L13, L51, Q50.

1 Introduction

Environmental concern is on the rise and represents one of the major areas of interest in economics. This growing interest created environmentally friendly consumers who desire to give their contribution to improving the environment with their purchases. Consumers consider the environmental impact before purchases, and this aspect induces an increase in demand for eco-friendly products. They begin to bias their demand towards green products and companies react by adopting, for instance, ecolabels on their products to satisfy such consumer's concern. Ecolabels, for example, are one of the most used communication tools to inform consumers on the green quality of the product relative to others. However, due to the lack of knowledge on the environmental issue, consumers may be confused or mislead by environmental claims of the companies. They can be deceived by environmental ads, which induces an overestimation or underestimation of the product.

Misperception about the greenness of product is reported to be widespread (Wagner, 2002; Yeung *et al.*, 2015). For instance, D'Souza *et al.* (2006) find a negative correlation between green quality perception and purchase intentions. Consumers thus react by underestimating the environmental quality due to the product uncertainty. By contrast, Barber (2010) shows that for a given level of environmental quality, consumers were likely to pay more for green wine packaging. They overestimate the environmental quality as in the case of eco-labeled products. Firms are used to certify that a product meets some quality standard, although such product does not strictly correspond to eco-friendly materials. Harbaugh et al. (2011) and Brecard (2014) show that different products, classified as biodegradable and chlorine-free, derive their ingredients from petrochemicals.[1] Moreover, Truong and Pinkse (2019) show that firms that have a lower environmental performance adopt more product preannouncements to influence external opinions on their green actions.

This paper deals with this issue. We investigate the interaction between consumers' misperception of environmental quality and firms' investment. This is the typical case of industries where deceptive advertising induces a change in the demand of consumers. As consumers cannot spot the value of the good, then there is a clear incentive of the companies to offer a product touting the virtues of their characteristics. Moreover,

[1] See https://www.gmaonline.org/downloads/research-and-reports/greenshopper09.pdf

many consumers, if not impulse buying, confuse the brand image with the quality of the product. This is the case of *greenwashing* practice where a company promotes green-based environmental images, while it operates in a way that is damaging to the environment. The tools used in *greenwashing* can include press releases about green projects, energy reduction or pollution reduction efforts, and rebranding of consumer products. Interesting conclusions can be derived when the level of emissions varies based on different technologies.

Therefore, in the first part of the model, we study the effect of environmental misperception when there are no regulatory policies. Our structure adopts an *end-of-pipe* process as one of the most common abatement technologies. It is normally implemented as a last stage of a production process before the stream is delivered. In principle, it does not include any interventions in the chemical phases producing the main products. The use of filters, treatment units, or catalytic converters that contributes to reduce pollution in the air are examples of *end-of-pipe* technology in the industry like automobile sector. In this framework, demand, environmental quality, and profits are increasing in the perception of quality.[2] Meanwhile, a high or low degree of substitutability increase the investment in environmental quality: this result can be explained by keeping in mind that a larger degree of substitutability implies a higher competition among companies. In case of harsh competition, a high quality investment is necessary to go neck and neck with the competitor. In case of soft competition, high environmental quality investments push the mark-up when consumers are environmentally concerned. These contrasting effects compensate each other for intermediate levels of differentiation, so that the level of quality investment is smaller in this case.

We then extend the analysis by considering an emission abatement technology that changes the production process. Any abatement process which eliminates undesirable by-products within the production processes by replacing the raw and auxiliary materials or reusing part of the waste resources is included in this kind of technology.

Further, it is well-known that any environmental regulatory regime matter in designing and inducing changes in the industrial and commercial activities. As the environmental issues are becoming more and more serious, governments have adopted

[2] Biswas (2016) discovers that the stronger the environmental perception of the product, the larger the intention to invest in clean technology.

different environmental policies to induce *green* initiatives by firms. This is the reason to consider some public interventions investigating their effect of market quality and in the reduction of environmental damages. The paper thus considers some government interventions. First, we investigate the effects of a tax on polluting emissions. The introduction of this regulatory measure increases the investment in environmental quality due to changes in firms' incentives (Petrakis and Xepapadeas, 2001, 2003; Poyago-Theotoky, 2007; and McDonald and Poyago-Theotoky, 2016; *inter alia*). A firm invests in environmental quality not only to capture the interest of consumers but also to reduce the tax burden. We then turn to investigate the introduction of an endogenous tax. The optimal tax rate increases with the quality misperception if the severity of environmental damage of emissions is sufficiently high. Intuitively, a bias in the perception of quality raises the demand. Whether the damage of emissions is significant, the polluting effect of the increase in demand needs to be compensated by the rise in taxation.

Alternatively, we investigate the impact of a minimum quality standard. We initially consider the exogenous case, and then we introduce an endogenous environmental standard. We find that such a threshold bites if the overestimation of quality of some consumers is large leading companies to invest more in quality. We compare these two interventions in a numerical simulation regarding environmental quality. For lower levels of damage, the environmental standard positively influences the quality and agents' welfare compared to the case of taxation. Instead, for a more substantial level of damage, the impact of the emission tax is higher. This result is due to the incentives that the tax creates on firms' profits when damage increases. When damage is lower, an environmental standard rapidly increases quality since it requires an immediate application of a minimum threshold. When the damage is more extensive, the taxation has a more significant effect due to incentives pressure received by firms.

The remainder of the paper is organized as follows. Section 2 surveys some of the contributions related to the present paper, while Section 3 introduces the model. Section 4 shows the baseline results on profits, quantities and prices. Section 5 extends these results to the adoption of an emission abatement technology that influences the production process. Section 6 considers the regulated equilibrium through the two interventions. These are developed and compared in Subsection 6.1, 6.2 and 6.3, respectively. Concluding remarks follows in Section 7.

2 Literature review

Access to knowledge and innovations in technology have led to an increasing awareness of environmental issues. Several studies have shown that worldwide, 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; Chamorro *et al.*, 2009; Mc Donagh and Prothero, 2014; Gu *et al.*, 2015; Zhu and Sarkis, 2016).[3] Robust empirical findings, however, suggest that consumers find it difficult to assess the environmental friendliness of a product.

The economic literature has recently analyzed the role played by environmental concern on consumers' choice. The first group of papers focused on the impact of higher consumers' consciousness on market equilibrium and social welfare (Eriksson, 2004; Conrad, 2005). A second group dealt with the presence of green consumers interacting with the optimal environmental policy (Arora and Gangopadhyay, 1995; Cremer and Thisse, 1999; Moraga-Gonzàlez and Padron-Fumero, 2002; Lombardini-Riipen, 2005; Yalabik and Fairchild, 2011) or trade liberalization (Ceccantoni *et al.*, 2018). The presence of green consumers has been even examined in the context of 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). Environmental awareness is even involved in supply chain analysis. Liu *et al.* (2012) 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.[4] In a similar spirit, Gosh and Shah (2015) investigate supply chain coordination in the reduction of environmental impact by sharing costs, and the effect of consumers' sensitivity towards green products.

We contribute to the literature on consumers' green awareness by explicitly modeling consumers' misperception. The impact of misperception on environmental quality follows Garella and Petrakis (2008). They apply a structure with exogenous signals

[3] See Kohl (1991) and Chang (2011) about the rise of environmental consciousness and its impact on green innovation and standard of production.

[4] They find that retailers and manufacturers with superior eco-friendly operations have a higher return when consumers' environmental awareness increases. Interestingly, higher levels of retail competition can make manufacturers with weak eco-friendly services benefit from the increase in consumers' environmental awareness.

and evaluate the effect of a minimum quality standard in a price-competitive market. Although we adopt the same signaling framework as in Garella and Petrakis, we focus on a different setting. Our structure involves an industry where firms compete in quantities, production is polluting, and consumers are sensitive to environmental quality. We consider a typical *end-of-pipe* technology and evaluate the implementation of an emission tax, as well as an environmental quality standard.

One of the most related contributions is Hattori and Higashida (2012). They focus on misleading advertising in a market with horizontal product differentiation plus an externality effect in firms' optimal advertising. Compared to Hattori and Higashida, we intentionally leave an exogenous signal structure to avoid any strategic behavior of firms in the quality misperception of consumers. Our baseline results are developed by taking into account the introduction of environmental policies. With this regard, Yu *et al.* (2016) develop a model that takes into account both green preferences and government subsidies to green production. They find that an increase of consumer environmental awareness induce manufacturers to ensure an improvement in the quality of products even if this investment might not lead to higher profits. These findings are empirically confirmed by Pekovic *et al.* (2018). Yu *et al.* (2019) compare different environmental tax policies in a supply chain network. They find that environmental concern provides an incentive for firms to improve the quality of their products. In the comparison of tax policies, they show that a low-cost progressive emission tax can be as effective as the high flat one in reducing carbon footprints. Hafezi and Zolfagharinia (2018) find that environmental regulation may have the unintended effect to refrain firms from engaging in green innovation. Our policy section partially differs from the previous setting as we propose a comparison between a typical emission tax and a minimum environmental standard when consumers misperceive the quality of the products.

3 The model

In this section we outline the theoretical framework. Table 1 provides a list of the notation used throughout the paper.

Table 1: notation

$1, 2, i, j$	Firms, $i, j \in \{1, 2\}, i \neq j$
$U(x_i, x_j)$	Utility
α	Minimum level of quality
e_i	Quality chosen by firm i
x_i	Quantity of good i demanded by a consumer type
q_i	Total demand of good i
$\beta \in (0, 1)$	Degree of differentiation
c_0	Numerâire good
I	Income
p_i	Price of good produced by i
e_0	Signal of low quality
e_m	Signal of high quality
$\overline{e}=\frac{1}{2}(e_m + e_0)$	Average misperception
$\lambda \in (0, 1)$	Share of individuals that perceive correctly the quality of one good
CS	Consumer surplus
π_i	Profits of firm i
$C_i = e_i^2$	Cost of quality investment (end of pipe)
$C_i^q(e_i) = \frac{1}{2}(q_i - e_i)^2$	Cost of quality investment (emission abatement technology)
$E = \overline{E} - (e_i + e_j)$	Net-of-abatement total emission level
$\overline{E} = \overline{E}_i + \overline{E}_j$	Gross total emission level
$\overline{E}_i$	Gross i's emission level
d	Severity of environmental damage caused by emissions
$D = dE^2$	Total environmental damage
t	Environmental tax rate
$T = 2tE$	Tax revenue
SW	Social welfare

3.1 Demand with complete information

We consider a market for differentiated goods with two firms, 1 and 2, and a continuum of consumers with total mass normalized to 1. In case of perfect information on environmental quality, a consumer's gross utility is:

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

As in Häckner (2000), utility is quadratic in the consumption of i-goods with $i \in \{1, 2\}$ and linear in the consumption of the composite good c_0 which is chosen as the numéraire. The demand shifter $\alpha + e_i$ identifies the environmental quality of good i. In particular, α is the minimum level of quality (exogenously taken) and e_i is the quality chosen by firm i. The 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, while the goods are perfect substitutes when $\beta = 1$. To ensure a well-defined demand, we assume that $\beta \in (0, 1)$ throughout the paper.

Consumers maximise their expected utility subject to budget constraint, $c_0 + \sum_{i=1}^{2} p_i x_i \leq I$, where the price of the *num éraire* is normalised to one and I denotes the level of income. Under perfect information, utility maximisation of the representative consumer with respect to x_i, $\forall i, j \in \{1, 2\}$ with $j \neq i$ induces the demand functions,

$$x_i(p_i, p_j, e_i, e_j) = \frac{\alpha(1 - \beta) + (e_i - \beta e_j) - p_i + \beta p_j}{1 - \beta^2} \quad (2)$$

3.2 Signal structure

Due to the general difficulty of observing green quality, many companies are marketing their products with eco-labels (Harbaugh *et al.*, 2011). More in general, they spend money for false advertisements trying to persuade consumers on the potential quality of the products.[5] This confusion may induce some consumers to overestimate the quality of the product. Instead other consumers who are uncertain of the exact standard that the label represents may instead underestimate the quality. For these reasons, consumers do not have the right perception of green characteristics of products. Our framework allows for some of these consumers to overestimate (or underestimate) at least partially the quality of both goods as in a real-world case.[6]

[5] As mentioned above, we do not study firms' potential choice of ecolabels 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.

[6] There are several implications in case of exogenous consumers' perception of quality. First, there is no communication between customers differing in the perception of environmental quality. Indeed, the actual fractions of consumers could be in principle the result of previous interactions among them.

Following Garella and Petrakis (2008), each individual i captures an exogenous informative signal $s_i \in \{e_i; e_0; e_m\}$, $\forall i \in \{1, 2\}$. Asymmetric information is identified by two of these signals as proxies of quality misperception perceived by consumers. These signals can be higher ($s_i = e_m > e_i$) or lower ($s_i = e_0 < e_i$) than the true quality e_i respectively. Indeed, λ is the proportion of consumers who recognise the true quality of good i, e_i, i.e., $s_i = e_i$, $\forall i \in \{1, 2\}$. Instead a proportion $(1 - \lambda)$ of consumers 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 realised, 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. The demand for good 1 is given by:

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

3.3 Demand with misperception

This approach allows identifying nine types of consumers according to the received signals: a fraction of fully aware consumers, four groups of partially aware consumers

Second, there is no credible third-party certification available or reliable for every consumer. That explains how consumers are skeptical towards some certifications. Third, informed consumers do not incur any cost while idiosyncratic preferences towards environmental awareness could motivate this result. Some consumers intrinsically care for the environment and enjoy to keep themselves informed without any cost.

and four groups of consumers with wrong signals from both goods. Substituting the demands (2) of each type into eq. (3) yields the total demand of good i denoted as:

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

where $\bar{e}=\frac{1}{2}\left(e_m+e_0\right)$ denotes the average value of quality misperception. By eq. (4), the firm i's inverse demand function is,

$$p_i=\alpha-\lambda(\bar{e}-e_i)+\bar{e}-q_i-\beta q_j$$

Consumer surplus CS is the difference between the consumer's willingness to pay and the price she pays. Appendix A shows a complete derivation of Consumer Surplus which, rearranged, yields:

$$\begin{aligned} CS \;=\;& \lambda^2\left(\left(\alpha+e_1\right)x_1+\left(\alpha+e_2\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}\right)+\lambda\left(1-\lambda\right)\left[\left(\alpha+e_1\right)x_1+\left(\alpha+e_0\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}\right. \\ & +\left(\alpha+e_1\right)x_1+\left(\alpha+e_m\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}+\left(\alpha+e_0\right)x_1+\left(\alpha+e_2\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2} \\ & \left.+\left(\alpha+e_m\right)x_1+\left(\alpha+e_2\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}\right]+\left(1-\lambda\right)^2\left[\left(\alpha+e_0\right)x_1+\left(\alpha+e_0\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}\right. \\ & +\left(\alpha+e_m\right)x_1+\left(\alpha+e_0\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}++\left(\alpha+e_0\right)x_1+\left(\alpha+e_m\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2} \\ & \left.+\left(\alpha+e_m\right)x_1+\left(\alpha+e_m\right)x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}\right]-x_1p_1-x_2p_2+I \end{aligned} \tag{5}$$

3.4 Supply side

The supply side is rather standard in the literature. We normalise marginal costs of production to zero, and assume a fixed quadratic cost in environmental quality (Garella and Petrakis, 2008 and Hattori and Higashida, 2012):

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

The assumption of zero marginal cost is to simplify the exposition, and it is not essential for the ongoing analysis. For instance we could assume constant marginal costs by obtaining qualitatively similar results.[7] 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 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 $E = \overline{E} - (e_1 + e_2)$. 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 cutting down emissions of pollutants into the atmosphere, in reality they do not eliminate the environmental damage. This type of abatement technology is called *end-of-pipe* emissions. As mentioned above, it limits emissions at the end of the manufacturing plants without modifying the primary production process. Waste and emissions, for instance, are blocked by filters and treatment units, avoiding part of the potentially toxic processes and materials in the air. Other examples of these technologies are scrubbers on smokestacks or catalytic convertors on automobile tailpipes that reduce emissions of pollutants after they have formed.[8] In other words, *end-of-pipe* technologies reduce emissions *ex-post*. In Section 5, we extend the analysis and show whether the results change by looking at an abatement technology that affects the production process.

[7] In Appendix B, we show that the baseline results are qualitatively similar to those obtained in a setting with quadratic cost function.

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

3.5 Environmental impact, welfare and timing

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.[9] 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 quantities. The equilibrium concept is the subgame perfect equilibrium by backward induction.

4 Baseline results

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

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

where $q_1^* = q_2^*$ if and only if $e_1 = e_2$. Eq. (8) is relevant in two respects. First 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 the quality misperception proxied by the average signal $\overline{e}$, the higher the price that a firm can impose. The average signal $\overline{e}$ is a shifter raising the demand of each product. Second, eq. (8) shows that the equilibrium quantity of firm i is decreasing in the level of quality chosen by its rival e_j. This negative effect is higher, the larger is the degree of product substitutability between the two goods β.

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

$$\max_{e_i} \pi_i = \left[q_i^*\left(e_i\right)\right]^2 - C_i\left(e_i\right) \tag{9}$$

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

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

$$e_i\left(e_j\right) = e\left(0\right) - \frac{2\lambda^2\beta}{\left(4-\beta^2\right)^2 - 4\lambda^2} e_j \tag{10}$$

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

$$e\left(0\right) = \frac{2\lambda(2-\beta)\left[\alpha + \overline{e}(1-\lambda)\right]}{\left(4-\beta^2\right)^2 - 4\lambda^2} \tag{11}$$

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

$$\frac{\partial^2 \pi_i}{\partial e_i^2} = \frac{8\lambda^2}{\left(4-\beta^2\right)^2} - 2 < 0 \tag{12}$$

for

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

A close inspection shows that $\widehat{\lambda}^2 > 1$, so that the SOC is verified for every $\lambda \in [0, 1]$. This result guarantees downward sloping best replies such that the qualities are strategic substitutes as,

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

where the denominator is always positive by $\widehat{\lambda}^2 > 1$. This preliminary result can be summarised as follows.

Lemma 1. *The problem of eq. (9) admits a maximum and green qualities are strategic substitutes.*

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 become more homogeneous and firms' profits necessarily decrease. Solving the system of eq. (10), the equilibrium qualities e_i^*, $\forall i \in \{1, 2\}$, are symmetric:

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

As underlined in Section 3, the lower bound signal e_0 should be lower than the true quality signal, i.e., $e_i^* > e_0$. Remembering that $\overline{e} = \frac{1}{2}\,(e_m + e_0)$, this is possible if and only if,

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

Eq. (14) suggests that for any upper bound signal e_m, the lower bound signal e_0 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).

At equilibrium, firm i's prices and profits are respectively,

$$p_i^* = \frac{\left(4-\beta^2\right)\left[\alpha + \overline{e}\,(1-\lambda)\right]}{(2-\beta)\,(2+\beta)^2 + 2\lambda^2} \tag{15}$$

and

$$\pi_i^* = \frac{\left[\left(4-\beta^2\right)^2 - 4\lambda^2\right]\left[\alpha + \overline{e}\,(1-\lambda)\right]^2}{\left[(2-\beta)\,(2+\beta)^2 + 2\lambda^2\right]^2} \tag{16}$$

We can now 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 shows the relationship between environmental quality and the level of differentiation among products.

Lemma 2. *The equilibrium level of environmental quality reaches its minimum at* $\beta = 2/3$.

Proof. Differentiating e_i^* with respect to β yields,

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

for $\beta = 2/3$. The second order condition yields

$$\frac{8\lambda\left[3\beta^4 + 8\beta^3 - 3\beta\lambda^2 - 2\lambda^2 + 16\right]\left[\alpha + \bar{e}(1-\lambda)\right]}{\left[(2-\beta)(\beta+2)^2 - 2\lambda^2\right]^3} > 0$$

□

Lemma 2 shows that, when the products have a very high or low level of substitutability, i.e., when competition is either harsh or soft, investing in quality is relatively more important, for two different and contrasting reasons. On the one hand, higher competition requires higher quality investment to go head to head with the competitor. On the other hand, very soft competition entails higher markups, which can be pushed by high quality investments when consumers are green.

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

$$\frac{\partial e_i^*}{\partial \bar{e}} = \frac{2\lambda(1-\lambda)}{(2-\beta)(2+\beta)^2 - 2\lambda^2} > 0 \qquad (17)$$

The uncertainty about the value of the quality of good has direct implications with personal misperception. The intuition behind this result is that higher (average) perceived quality increases the quality of the product. It even has a positive effect on the price, making it more profitable to raise demand from fully informed consumers. In particular, given eq. (17) together with eqs. (8), (15) and (16), it follows that:

Proposition 1. *Environmental qualities, profits, quantities and prices in equilibrium increase in the average perception of quality* $\bar{e}$ *.*

Proof. The positive relationship between equilibrium quality and average misperception can be seen by eq. (17). Looking at eqs. (8), (15) and (16), we note that quantities, prices and profits at the equilibrium are increasing in $\bar{e}$. □

Proposition 1 states that the higher the average signal received by consumers, the higher is the perception of quality they perceive. It raises 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 a higher price to consumers, sell more and consequently make higher profits.

We conclude the section by considering the case in which the average signal of quality misperception $\overline{e}$ coincides with the real quality e_i^*, i.e., consumers have on average a correct perception of the real quality, $\overline{e} = e_i^*$. This case is particularly relevant to investigate the effects of overestimation or underestimation of environmental quality. Indeed, this is possible in the present framework only by keeping the true quality as a reference point. Formally, substituting $\overline{e}$ into eq. (13), and solving for e_i^* yields,

$$e_i^{True} = \frac{2\alpha\lambda}{(2-\beta)(\beta+2)^2 + 2\lambda} \tag{18}$$

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

Lemma 3. *Equilibrium profits, quantities and prices are higher in case of quality misperception if and only if* $\overline{e} > e_i^{True}$.

Proof. See Appendix A □

The result summarised in Lemma 3 is helpful to understand what happens at the equilibrium values in case of the over-estimation and underestimation of quality. When over-estimation is in place $\left(\overline{e} > e_i^{True}\right)$, firms exploit the exogenous misperception of consumers, charge a higher price and gain larger profits: the higher the overestimation, the greater the gain in terms of profits. The opposite applies in case of underestimation, $\overline{e} > e_i^{True}$. In this case consumer misperception is detrimental for firms' profits.

5 Modifying the production-process through abatement

Here, we examine whether the baseline results are robust when we introduce an emission abatement technology that changes the production process. Some evidence shows that this type of abatement is relevant in several industries (Hartman *et al.*, 1997). Examples of this abatement technology are the substitution of raw materials and auxiliary materials, the life increase of extra materials and process liquids, the improved control in the automatization process, the reuse of waste or a low waste technological process. In the steelmaking and cement industry, air pollution is contrasted by electrostatic precipitators to remove particulates. In the pulp industry, wet scrubbers are employed to remove sulfur gases.

Following the relevant literature (Parry and Toman, 2002; Kennedy, 2002; Subramanian *et al.*, 2007: Christin *et al.*, 2013; and Anand and Giraud-Carrier, 2017, *inter alia*), the cost of emissions reduction is convex in the level of production as follows:

$$C_i^q(e_i) = \frac{1}{2}(q_i - e_i)^2 \tag{19}$$

where superscript q mnemonics for the adoption of an abatement technology influencing the production process, i.e., the quantity. Market competition in the second stage is

$$q_i^q = \frac{\alpha(3-\beta) + (3e_i - \beta e_j)(1+\lambda) + (3-\beta)(1-\lambda)\overline{e}}{9-\beta^2}$$

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

$$\max_{e_i} \pi_i^q = [q_i^q(e_i, e_j)]^2 - C_i^q(e_i) \tag{20}$$

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

$$\frac{\partial \pi_i}{\partial e_i} = \frac{9\alpha(3-\beta)(1+\lambda) + e_i\left[18\beta^2 - 27(2-\lambda(2+\lambda)) - \beta^4\right] + 9(1+\lambda)\left[(3-\beta)(1-\lambda)\overline{e} - \beta(1+\lambda)e_j\right]}{\left(9-\beta^2\right)^2} = 0 \tag{21}$$

which gives the following reaction function,

$$e_i^q(e_j) = \frac{9(1+\lambda)\left[\alpha(3-\beta) - \beta e_j(1+\lambda) + (3-\beta)(1-\lambda)\overline{e}\right]}{\beta^4 - 18\beta^2 + 27\left(2 - 2\lambda - \lambda^2\right)} \tag{22}$$

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

$$\frac{\partial^2 \pi_i}{\partial e_i^2} = \frac{18\beta^2 - \beta^4 + 27\left(\lambda^2 + 2\lambda - 2\right)}{\left(9-\beta^2\right)^2} < 0$$

for $\lambda \in (0, \lambda^q)$, where

$$\lambda^q \equiv \frac{9-\beta^2}{3\sqrt{3}} - 1 < 1$$

which belongs to the unit interval for all $\beta^2 > -1.392$, i.e., always.

As in the baseline model, we investigate the solution of the green quality by studying the map of the reaction functions:

$$\frac{\partial e_i^q(e_j)}{\partial e_j} = -\frac{9\beta(1+\lambda)^2}{\beta^4 - 18\beta^2 + 27\left(2 - 2\lambda - \lambda^2\right)} < 0$$

Hence the strategic nature of environmental quality is robust to the baseline case.

Lemma 4. *Suppose that emission abatement technology is introduced. Then green qualities are strategic substitutes.*

Solving the system of FOCs given by eq. (21), the equilibrium qualities are:

$$e_i^q = \frac{9(1+\lambda)\left(\alpha + (1-\lambda)\,\bar{e}\right)}{\beta\left[9 - \beta(3+\beta)\right] + 9\left[2 - \lambda(2+\lambda)\right]} > 0$$

for

$$\lambda < \frac{\sqrt{3}-\beta}{3} - 1$$

where $\frac{\sqrt{3}-\beta}{3} - 1 > \lambda^q$, so that $\lambda < \lambda^q$ is a sufficient condition to ensure that equilibrium qualities are positive.

Let us turn now on the comparative statics of e_i^q. Unlike the baseline case, differentiation of e_i^q with respect to β yields

$$\frac{\partial e_i^q}{\partial \beta} = -\frac{27(1-\beta)(3+\beta)(1+\lambda)\left(\alpha + (1-\lambda)\,\bar{e}\right)}{\left[\beta(9 - \beta(3+\beta)) + 9(2 - \lambda(\lambda+2))\right]^2} < 0$$

such that optimal investment in green quality is decreasing as the level of substitutability increases. Conversely, differentiating the equilibrium qualities yields

$$\frac{\partial e_i^q}{\partial \bar{e}} = \frac{9\left(1-\lambda^2\right)}{\beta\left[(9 - \beta(3+\beta)\right] + 9\left[2 - \lambda(2+\lambda)\right]} > 0$$

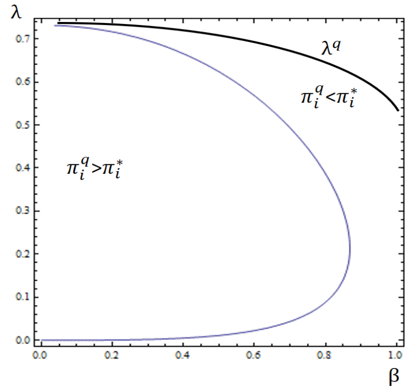

Figure 1: Comparing profits with the two emission abatement technologies

which exhibits the same sign as in the baseline case, where emissions reduction does not depend on production. Therefore the results in Proposition 1 are confirmed also when the cost of emission abatement is convex in the level of production.

We are now in a position to compare the two technologies with respect to equilibrium qualities and profits. The comparison between qualities yields

$$e_i^q - e_i^* =$$

$$\frac{\left[(\beta(18-\beta(12+7\beta))+36)\lambda+9(2-\beta)(2+\beta)^2+18\lambda^2\right](\alpha+(1-\lambda)\,\overline{e})}{\left[(2-\beta)(2+\beta)^2-2\lambda^2\right]\left[(9-\beta(\beta(\beta+3))+9\,(2-\lambda(\lambda+2))\right]}>0$$

Thus, the emission abatement technology induces a high level of quality compared to the baseline case. However, the results in terms of profits are not so obvious and strictly depends on product differentiation. In particular, we observe that when $\beta = 0$ (products are independent), the profits π_i^q in eq. (20) are always higher than profits π_i^* of eq. (16) in the baseline case, i.e., $\pi_i^q > \pi_i^*$. The reason is due to the lower competition that a higher level of product differentiation induces in the market. Alternatively, when $\beta = 1$ and the products are perfect substitutes, then the profits are always larger in the baseline case, i.e., $\pi_i^q > \pi_i^*$. Intuitively, this suggests that companies prefer to adopt an *ex-post* technology does not require a change in the production process (that requires larger investments) when the competition in the market is higher. Figure 1 helps to understand the general comparison of profits in the space (β, λ).

6 Regulatory interventions

As the literature suggests (e.g., 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. The incentives towards greener production processes are not cost-competitive, and many companies may hesitate to make a strategic investment in the absence of regulation. The regulators should, therefore, adopt several instruments such as subsidies, environmental taxes, fines, or minimum quality standards. However, the effects of these policies are far from reaching a unanimous consensus. Recent developments in the theoretical analysis of environmental policies have shown different results as Yu *et al.* (2016), Hafezi and Zolfagharinia (2018) and Yu *et al.* (2019), *inter alia* (see Section 2 for details). In a model of quality misperception, we intentionally focus on the potential impact of incentive-based instruments in a framework characterized by quality misperception. In particular, emission taxes and quality standards figure out as the most common policy instruments for the regulation of environmental externalities.[10] 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 can enforce the standard.

6.1 Emissions Tax

We first 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 to reduce the tax burden. Both firms pay less when the optimal quality increases.

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

$$\pi_i = p_i q_i (p_i, p_j) - C_i - tE \tag{23}$$

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

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,

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

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

$$e_i^{t*} = \frac{(2-\beta)(\beta+2)^2 t + 4\lambda\left[\alpha + \overline{e}\,(1-\lambda)\right]}{2(2-\beta)(\beta+2)^2 - 4\lambda^2} \tag{24}$$

As expected, eq. (24) 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

$$e_i^* - e_i^{t*} = -\frac{t\,(2-\beta)\,(2+\beta)^2}{2\,(2-\beta)\,(2+\beta)^2 - 4\lambda} < 0 \tag{25}$$

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. *Environmental qualities, quantities and prices rise in equilibrium after the introduction of an emissions tax t.*

Interestingly, according to Proposition 2, the primary result of introducing an emissions tax is the rise of the environmental quality chosen by firms. Note that there is also a secondary effect passing through consumers' welfare. Indeed, a rise in quality corresponds to an increase in customers' demand, and this necessarily increases price and quantity at the equilibrium. The effect on profits is relatively different than 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 fiscal variations and profits may increase if the maximum level of emissions 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 Appendix A.*

Proof. See Appendix A □

Intuitively, Proposition 3 suggests that the secondary effect that increases consumers' demand positively impacts on firms' profits, whenever the maximum level of emissions is relatively small. When the level of emission is higher than threshold Ξ, firms are less able to pass the tax burden to consumers, so that profits decrease.

Next, we assume the introduction of an optimal endogenous 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

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

$$B = \frac{2(1-\lambda)\lambda\left[(\beta+2)\beta^3 - (\beta+5)\beta + 8\left(\beta^2-1\right)d + 2(\lambda-3)\right]}{(2-\beta)\left[(\beta+2)^2\lambda - 2\left(1-\beta^2\right)(\beta+2)^2(2d+1) - (\beta(\beta+1)(\beta+3)+1)\lambda^2\right]}$$

The second order condition is

$$\frac{\partial^2 SW}{\partial t^2} = \frac{\left(4-\beta^2\right)^2}{2\left(1-\beta^2\right)\left[\beta^3+2\beta^2-4\beta+2\lambda^2-8\right]^2} \times$$

$$\left[2\beta^4 - \beta^3\left(\lambda^2-8\right) + \beta^2\left(-4\lambda^2+\lambda+6\right) + \beta\left(-3\lambda^2+4\lambda-8\right) + 4(\beta+2)^2\left(\beta^2-1\right)d - \lambda^2 + 4\lambda - 8\right] < 0$$

for $d > \widetilde{d}$, where

$$\widetilde{d} \equiv \frac{\lambda\left[\beta(\beta+4) + 4 - \beta(1+\beta)(3+\beta)\lambda - \lambda\right]}{4(\beta+2)^2\left(1-\beta^2\right)} - \frac{1}{2}$$

In addition, $B < 0$ for $d > \widetilde{d}$ so that,

Proposition 4. *The level of optimal taxation decreases with the average signal of environmental quality* $\overline{e}$.

The results of Proposition 4 can be explained as follows. The environmental damage negatively influences the good's demand through the endogenous tax rate. Thus, a lower level of misperception $\overline{e}$ requires a higher tax rate to compensate the fall in tax revenue, due to the lower demand. The same optimal tax revenue can be obtained with a lower tax rate as misperception $\bar{e}$ increases.

6.2 Environmental standard

In this section, we introduce an environmental standard in the spirit of Motta and Thisse (1999), Moraga-González and Padrón-Fumero (2002) and Garella and Petrakis (2008). The primary 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. Whenever $\widehat{e} > e_0$, uninformed consumers who receive low-quality information for product i revise 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:

$$\frac{\partial e_i^*}{\partial e_0} = \frac{(1-\lambda)\lambda}{(2-\beta)(\beta+2)^2 + 2\lambda^2} > 0 \tag{26}$$

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.*

The proposition shows that 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 eq. (26) with respect to β as follows,

$$\frac{\partial e_i^*}{\partial e_0 \partial \beta} = \frac{(\beta+2)(3\beta-2)(1-\lambda)\lambda}{\left[(2-\beta)(\beta+2)^2 - 2\lambda^2\right]^2} > 0 \tag{27}$$

for $\beta > 2/3$. This result is consistent with Lemma 2 and suggests that, even if the environmental standard succeeds in improving the environmental quality of goods, its efficacy depends on their degree of substitutability. By Lemma 2, a sufficiently high degree of substitutability among goods entails harsher competition that spurs quality investment. In turn, the introduction of an environmental standard has a stronger impact in the level of product quality.

Let us evaluate next how the impact of the environmental standard influences qualities, prices, quantities, and profits. Observing the role of the standard in eq. (26), it follows that:

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

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 products of higher quality so that they can also charge higher prices. In turn profits increase.

Consider next the introduction of an endogenous environmental standard.[11] Suppose that there is a pre-stage in which the government sets an environmental standard $\widehat{e} > e_0$ to maximise social welfare. Consumers will update their evaluation of the lower bound of environmental quality, so that $e_0^* = \widehat{e}$ (see A for the explicit derivation or e_0^*).

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

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

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

Proof. See Appendix A. □

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

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

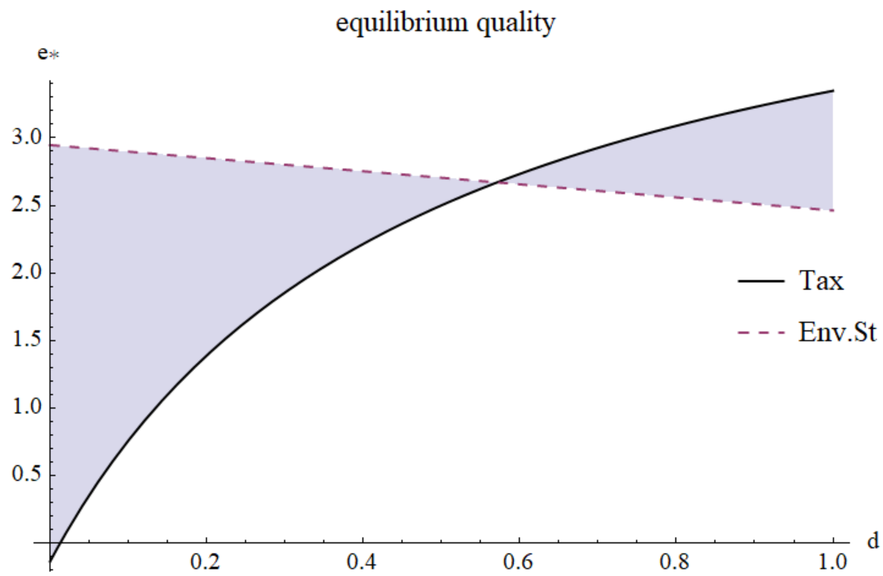

Figure 2: Tax vs Emission Standard - The effect on environmental quality

consumers' upper bound, e_m, is high, then firms have more incentives to invest in environmental quality.

Finally, note that there is no trade-off between consumer surplus and the damage function. It is because the quality is green and consumers internalise their benefits in their utility function so that incentives are aligned. This trade-off emerges in situations where quality is hedonic rather than green. In this case, an increase in consumer surplus would imply higher emissions (Lambertini and Tampieri, 2012 and Ecchia *et al.*, 2013).

6.3 Tax vs standard

We now propose a simple simulation 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 according to whether an emission tax or a standard is implemented.

Figure 2 compares the equilibrium qualities when either the optimal tax or the optimal environmental standard can be applied. We allow the quality levels to change

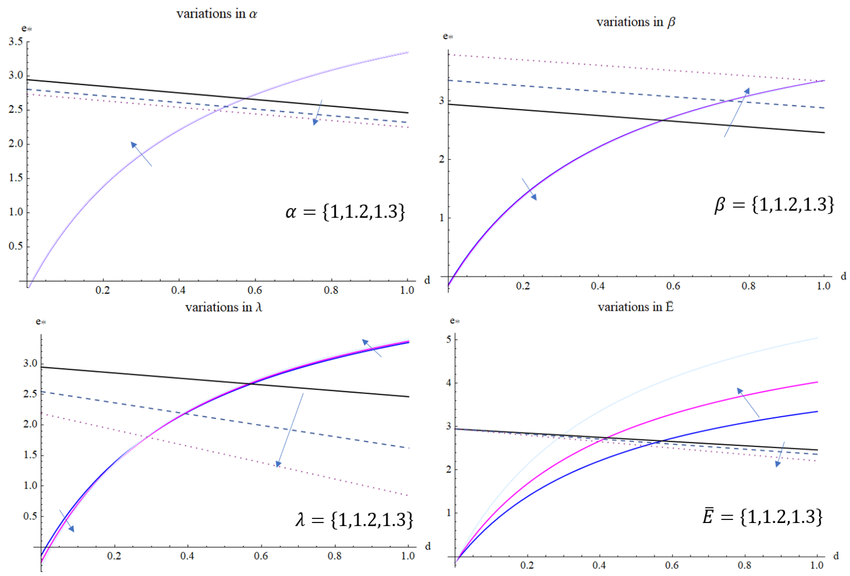

Figure 3: Tax vs Emission Standard - Sensitivity of parameters

according to the severity of the environmental damage of emissions d.[12] We assume generic values of parameters of the model: the proportion of consumers that recognise the quality of one good (λ) is equal to 0.1; the substitutability among goods, β, is assumed to be 0.3; while, the constant coefficient α is 1. 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 3 shows the sensitivity of the results to changes in the parameter values. We explore the change in exogenous quality α, degree of substitutability β, proportion of aware consumers λ and maximum level of emission $\overline{E}$.

Both interventions exert an ongoing pressure on price competition and reduce the emissions of not eco-friendly products. However, we may observe that for a lower level of damage, environmental standard ensures a higher level of quality in case of misperception. Results change for larger values of d while the emission tax guarantees a higher level of environmental quality. It relates to incentives that taxation imposes on firms' profits when damage increases. More in details, a standard rapidly raises the level of environmental quality and social welfare due to the application of a minimum

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

threshold. This effect is relatively efficient when the damage is relatively small. When the damage is bigger, the effect of minimum standard decreases. An emission tax becomes effective due to positive incentives of increasing qualities received by firms.

7 Concluding remarks

The idea of the paper is simple in concept. As environmental consciousness continues to increase in the last decades, consumers are more exposed to companies' environmental claims and may consequently purchase more environmental products and services. While their level of environmental attention increases, consumers' ability to detect the real quality of the product becomes weaker. Companies take advantages of this uncertainty, trying to influence the perception of the quality of the product. For instance, deceptive advertising is a typical business practice that violates the trust of consumers overstating the quality of the related product. This aspect is even more important in the case of environmental issues, due to the strong desires of consumers to be '*green*'. In particular, *greenwashing* ads are misleading marketing strategy about the environmental benefits of a product. Starting from this view, consumers can, in principle, misreport the advantage of the product by underestimating (or overestimating) its quality.

We have proposed a novel setting with the consumers' misperception of the quality of the product. We have investigated the impact that this uncertainty has on firms' incentives on market equilibrium, i.e., prices, quantity, profits, and quality. The model allows for changes in the demand based on the exogenous signals that may overstate (or not) the quality. We adopt one of the most common abatement technology which treats pollutants at the *end-of-pipe* for emissions without influencing the phase of production. Results suggest that quality misperception is positively related to demands, environmental qualities, and profits. Besides, equilibrium qualities decrease, the more the goods are substitutes. However, *end-of-pipe* technology only increases the emission costs as it required to install them *ex-post* at the end of the manufacturing facilities. Therefore, we have extended the analysis by considering a emission abatement technology that influences the production process. Compared to the baseline case, we confirm that optimal investment in green quality increases with more significant consumers' misperception. Moreover, a combination of the two technologies increases environmental quality. However, the adoption of both technologies does not always imply an increase in profits. The results instead depend on the level of product differentiation in the market.

The importance of environmental regulations is motivated by the net positive impact that induces private companies to increase the environmental quality of the product. Our framework even allows for public policy interventions. The introduction of either a tax on emissions or an environmental standard raises the equilibrium. When the regulator increases the tax rate, companies will increase the level of environmental quality and market price and quantity accordingly, while profits increase if the level of emissions is not so large. Interestingly, the optimal taxation level decreases when the average misperception increases. Results are similar for the environmental standards, although it depends on the signals received by consumers. A comparison between the two instruments suggests that when the damage is relatively lower, the environmental standard ensures a higher level of environmental quality. In case of larger damage, instead, an emission tax seems to guarantee a higher level of quality. Results are robust to different changes in the parameter values.

A possible limitation of this framework is related to the misperceptions of the quality. In our structure, they are exogenous, but one may expect they are functions of the optimal firms' choice of advertising. A potential extension would consider that consumers receive a noisy signal, correlated to environmental quality updating their beliefs based on the optimal strategy of the firms. Another limitation could involve the government's information set. In particular, the underlying assumption here is that the government can enforce its environmental policy. This information problem may be an interesting point to investigate further.

One could even take into account asymmetric technologies among firms. Indeed, the importance of environmental perception reduces whenever one firm is more efficient than the competitor. It 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. 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 emissions 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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Appendix

A Consumer surplus

In this section we derive consumer surplus. Solving the budget constraint $p_1x_1 + p_2x_2 + c_0 = I$ for the numéraire c_0, and substituting the expression into equation (1), the representative consumer maximises her utility and gets

$$x_i = \frac{\alpha(1-\beta) + (e_i - \beta e_j) - p_i + \beta p_j}{1-\beta^2}, \tag{28}$$

for each $i, j \in \{1, 2\}$ with $j \neq i$. In case of perfect information, equation

$$U(x_1, x_2) = \left[(\alpha + e_1) x_1 + (\alpha + e_2) x_2 - \frac{x_1 + 2\beta x_1 x_2 + x_2}{2} \right] - [p_1x_1 + p_2x_2] + I, \tag{29}$$

corresponds to consumer surplus, given optimum quantities x_i and known qualities e_1 and e_2. We may thus denote it as $U(x_1, x_2) = CS(e_1, e_2)$. In our setting though, some consumers do not perceive the exact quality of either good 1 or 2, or both, based on the discussion on Section 3.2: overall, there are nine consumer types. Therefore consumer surplus is determined by evaluating the weighted sum of each consumer type:

$$\begin{aligned} CS &= \lambda^2 CS(e_1, e_2) + \lambda(1-\lambda)[CS(e_1, e_0) + CS(e_1, e_m) + CS(e_0, e_2) + CS(e_m, e_2)] + \\ &\quad (1-\lambda)^2 [CS(e_0, e_0) + CS(e_m, e_0) + CS(e_0, e_m) + CS(e_m, e_m)]. \end{aligned}$$

Substituting (29), we get

$$
\begin{aligned}
CS &= \lambda^2\left((\alpha+e_1)\,x_1+(\alpha+e_2)\,x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}-x_1p_1-x_2p_2+I\right)+\\
&\lambda\,(1-\lambda)\Big[(\alpha+e_1)\,x_1+(\alpha+e_0)\,x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}\\
&+(\alpha+e_1)\,x_1+(\alpha+e_m)\,x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}+(\alpha+e_0)\,x_1+(\alpha+e_2)\,x_2\\
&-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}+(\alpha+e_m)\,x_1+(\alpha+e_2)\,x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}-x_1p_1-x_2p_2+I\Big]\\
&+(1-\lambda)^2\Big[(\alpha+e_0)\,x_1+(\alpha+e_0)\,x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}+(\alpha+e_m)\,x_1+(\alpha+e_0)\,x_2\\
&-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}++(\alpha+e_0)\,x_1+(\alpha+e_m)\,x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}\\
&+(\alpha+e_m)\,x_1+(\alpha+e_m)\,x_2-\frac{x_1^2+2\beta x_1x_2+x_2^2}{2}-x_1p_1-x_2p_2+I\Big]
\end{aligned}
$$

Rearranging, we get equation (5).

B. Quadratic cost function

In this section we show that the baseline results are robust to the assumption of quadratic production costs. In this modified setting, profits of firm i are

$$\pi_i = (p_i - cq_i)\,q_i - C_i. \tag{30}$$

The demand side is the same as in the baseline model. In the second stage, firms maximise their profits with respect to quantities. The first order condition is

$$\frac{\partial \pi_i}{\partial q_i} = \frac{1}{2}\left[2(\alpha - 2cq_i + e_i\lambda - 2q_i - \beta q_j) + (e_m + e_0)\,(1-\lambda)\right] = 0, \tag{31}$$

for $i \in \{1, 2\}$. Setting $\overline{e} = \frac{e_m+e_0}{2}$, and solving for q_i, equilibrium quantity is

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

Rolling over to the first period, profit maximisation with respect to environmental qualities give

$$\frac{\partial \pi_i}{\partial q_i} = -\frac{4(1+c)^2\lambda\left[\alpha(\beta-2c-2)+\lambda(\beta e_j - 2(1+c)e_i) - \overline{e}(1-\lambda)(2+2c-\beta)\right]}{\left(4-\beta^2+4c^2+8c\right)^2} - 2e_i = 0.$$

The equilibrium qualities are thus

$$e_i^* = \frac{2(1+c)^2\lambda\left[\alpha + \overline{e}\,(1-\lambda)\right]}{(2+2c-\beta)(2c+2+\beta)^2 - 2(1+c)^2\lambda^2} \tag{32}$$

Plugging (32) into prices, and profits, we get

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

and

$$\pi_i^* = \frac{(1+c)\left(\left(\beta^2-4(c+1)^2\right)^2 - 4(c+1)^3\lambda^2\right)\left[\alpha + \overline{e}\,(1-\lambda)\right]^2}{(\beta-2c-2)^2(\beta+2c+2)^4 + 4(c+1)^4\lambda^4 - 4(1+c)^2\lambda^2(2+2c-\beta)(2c+2+\beta)^2}.$$

We are now in a position to evaluate whether the results of Proposition 1 holds if the cost function is quadratic. Differentiation of qualities, prices, quantities and profits with respect to $\overline{e}$ yields:

$$\frac{\partial e_i^*}{\partial \overline{e}} = \frac{2(1-\lambda)\lambda(c+1)^2}{(2+2c-\beta)(2c+2+\beta)^2 - 2(c+1)^2\lambda^2} > 0,$$

$$\frac{\partial p_i^*}{\partial \overline{e}} = \frac{(2c+1)(1-\lambda)\left(-\beta^2+4c^2+8c+4\right)}{4\beta+8c^3+c^2\left(4\beta-2\lambda^2+24\right) - 2c\left(\beta^2-4\beta+2\left(\lambda^2-6\right)\right) - 2\lambda^2+8-\beta^3-2\beta^2} > 0,$$

$$\frac{\partial q_i^*}{\partial \overline{e}} = \frac{(1-\lambda)(-\beta+2c+2)(\beta+2c+2)}{4\beta+8c^3+c^2\left(4\beta-2\lambda^2+24\right) - 2c\left(\beta^2-4\beta+2\left(\lambda^2-6\right)\right) - 2\lambda^2+8-\beta^3-2\beta^2} > 0,$$

$$\frac{\partial \pi_i^*}{\partial \overline{e}} = \frac{2(c+1)(1-\lambda)\left[\alpha+\overline{e}\,(1-\lambda)\right]\left[\beta^4-8\beta^2+16c^4-4c^3\left(\lambda^2-16\right)-4c^2\left(2\beta^2+3\left(\lambda^2-8\right)\right)-4c\left(4\beta^2+3\lambda^2-16\right)-4\lambda^2+16\right]}{\left(\beta^3+2\beta^2-4\beta-8c^3+c^2\left(-4\beta+2\lambda^2-24\right)+2c\left(\beta^2-4\beta+2\left(\lambda^2-6\right)\right)+2\lambda^2-8\right)^2} > 0.$$

Therefore, our baseline results are robust to the extension of quadratic production cost.

C. 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,

$$\begin{aligned} p_i^{True} &= q_i^{True} = \frac{\alpha\left(4-\beta^2\right)}{(2-\beta)(\beta+2)^2-2\lambda}, \\ \pi_i^{True} &= \frac{\alpha^2\left[\left(4-\beta^2\right)^2-4\lambda^2\right]}{[(2-\beta)(\beta+2)^2-2\lambda]^2}, \end{aligned}$$

We compare these values of price, quantity and profit of firm i with respect to the values of quantity, price and profit of firm i when $\overline{e} \neq e_i^*$, as proposed in eqs. (8), (15) and (16). It follows that if $\overline{e} > e_i^{True}$, then

$$\begin{aligned} p_i^* - p_i^{True} &= q_i^* - q_i^{True} = \\ &= \frac{\left(4-\beta^2\right)(1-\lambda)\left[(2-\beta)(\beta+2)^2\overline{e}-2\lambda(\alpha+\overline{e})\right]}{[(2-\beta)(\beta+2)^2-2\lambda]\left[(2-\beta)(\beta+2)^2-2\lambda^2\right]} > 0, \end{aligned}$$

and

$$\begin{aligned} \pi_i^* - \pi_i^{True} &= \frac{(1-\lambda)\left(4+2\lambda-\beta^2\right)\left(\beta^2+2\lambda-4\right)\left[(2-\beta)(\beta+2)^2\overline{e}-2\lambda(\alpha+\overline{e})\right]}{[(2-\beta)(\beta+2)^2-2\lambda]^2\left[(2-\beta)(\beta+2)^2-2\lambda^2\right]^2} \times \\ &\quad \left[2\alpha\left(\overline{e}(1-\lambda)\left((2-\beta)(\beta+2)^2-2\lambda\right)-(\beta-2)(\beta+2)^2+\lambda^2+\lambda\right)\right] \\ &> 0. \end{aligned}$$

The results suggest that prices, quantities and profits are higher when $\overline{e} \neq e_i^*$ 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, $\overline{e} = e_i^*$.

D. Proof of Proposition 3

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

$$\frac{\partial \pi_i^*}{\partial t} = \frac{2\lambda\left[8\lambda^2-(\beta-4)(\beta-2)(\beta+2)^2\right](\bar{e}(\lambda-1)-\alpha)-2\overline{E}\left[(\beta-2)(\beta+2)^2+2\lambda^2\right]^2}{2\left[(\beta-2)(\beta+2)^2+2\lambda^2\right]^2}$$

$$\frac{(\beta-2)(\beta+2)^2 t\left[(\beta+6)\lambda^2+3(\beta-2)(\beta+2)^2\right]}{2\left[(\beta-2)(\beta+2)^2+2\lambda^2\right]^2} > 0, \tag{33}$$

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

$$\Xi \equiv \frac{2\lambda\left[8\lambda^2-(\beta-4)(\beta-2)(\beta+2)^2\right][\bar{e}(\lambda-1)-\alpha]+(\beta-2)(\beta+2)^2 t\left[(\beta+6)\lambda^2+3(\beta-2)(\beta+2)^2\right]}{2\left[(\beta-2)(\beta+2)^2+2\lambda^2\right]^2},$$

such that this threshold is the maximum level of emissions to ensure the positivity of eq. (33).

E. Characterisation 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:

$$e_0^* = (\Phi + e_m \digamma)\,\Psi^{-1}, \tag{34}$$

which is a linear form describing the optimal level of quality, where

$$\begin{aligned}
\digamma &\equiv (1-\lambda)\left(\left(\beta^2-4\right)^2(\beta(\beta+1)(\beta+3)+1)-8\left(\beta^2-1\right)(2d+1)\lambda^2-4\lambda^3\right) \\
&\quad -8\left(\beta^2-1\right)d\overline{E}\lambda\left((\beta-2)(\beta+2)^2+2\lambda^2\right) \\
\Phi &\equiv 2\alpha\left((\beta-1)(\beta+1)(\beta+3)\left(\beta^2-4\right)^2-2\lambda^2\left(\beta(\beta(\beta+6)-4)+8\left(\beta^2-1\right)d-12\right)-4\lambda^3\right)- \\
&\quad 8\left(\beta^2-1\right)d\overline{E}\lambda\left((\beta-2)(\beta+2)^2+2\lambda^2\right) \\
\Psi &\equiv \left(\beta^2-4\right)^2[\beta(\beta+1)(\beta+3)+1]\lambda-\left(\beta^2-4\right)^2(\beta(\beta(\beta+2)-5)-7)+ \\
&\quad 4\lambda^3\left(-2\beta^2(2d+1)+4d+3\right)+8\lambda^2\left((\beta-1)\beta(\beta+4)+2\left(\beta^2-1\right)d-9\right)+4\lambda^4.
\end{aligned}$$

In particular, note that it is composed by two parts where the first part, Φ, is independent by e_m.

The second order condition of SW with respect to e_0 yields:

$$\frac{(1-\lambda)\left[\begin{array}{c}\beta^7(\lambda-1)+\beta^6(4\lambda-2)+\beta^5(13-5\lambda)+\beta^4(23-31\lambda)+8\beta^3\left(\lambda^2-\lambda-7\right)\\+\beta\left(-32\lambda^2+48\lambda+80\right)-8\beta^2\left((2d+1)\lambda^3-(2d+3)\lambda^2-7\lambda+11\right)\\\left(4\left((4d+3)\lambda^3-2(2d+9)\lambda^2+\lambda^4+4\lambda+28\right)\right)\end{array}\right]}{2\left(1-\beta^2\right)\left(\beta^3+2\beta^2-4\beta+2\lambda^2-8\right)^2}<0$$

for $d>\widehat{d}$, where

$$\begin{aligned}\widehat{d} \equiv\ & \frac{4\left(3-2\beta^2\right)\lambda^3+\left(\beta^2-4\right)^2(\beta(\beta+1)(\beta+3)+1)\lambda-\left(\beta^2-4\right)^2(\beta(\beta(\beta+2)-5)-7)}{16\left(1-\beta^2\right)(1-\lambda)\lambda^2}+\\ & \frac{8((\beta-1)\beta(\beta+4)-9)\lambda^2+4\lambda^4}{16\left(1-\beta^2\right)(1-\lambda)\lambda^2}\end{aligned}$$

F. 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. (34). Then, comparing $\widehat{e}$ with e_i^* (the equilibrium quality in the unregulated case) yields $\widehat{e}-e_i^*>0$, for $e_m<\widetilde{e}_m$, where $\widetilde{e}_m\equiv\chi/\varrho$, and

$$\begin{aligned}\chi\ =\ & 8\left(\beta^2-1\right)d\overline{E}\lambda\left((\beta-2)(\beta+2)^2+\lambda^2+\lambda\right)\\ & -2\alpha\left((\beta-1)(\beta+1)(\beta+3)\left(\beta^2-4\right)^2+(\beta-2)(\beta+2)^2\lambda-\lambda^2\left(\beta(\beta(\beta+10)-4)+16\left(\beta^2-1\right)d-16\right)\right)\\ \varrho\ \equiv\ & (1-\lambda)\left(\left(\beta^2-4\right)^2(\beta(\beta+1)(\beta+3)+1)+2(\beta-2)(\beta+2)^2\lambda-8\left(\beta^2-1\right)(2d+1)\lambda^2\right)\end{aligned}$$