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Andrea Mantovani
Ornella Tarola
Cecilia Vergari

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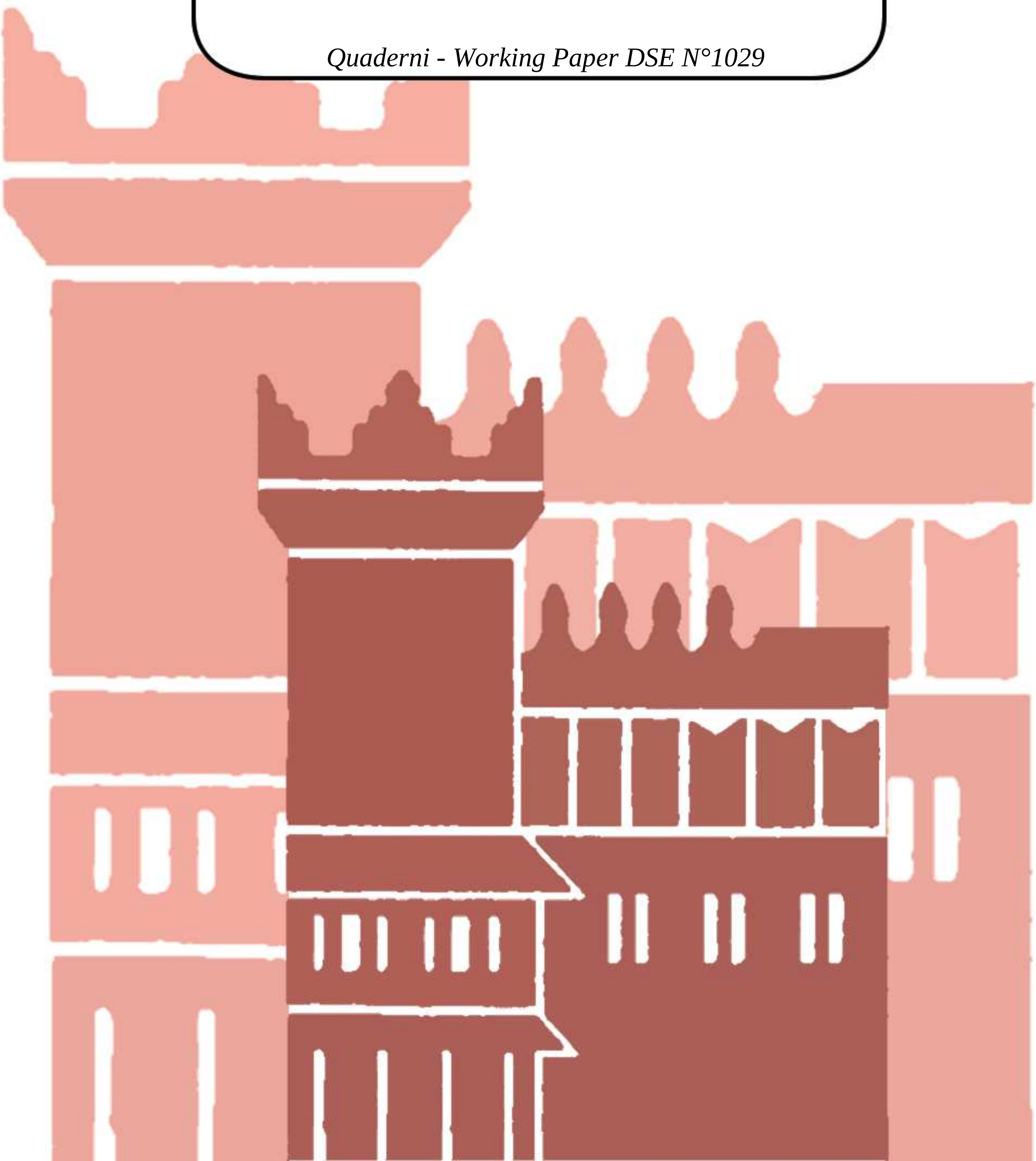

Hedonic Quality and Social Norms: a hybrid model of product differentiation*

Andrea Mantovani†, Ornella Tarola‡ and Cecilia Vergari§

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Abstract

We analyse how strategic competition between a green firm and a brown competitor develops when their products are differentiated along two dimensions: hedonic quality and environmental quality. The former dimension refers to the pure (intrinsic) performance of the good, whereas the latter dimension has a positional content: buying green goods satisfies the consumers' desire to be socially worthy citizens. Product variants thus comply at different levels with "green" social norms. Consumer preferences depend on a combination of hedonic quality and compliance with social norms. Assuming that the high hedonic quality variant complies less with these norms than the low hedonic quality variant, we characterize different equilibrium configurations which appear as a result of both the intensity of such norms and the willingness to pay for the hedonic quality. Afterwards, we discuss the policy implications of our analysis.

Keywords: Hedonic quality, environmental quality, relative preferences.

JEL Classification: D62; L13; H13.

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†Department of Economics, University of Bologna, Strada Maggiore 45, 40125 Bologna, Italy, and Barcelona Institute of Economics (IEB), C/ Tinent Coronel Valenzuela 1-11, 08034 Barcelona, Spain; email: a.mantovani@unibo.it.

‡Department of Economics and Social Sciences, University of Rome "La Sapienza"; email: ornella.tarola@uniroma1.it.

§Department of Economics, University of Bologna, Strada Maggiore 45, 40125 Bologna, Italy, email: cecilia.vergari@unibo.it

1 Introduction

In this paper, we analyse how strategic competition between a green firm and a brown competitor develops when their products are differentiated along two dimensions: hedonic quality and environmental quality. The former dimension refers to the pure (intrinsic) performance of the good, whereas the latter dimension has a positional content: buying green goods satisfies the consumers' desire to be socially worthy citizens. Finally, these quality dimensions are in conflict so that the higher is the hedonic quality of a good, the lower is the corresponding environmental quality. Also, we consider whether the attitude of consumers toward green goods can help make policy makers to enhance policy measures against pollution thereby allowing consumers to play an active role in environmental protection.[1]

Two main considerations inspire our analysis. *First* of all, people are increasingly aware of the role that their behaviour has on the environment. There is a large strand of literature that states that consumers care about the impact of their consumption choices on the environment, thus affecting the quality of life of friends, relatives, and colleagues (Ostrom, 2000; Heffner *et al.*, 2007; Carlsson *et al.*, 2010, Deltas *et al.* 2013). When buying "green" products, people feel that they comply with a *social norm* for which such a *green consumption behavior* is a byword of *good citizenship.* Consequently, an environmentally friendly product may contribute to satisfy the desire to stand out as a good citizen and of being *socially worthy* (Ostrom, 2000).[2] As a such, green goods can be attributed to the set of positional products which provide buyers with some social/psychological benefits beyond the material needs that products traditionally satisfy.[3] On the contrary, when buying "brown" products, consumers may incur a social stigma as they fail to comply with the norm of responsible citizens. *Green consumption is a byword for good citizenship, likewise brown purchases leads to a blameworthy social image.*[4] Since people seek a relative position among peers and buy products also because of their social value, the higher the quality of the product compared to the alternative, namely its

[1] Interstingly, this question has been recently faced by the European Commission: in the Energy Union Package, for the first time EU has stated that consumers can play a key role against pollution.

[2] If a consumer buys a product which lacks any environmental friendly characteristics, he might have a bad conscience because environmental awareness is expected from him. (Conrad 2, 2005).

[3] Notice that this positional content has no direct relationship with the current regulation adopted in a specific country. Take as an example the automotive emissions standards set by the European Union. Two types of car can meet the requirements, while having different emissions levels. From the EU viewpoint, both of them are *sufficiently* green and therefore do not incur any restriction to circulation. However, from the consumers' viewpoint, the less pollutant the car, the more significant the contribution to the environment and therefore the better the social image.

[4] This behavior has been well described since Veblen (1899) by the theory of conspicuous consumption, in which consumer's utility (or status) depends at least partially on the comparison of one's own consumption and good's quality to that of others. Under conspicuous consumption, buyers are willing to pay a higher price for a functionally equivalent good in order to reveal their wealth, their social status or other specific characteristics. See Bagwell and Bernheim (1996) and Bowles and Park (2005) for recent contributions.

ranking along *the quality ladder*, the higher its social value and the corresponding position it confers to the buyer along the *social ladder*. Therefore, the environmental quality gap between variants is a measure of the positive (or negative) contribution to environmental protection.[5]

If this is the case, why are brown products still so popular? In several circumstances, brown goods meet the consumers' requirements better than the green alternatives. They can have higher levels of performance than green products (Carrigan and Attalla, 2001; Gupta and Ogden 2009, Weatherell *et al.*, 2003). For example, conventional internal combustion engine vehicles, although dominated by green alternatives in terms of polluting emissions, are still superior in most cases to electric or hybrid vehicles based on pure performance. Paper produced from trees instead of recycled paper is often preferred because it is softer to the touch; even for short trips, flying is commonly preferred over taking the train because of time efficiency. Whatever the intrinsic driver to brown consumption, as Conrad states "there is a trade-off between utility derived from preferred characteristics of a product and the moral behavior of buying "green", expected by part of the society.[...] Producers are aware of the conflict of consumers between preferred characteristics and their environmental incompatibility. They know that customers, getting their preferred characteristics from an environmental friendly product, welcome that coincidence but if environmental aspects are missing, they might anyhow buy the product." (Conrad 2, 2005).

An immediate by-product of the above evidence is that, when the nature of the most preferred good is not green, its ranking along the quality ladder mainly depends on the importance that people attach to the environmentally friendly nature of the product as compared to other attributes. The existence of a *conflict between* the social component of consumption and the individual-rationality-based motive constitutes the *second* ingredient of the analysis.[6]

The modeling framework: a hybrid category of product differentiation

In order to formalize the above evoked ingredients, we define a market consisting of two firms providing differentiated goods to a population of consumers. The functionality of a product determines its hedonic quality so that goods can be ranked along a quality ladder depending on their performance. The variant characterized by a better (resp. lower) performance is thus the high (resp. low) quality good in terms of hedonic quality. Nonetheless, the better is its performance, the more polluting is the good. We assume that, the utility deriving from consuming a product depends also on the *environmental quality gap* between this variant and the other available in the market, thereby

[5] This approach stems from the notion of relative preferences, introduced in the literature by Akerlof (1997). In Akerlof (1997), the satisfaction of a consumer increases with the difference between the personal status and others' status. Later contribution come from Alexopoulos and Sapp (2006) and Riechmann (2006) with relative preferences from the point of view of firms. These preferences are also labeled "*other-regarding preferences*". Ben-Elhadj and Tarola (2015) apply these preferences to environment.

[6] Of course, often this conflict does not arise. In Ben-Elhadj and Tarola (2015), the consumption behavior is described under the assumption that a product with high performance is also green. As we explain later, the current paper can be also viewed as a complement to that analysis.

nesting the notion of relative preferences in the utility function. While this assumption allows us to describe the social role of consumption in enhancing environment protection, it makes the choice between the two variants far from being evident. Indeed, it adds a further dimension of product heterogeneity with unexpected effects on the traditional mechanism of competition between firms in a vertically differentiated market.

By definition, in the case of vertical differentiation, when two variants are marketed at the same price, then all consumers prefer the same one (the high-quality variant): they all agree on the goods' ranking along the quality ladder. However, if a product is better than the alternative according to one characteristic but worse than it according to another feature, then the defining property of vertical differentiation can cease to hold. In this case, it may occur that, at the same price, some consumers buy a good, and some others buy the other one: there exists heterogeneity among consumers in the products' ranking. Since in our approach products are differentiated along two different dimensions, we deal with both vertical and horizontal differentiation. Competition between firms is described by a model of vertical differentiation as long as all consumers agree that the good performance of a product values more than its green nature (or the reverse!). A model of horizontal differentiation is instead evoked as soon as non-unanimity among consumers arises. Interestingly, in our approach, the traditional result of horizontal differentiation that states that symmetric firms quote an equal price for their products at equilibrium can never be observed. The asymmetry between firms stemming from the two dimensions of differentiation is such that, when the defining property of vertical differentiation stops holding, the horizontal differentiation does not apply *sensu stricto*. Rather, competition falls into a hybrid category where at equal prices both variants have a positive demand (horizontal differentiation) but at equilibrium their prices do not coincide (vertical differentiation).[7]

More precisely, in this hybrid category of product differentiation, first we observe that when both firms are active at equilibrium, in some circumstances the price of the green good (the low hedonic quality product) ceases to be lower than the price of the competing variant (we label this the *price switch* effect). Of course, this result cannot be reconciled with that emerging in vertical differentiation where the high quality good is *always* sold at a higher price than the low quality variant. Second, we find that a *market-monopolization effect* takes place whenever the intensity of relative preferences is sufficiently high; only the green firm can stay active in the market, the "dirty" competitor being pushed off the market. A monopoly configuration can be observed in a vertically differentiated setting only under a restrictive assumption on the heterogeneity of the consumers in the market which leads to the so called natural monopoly. Third, at this monopoly equilibrium configuration, for extremely high intensity of relative preferences, the green monopolist extends the market coverage farther than what is typically observed in a vertically differentiated setting, thereby

[7] There is strand of literature combining horizontal and vertical differentiation. See among others, Gabszewicz and Thisse (1986), Neven and Thisse (1990), and more recently Gabszewicz and Wauthy (2012).

inducing a *market-coverage effect*.

Finally, we develop some policy considerations. Although the set of policy tools for emissions abatement is rather wide, some researchers and policy-makers share the view that a price on carbon could be one of the most efficient means of reducing the emissions. Also, a recent trend among firms is the voluntary and responsible reduction of emissions that is gradually spreading worldwide with an increasing involvement of well-known Multinational Enterprises (MNEs).

Although these two approaches do not share the same rationale (a carbon tax imposing a penalty on polluting firms, the voluntary programs being based on a free participation), a common trait is that firms can escape from abatement effort, if it is relatively too costly. Whenever a carbon tax is unilaterally set by a virtuous country, firms in the country can choose to relocate abroad, if this is more profitable than abating emissions. An immediate consequence of this is the emergence of the so called pollution havens, which have ambiguous effect on the global environmental damage. As for the voluntary programs, since they are not imposed by law, it is not yet clear among policy-makers whether they can somehow induce more and more firms to abate emissions with significant effects on the pollution damage. Incidentally, the idea that firms can refrain from investing in green productions if this investment is too costly is at the basis of the cap-and trade-system. Under this system, emission limits are set on firms. The limit or cap is allocated and/or sold by a central authority to firms in the form of emissions permits. These permits enables firms to emit a specific volume of the specified pollutant. Then, firms can either use carbon offsets to meet standards or trade emissions credits thereby escaping the effort to abate emissions.

In this paper, we consider whether a relevant effect on the environmental damage can be obtained when only one firm undertakes an abatement effort. In line with a recent strand of literature stating that there exists a trade-off between economic performance and environmental quality (Boucekkine *et al.*, 2011, 2013), in our model the abatement effort improves the environmental quality of the good at the expenses of the corresponding hedonic quality. Since complying with stricter environmental norms is costly, when a firm invests in cleaner technology, it sacrifies at least *in a short-run* perspective its own economic performance.[8] For example, Wagner et al. (2002) found a negative relationship between economic performance and a composite environmental indicator over the period 1995-1997.[9]

Interestingly, we find that when only the brown producer improves its environmental quality, the total damage can increase. This surprising result can be explained when taking into account that changing the quality of a good modifies its corresponding market share and possibly that of the rival. The effect, already known and labelled by the literature on trade and environment, composition effect

[8] Admittedly, some argue that there is no way to offset this trade-off regardless of the time horizon (Luken *et al.* 1996), while others suggest that in the long-run, getting better technologies in all respects (both environmental and hedonic dimensions) is feasible (Boucekkine et al., 2011).

[9] The economic performance has been measured by the return to capital employed. The environmental indicator has been defined taking into account emissions of SO2 and NOx, and chemical demand for oxygen in German, Italian, Dutch and British industries.

is mitigated or rather intensified by the existence of social preferences. These preferences can shape it in such a way that an effort for pollution abatement by the brown firm can have the undesirable effect to raise the pollution emitted by the industry as a whole! Rather, when green firms improve their environmental quality, the damage in the industry can decrease even if the pollution coming from the brown producer increases. We show how these effects are related to the equilibrium structure emerging in the market. It is worth noting that these findings support the view that pollution is a global issue and as a such it requires multilateral agreements among countries. If unilateral policies enable firms to escape from emissions abatement (through relocation or trade of permits, *inter alia*), then one could observe a raise in global pollution as a consequence of an asymmetric effort among firms.

Related Literature

Throughout the course of the last decade, increasing attention has been devoted to the impact of environmental awareness on market equilibrium (Conrad, 2005; Eriksson, 2004; García-Gallego and Georgantzís, 2009; Moraga-Gonzalez and Padro-Fumero, 2002; Nyborg *et al.,* 2006; Rodriguez-Ibeas, 2007; Ben Elhadj and Tarola, 2015, *inter alia*). However, to the best of our knowledge, we are the first to combine in a unified setting of vertical differentiation the notion of relative preferences and the possibility of a conflict between traditional hedonic qualities and newly established environmental qualities. In this perspective, we complement the paper by Conrad (2005) and that by Ben Elhadj and Tarola (2015). The former considers the trade-off between the utility derived from the preferred characteristics of a product and the moral behavior of buying "green" in a horizontal differentiation setting. The latter is based instead on a vertically differentiated setting where relative preferences are explicitly taken into account, as people seek a *relative* position among peers and buy products also for their social value.

More specifically, Conrad (2005) analyzes a two stage game where firms define the environmental characteristic of the products at the first stage, thereby competing in price at the second stage.[10] We share the view that environmental concern can modify traditional consumers' preferences and, accordingly, it must be incorporated directly into the utility function. Nevertheless, we depart from his model as our analysis is conceived in a setting dealing a priori with both vertical and horizontal differentiation, and we embrace the view that the environmental quality is perceived as a positive characteristic of the product, and consumers may be willing to pay a higher price for a green good (Farhar and Houston, 1996; Wasik, 1996; Lombardini-Riipinen, 2005; García-Gallego and Georgantzís, 2009). Finally, far from Conrad (2005), we assume that both the social benefit and the

[10] Coad *et al.* (2009) consider the processes of adoption of pro-environmental innovations by individual consumers. They point out that, since environmental protection is a public good, not all agents can be willing to preserve environment. In this view, they consider whether the Government policy may intervene in order to sustain the adoption of green innovations such as environmentally-friendly cars. Although they are mainly concerned with the notion of public good, their discussion on intrinsic motivation and environmental morale provides useful insights to our analysis.

social stigma attached to buyers increase with the environmental quality gap between variants.[11]

Ben Elhadj and Tarola (2015) introduce relative preferences in a model of vertical differentiation, and we follow such an approach. As in their paper, we also consider that the relative position of a consumer in the social ladder depends on the relative position of the product variant that she buys along the quality ladder. Nevertheless, they limit their attention to the case in which a variant is simultaneously of higher hedonic quality and more environmentally friendly than the alternative. Accordingly, it never arises a conflict for the consumer between the pure performance of a product and the social image that can be associated to its consumption. We complement their analysis by introducing such a conflict into the utility function.[12]

Our paper is finally linked to a significant stream of the behavioral economics literature studying pro-environmental behaviors (for a detailed review, see Turaga *et al.*, 2010). This literature aims at explaining the discrepancy between the predictions of the economic models based on the *homo economicus* assumption and the empirical evidence on the voluntary contribution to public goods. Drawing insights from social psychology, the idea is to extend the standard models incorporating the incentive coming from moral/social motivation. Besides the important works by Andreoni (1988, 1990), there are many recent theoretical as well as empirical contributions in the ecological economics literature (see among others, Brekke *et al.*, 2003; Nyborg *et al.*, 2006; Manner and Gowdy, 2010; Ek and Soderholm, 2008; Owen and Videral, 2006). While we take inspiration from this literature, we depart from it as we do not endogenise the moral/social incentive to pro-environmental behaviors, we rather study how it affects market competition (and in turn the environmental damage) in the presence of product differentiation.

The structure of the paper is as follows. In Section 2 we set up the model. In Section 3 we develop the equilibrium analysis. In Section 4 we develop some environmental policy considerations. Section 5 concludes.

2 The Model

Consider a vertically differentiated market with two variants of the same good. Similarly to the models of vertical differentiation (Mussa and Rosen, 1978), we state that the performance of the variant i, with $i = L, H$, determines its *intrinsic* or *hedonic quality* q_i. Accordingly, $q_H > q_L$: variant H has a higher intrinsic quality than variant L so that q_H is ranked higher along the *hedonic quality ladder*. Nevertheless, variant q_i generates polluting emissions per unit of production at some level $e_i = \phi q_i$. Accordingly, variant q_H represents the brown good. Conversely, variant L is considered as

[11] In Section 2, we will discuss at length how our utility function differs from that modeled by Conrad (2005).

[12] Notice also that, whenever a vertically differentiated setting is used to analyze an environmental problem, it is generally assumed that otherwise identical products differ in their emissions so that the environmental quality represents the only source of differentiation (Moraga-Gonzales and Fumero 2002, Lombardini-Riipinen 2005, and García-Gallego and Georgantzís 2009). Accordingly, our analysis also complements this strand of literature.

green because its emissions e_L are lower than those deriving from variant q_H, namely $e_L = \phi q_L < e_H$. The *environmental quality* of L is then higher than that of H. The ranking between q_H and q_L is reversed when considered in terms of this latter dimension of quality: variant q_L is ranked higher than variant q_H along the *environmental quality ladder*.[13]

There is a continuum of consumers indexed by θ and uniformly distributed in the interval $[0, b]$ with density $\frac{1}{b}$. Keeping the traditional interpretation from vertical differentiation models, parameter θ is proportional to the willingness to pay (henceforth WTP) for intrinsic quality, so that b denotes the maximal WTP for the performance of a product among consumers.[14] Formally, the indirect utility of consumer type θ writes as:

$$U(\theta) = \begin{cases} \theta q_H - p_H - \gamma(e_H - e_L), \text{ if she buys the high quality good,} \\ \theta q_L - p_L + \gamma(e_H - e_L), \text{ if she buys the low quality good,} \\ 0, \text{ if she refrains from buying.} \end{cases}$$

We add to the traditional component of the indirect utility function $(\theta q_i - p_i)$ a further ingredient, namely $\gamma(e_H - e_L)$ with $i \neq j$, such that the satisfaction of buying a product variant can be either amplified or decreased by the environmental characteristics of variant i as compared with j. It is worth noting that, it is not the level of emissions *per se* to determine the utility of consuming a variant. Rather, as both the green and the brown variant are intended as positional goods, it is the *relative* pollution coming from them - captured by the term $|\gamma(e_H - e_L)|$ - to affect consumers' utility.[15] Parameter $\gamma \geq 0$ measures the intensity of the relative dimension of consumption;[16] the higher the value of γ, the stronger the relative (or social) preferences with respect to the hedonic ones.[17] For the sake of simplicity and without any loss of generality, we can assume that $\phi = 1$, so that $(e_H - e_L) = (q_H - q_L)$.[18]

From the above formulation of the utility function, the consumer that is indifferent between buying the low quality good and not buying at all is:

$$\theta_L = \gamma + \frac{p_L - \gamma q_H}{q_L} = \frac{p_L - \gamma(q_H - q_L)}{q_L}. \tag{1}$$

with $\theta_L > 0 \iff p_L > \gamma(q_H - q_L)$. The consumer that is indifferent between buying the low quality good and the high quality good is:

$$\theta_H = 2\gamma + \frac{p_H - p_L}{q_H - q_L}. \tag{2}$$

[13] It is worth noting that, from a social welfare viewpoint, the relative environmental quality of a variant does not play any role, being rather the absolute level of emissions, e_L and e_H, the reference point of a social planner.

[14] Under this assumption on density, the population of consumers is always constant. See Garcia-Gallego and Georgantzis (2009).

[15] See Ben Elhadi *et al.* (2014) for an indepth discussion of this formalization.

[16] In our work, we use the terms *social* and *relative* as synonymous given that they both indicate that consumption has a social dimension. Likewise, the resulting satisfaction also depends on the characteristics of society.

[17] The extreme case $\gamma = 0$ reduces the model to the traditional vertical differentiation framework with hedonic preferences as unique drivers for consumption.

[18] We could consider a generic $\phi > 0$ without normalizing ϕ to 1. However, this would not bring any further insight to the model while making the analysis by far more cumbersome.

Thus, we immediately write the demand function faced by firm i, x_i:

$$\begin{aligned} x_H &= \frac{1}{b}(b-\theta_H) = \frac{1}{b}\left[b - \left(2\gamma + \frac{p_H - p_L}{q_H - q_L}\right)\right] \\ x_L &= \frac{1}{b}(\theta_H - \max\{\theta_L, 0\}) = \begin{cases} \frac{1}{b}\left[\frac{p_H q_L - q_H p_L}{q_L(q_H - q_L)} + \frac{\gamma(q_H + q_L)}{q_L}\right] \text{ if } p_L > \gamma(q_H - q_L), \\ \frac{1}{b}\left(2\gamma + \frac{p_H - p_L}{q_H - q_L}\right) \text{ if } p_L \leq \gamma(q_H - q_L). \end{cases} \end{aligned}.$$

Note that as soon as θ_L is not positive, the market is covered, that is also consumer type $\theta = 0$ is willing to buy.

It is easy to see that the defining property of vertical differentiation can cease to hold in this setting. In particular, when q_H and q_L are sold at the same price, the demand function faced by firms H and L, respectively write as:

$$\begin{aligned} x_H\ (p_H &= p_L) = \frac{1}{b}(b - 2\gamma) \\ x_L\ (p_H &= p_L) = \begin{cases} \frac{1}{b}\left[\frac{\gamma(q_H + q_L) - p_L}{q_L}\right] \text{ if } p_L > \gamma(q_H - q_L), \\ \frac{2\gamma}{b} \text{ if } p_L \leq \gamma(q_H - q_L). \end{cases} \end{aligned}$$

Notice that:

$$\begin{aligned} x_H\ (p_H &= p_L) > 0 \iff \gamma < \frac{b}{2} \equiv \gamma^H. \\ x_L\ (p_H &= p_L) > 0 \iff \begin{cases} \gamma > \frac{p_L}{q_H + q_L} \equiv \gamma^L(p_L) \text{ if } p_L > \gamma(q_H - q_L) \\ \forall\ \gamma > 0 \text{ if } p_L \leq \gamma(q_H - q_L) \iff \gamma \geq \frac{p_L}{q_H - q_L} \end{cases}, \end{aligned}$$

with $\frac{p_L}{q_H - q_L} > \gamma^L(p_L)$. Thus, the market can be properly defined as a vertical differentiated market for extreme values of γ: namely, either $\gamma \leq \min\{\gamma^L(p_L), \gamma^H\}$ or $\gamma \geq \max\{\gamma^L(p_L), \gamma^H\}$. In the former case the environmental awareness is not very significant and no consumer would be willing to buy the green good if its price is equal to that of the brown alternative: the performance of a product defining its hedonic quality dominates the environmental impact which rather describes its environmental quality and we are in the case of hedonic vertical differentiation. In the latter case, on the contrary, the consumers' involvement in environmental protection is so strong that nobody would buy the brown good, in spite of its better performance if the prices coincide: the importance of the hedonic dimension of quality is dominated by the environmental dimension of quality and we observe environmental vertical differentiation. Finally, for intermediate values of γ, namely $\gamma \in \left(\min\{\gamma^L(p_L), \gamma^H\}, \max\{\gamma^L(p_L), \gamma^H\}\right)$ both firms could get a positive market share at the same price so that the approach of horizontal differentiation turns out to be the proper way to describe the competition between firms. In particular, both firms get a positive market share for $b \geq b_D(p_L)$ with

$$b_D(p_L) \equiv \frac{2p_L}{(q_H + q_L)}. \tag{3}$$

In other words, when $b \in (0, b_D(p_L))$, in $\gamma \in (\gamma^H, \gamma^L(p_L))$ neither firm has a positive demand in the market when they charge the same price, while in $b \geq b_D$ we have that $\gamma \in (\gamma^L(p_L), \gamma^H)$ and both players are active in the market.

We can summarize the above findings in the following Proposition:

Proposition 1 *For extreme values of γ, namely either $\gamma \leq \min\{\gamma^L(p_L), \gamma^H\}$ or $\gamma \geq \max\{\gamma^L(p_L), \gamma^H\}$, the defining property of vertical differentiation holds. In the former (resp. the latter) case, the hedonic quality dimension (resp. the environmental quality dimension) is the main driver to consumption.*

We assume that profit functions of firms H and L write, respectively as:

$$\pi_H = x_H \cdot p_H, \tag{4}$$

$$\pi_L = (p_L - c)\, x_L. \tag{5}$$

where $c > 0$ is the cost per unit of green production. In the above formulation, it is implicitly stated that production costs for firms only come from producing an environmentally friendly good. Otherwise, one could imagine that there exists a cost function $c_i = h_i + E_i$ where h_i denotes the hedonic-quality specific cost borne by firm i, with $h_H > h_L$ and E_i the environmental quality specific cost, with $E_H < E_L$.[19] Since it is reasonable that $h_H > h_L$ always holds, the only way to get $c_H < c_L$ is to assume that $(E_L - E_H) > (h_H - h_L)$. Without any loss of generality, we can write $c_L > c_H = 0$.[20]

We will show in the following analysis that different market equilibrium configurations may arise, depending on the parameters' values. In order to solve the model, we compute the price equilibrium candidates corresponding to each market configuration and provide the parameter intervals for which they yield the corresponding market outcomes.[21] Without loss of generality, in the text we confine the analysis to the case where the quality gap is such that $q_H/q_L \in (1, 2)$ and we provide in the Appendix the complementary analysis where $q_H/q_L \geq 2$. We will show there that our qualitative findings are robust to this extension.

3 The equilibrium analysis

Typically, in a vertically differentiated setting, in absence of production costs, there is always room for two firms if the market is not a *natural duopoly*.[22] Furthermore, when the lowest WTP in the

[19] The case when $c_H > c_L$ has been largely treated in the literature on vertical differentiation (Cremer and Thisse 1994). Thus, we can disregard it.

[20] One may wonder why we do not introduce some fixed costs to capture the role of green technologies in production. Admittedly, when the quality is mainly related to investments in new technologies or in R&D, the assumption of fixed quality-specific costs can be reasonable. Nevertheless, a fixed cost does not affect the price game as it does not alter firms' best reply functions.

[21] This is standard in models of vertical differentation. See Wauthy (1996) for more details.

[22] The upper bound to the number of firms which can coexist at equilibrium with positive market share and positive equilibrium prices has nothing to do with costs and only depends on pattern of tastes and willingness to pay distribution.

market is equal to zero, firms never find it profitable to cover the market. Accordingly, the starting point of our analysis is that both firms are active and the market is uncovered. Therefore, demands are defined as $x_L = \frac{1}{b}(\theta_H - \theta_L)$ and $x_H = \frac{1}{b}(b - \theta_H)$. Profit functions for firm H and firm L are given by:

$$\pi_H = x_H \cdot p_H, \tag{6}$$

$$\pi_L = (p_L - c)\, x_L, \tag{7}$$

and the pair of candidate equilibrium prices can be easily obtained:

$$p_L^* = \frac{2cq_H + (q_H - q_L)(2\gamma q_H + bq_L)}{4q_H - q_L}, \tag{8}$$

$$p_H^* = \frac{cq_H + (q_H - q_L)[2bq_H - \gamma(3q_H - q_L)]}{4q_H - q_L}. \tag{9}$$

Formally, for this candidate to be an equilibrium, we need to verify that both prices are positive and that p_L is higher than the marginal cost, namely $p_L^* > c$ and $p_H^* > 0$:

$$p_L^* \geq c \iff \gamma \geq \frac{c(2q_H - q_L) + bq_L(q_L - q_H)}{2q_H(q_H - q_L)} \equiv \underline{\gamma}, \tag{10}$$

$$p_H^* \geq 0 \iff \gamma \leq \frac{q_H[2b(q_H - q_L) + c]}{(q_L - 3q_H)(q_L - q_H)} \equiv \overline{\gamma}, \tag{11}$$

with

$$\underline{\gamma} > 0 \iff b < b_0 \equiv \frac{c(2q_H - q_L)}{q_L(q_H - q_L)}, \tag{12}$$

$$\overline{\gamma} > \underline{\gamma} \iff b > \underline{b} \equiv \frac{c}{(q_H + q_L)}, \tag{13}$$

and $b_0 > \underline{b}$. Moreover, we have to demonstrate that the market is uncovered, and that both goods have positive demands, *i.e.* $0 < \theta_L < \theta_H < b$. Then, by plugging (8) and (9) into (1) and (2), we obtain:

$$\theta_H^* \leq b \iff \gamma \leq \overline{\gamma},\ \theta_L^* \leq \theta_H^* \iff \gamma \geq \underline{\gamma},$$

$$\theta_L^* \geq 0 \iff \gamma \leq \widehat{\gamma} \equiv \frac{2cq_H + b(q_H - q_L)q_L}{(2q_H - q_L)(q_H - q_L)}, \tag{14}$$

where the precise values of θ_L^* and θ_H^* are reported in the Appendix (see proof of Lemma 1). Moreover:

$$\widehat{\gamma} > \overline{\gamma} \iff b < \widehat{b} \equiv \frac{cq_H}{(q_H - q_L)^2}.$$

One can already notice that there are situations where an interior duopoly solution with uncovered market cannot be sustained at equilibrium. For example, when $\gamma > \overline{\gamma}$, $\theta_H^* > b$ (and $p_H^* < 0$), then

In particular, given a population of consumers, identified by the parameter $\theta \in [\alpha, \beta]$, $0 \leq \alpha < \beta$ the upper bound to the number of firms is 2 so that the market is a natural duopoly iff $\frac{\alpha}{\beta} \in \left[\frac{1}{4}, \frac{1}{2}\right]$.

firm H can not be active at the duopoly equilibrium. Moreover, in the parametric region where $b > \widehat{b}$ and $\gamma > \widehat{\gamma}$, $\theta_L^* < 0$ then the market is covered.

The following lemmas identify the market configurations that emerge for each combination of b and γ, the crucial parameters of our model. We confine in the Appendix the mathematical proofs. Lemma 1 specifies the conditions for the duopoly equilibrium to hold:

Lemma 1 *Provided $b > \underline{b}$, both firms are active in the market when $\gamma \in [\max\{0, \underline{\gamma}\}, \max\{\overline{\gamma}, b\})$. The duopoly is sustained by an interior equilibrium for $\gamma \in [\max\{0, \underline{\gamma}\}, \min\{\overline{\gamma}, \widehat{\gamma}\})$, while it is sustained by a corner equilibrium with the market covered for $\gamma \in [\widehat{\gamma}, b)$. The latter possibility only occurs when $b \geq \widehat{b}$.*

Proof. See Appendix. ■

It follows that, when b is sufficiently high and γ is not excessive, a duopoly emerges at the equilibrium. When this happens, two additional results are worth the attention. First, by comparing equilibrium prices in the duopoly scenarios, we find that:

Remark 1 *When the market is characterized by a duopoly, the equilibrium price of the green variant can be higher than that of the brown variant. In particular, this always holds when the duopoly is covered at the limit, and in $\gamma \in (\widetilde{\gamma}, \min\{\overline{\gamma}, \widehat{\gamma}\})$ when the duopoly is uncovered, given that* $p_L^* > p_H^* \iff \gamma > \dfrac{b(2q_H^2 - 3q_H q_L + q_L^2) - cq_H}{(q_H - q_L)(5q_H - q_L)} \equiv \widetilde{\gamma}.$

Proof. See Appendix. ■

Second, by recalling Proposition 1, we find that:

Remark 2 *For intermediate values of γ the duopoly equilibrium is characterized by horizontal differentiation and both firms get a positive market share when selling at the same price. For relatively high (low) values of γ, environmental (hedonic) vertical differentiation prevails.*

Proof. See Appendix. ■

By combining the results of Lemma 1 and Remarks 1-2, one realizes how the duopoly equilibrium is crucially affected by social preferences. For relatively low levels of γ, hedonic vertical differentiation characterizes the market interaction between the brown and the green producer. Consumers are mainly interested in the intrinsic quality of the product rather than its environmental impact, and the brown firm can charge a higher price than its green rival. For intermediate values of γ, horizontal differentiation prevails and both producers obtain a positive market share even when charging the same price. Within this parametric region a *price switch* occurs for $\gamma > \widetilde{\gamma}$, meaning that the green producer obtains a price premium since environmental savvy consumers highly value the green dimension of quality. Such a price gain is more pronounced when γ further increases. Moreover, as we enter the interval region $\gamma > \gamma^H$, environmental vertical differentiation properly describes market competition, as we know from Proposition 1. In the last region compatible with a duopoly equilibrium, *i.e.* $\gamma \in [\widehat{\gamma}, b)$, not only the green producer enjoys the price premium, but it also covers the market at the limit.

In order to complete the characterization of the market equilibria, we next move to consider the possibility for either firm to monopolize the market. Our results are gathered in Lemmas 2 and 3.

Lemma 2 *For each level of b, the green firm monopolizes the market for* $\gamma > \max\{\underline{\gamma}^M, \overline{\gamma}, b\}$, *where* $\underline{\gamma}^M \equiv \dfrac{c - bq_L}{q_H - q_L}$. *The green monopoly market is covered for* $\gamma \geq \gamma^M \equiv \dfrac{c + bq_L}{q_H - q_L}$, *otherwise it remains uncovered.*

Proof. See Appendix. ■

Lemma 3 *The brown firm monopolizes the market in the range of parameters such that* $b \in [0, b_0)$ *and* $\gamma < \min\{\underline{\gamma}, \overline{\gamma}^M\}$, *where* $\overline{\gamma}^M \equiv \dfrac{bq_H}{(q_H - q_L)}$.

Proof. See Appendix. ■

Finally, we can identify a relatively small interval region where neither the brown nor the green producer is active on the market. In particular,

Lemma 4 *There is no active firm at the market equilibrium when* $b \in [0, \underline{b})$ *and* $\gamma \in (\overline{\gamma}^M, \underline{\gamma}^M)$.

Proof. See Appendix. ■

While the results of Lemma 4 complete our equilibrium analysis, our focus is on the interval regions where at least one firm is active. The following Proposition summarizes the main findings of Lemmata (1-3):

Proposition 2 *Depending on the interplay between b and* γ, *we can characterize two relevant interval regions*:

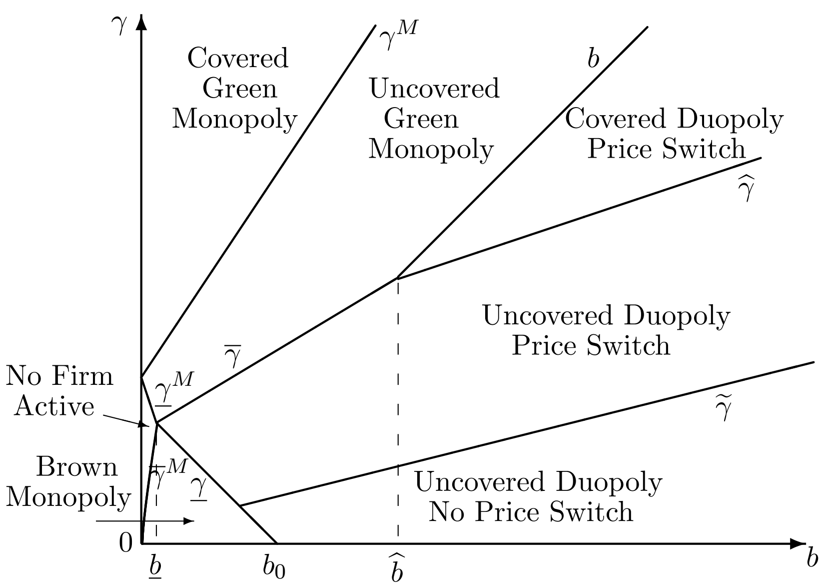
(i) *For relatively low values of b* ($b \in (\underline{b}, \widehat{b})$), *both firms are active at the interior equilibrium when* γ *takes intermediate values, while the market is monopolized by the green (resp. brown) producer for* γ *sufficiently high (resp. low). At the green monopoly equilibrium, the green producer finds it profitable to cover the whole market when* γ *is extremely relevant.*

(ii) *When b is relatively high* ($b \geq \widehat{b}$), *the brown producer never monopolizes the market. Further, under duopoly the green firm can optimally cover the market. This happens for relatively high values of* γ. *Finally, it becomes increasingly difficult for the green firm to monopolize the market.*

Proof. It directly follows from combining the proofs of Lemmata 1-3. ■

Figure 1 represents all the different market configurations which emerge at equilibrium, together with the *price switch* discussed in Remark 1.[23] As we restricted our attention to the case $q_H/q_L \in [1, 2)$, Figure 1 was plotted by fixing $q_H = 1.5$ and $q_L = 1$, together with $c = 1$. This is without loss of generality. We consider in the Appendix the case where $q_H/q_L \geq 2$.

Figure 1: $q_H/q_L \in (1, 2)$



It is worth noting that, compared with the traditional setting of vertical differentiation, the equilibrium configurations are affected here not only by conventional parameter b, which measures the willingness to pay for the hedonic quality, but also by parameter γ, which captures the additional social component of consumption. The existence of social preferences represents a benefit for the green firm, and its intensity determines which market configuration prevails for each given value of b.

Consider sufficiently high values of b ($b > \underline{b}$) and γ ($\gamma > \underline{\gamma}$) and focus on Lemmas 1 and 2, combined with Remarks 1 and 2. Figure 1 shows that the duopoly holds at equilibrium when $\gamma \in [\max\{0, \underline{\gamma}\}, \max\{\overline{\gamma}, b\})$, as from Lemma 1. Indeed, it shows the interval region where the *price switch effect* takes place ($\gamma > \widetilde{\gamma}$, as from Remark 1) and the green firm can quote a price higher than the brown rival, its variant being perceived above than the other one along the quality ladder. In this case, the environmental dimension of quality is more valuable than the hedonic counterpart, and we can even have a region characterized by environmental vertical differentiation (Remark 2).

Another interesting feature of our model is related to the fact that both the price of the green

[23] The issue of vertical *vs.* horizontal differentiation reported in Remark 2, while being useful in interpreting our results, does not add much in terms of graphical representation.

variant and the corresponding market share at equilibrium increase with γ, whatever the equilibrium market configuration.[24] Accordingly, there is no trade-off between the price switch effect and the market share enjoyed by the green firm. For sufficiently high values of γ, in fact, the brown firm is forced to exit the market. This is represented in Figure 1 in the region $\gamma > \max\{\underline{\gamma}^M, \overline{\gamma}, b\}$, where a *green monopolization effect* enters the scene, as we know from Lemma 2. Finally, for extremely high values of γ ($\gamma \geq \gamma^M$), a positive *market coverage effect* appears, with the green producer selling its variant to the whole set of consumers.

Notice that these effects are always mitigated by the parameter b, whose intensity favours the brown producers as it indicates that consumers are willing to pay more for the hedonic dimension of quality. This is evident in Figure 1, where, the higher b, the higher the $\gamma - value$ required for the above effects to emerge. As a conclusive point, we can state:

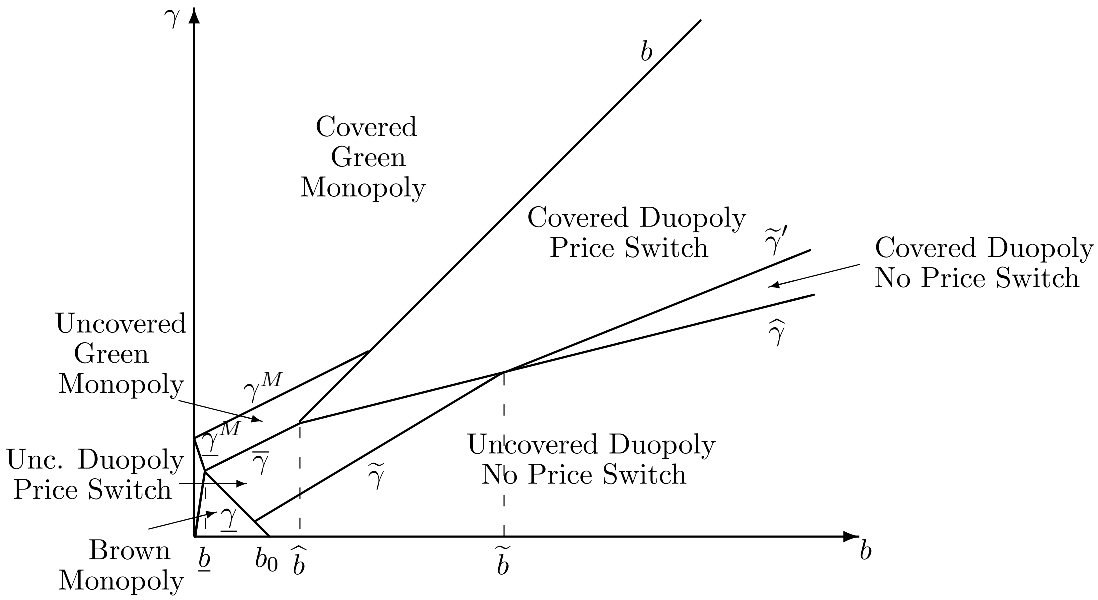
Corollary 1 *Ceteris paribus, both the price switch effect and the green monopolization effect are more likely to occur for relatively low values of b.*

Proof. It is relatively easy to show that all the relevant threshold values of γ are increasing in b. This, combined with the proofs of Lemmata 1-3, completes the demonstration. ■

Finally, the above results can be applied to each specification of the quality ratio q_H/q_L. The equilibrium analysis reported in this section assumes a quality gap such that $q_H/q_L \in (1, 2)$. In the Appendix we show that the same qualitative results hold for $q_H/q_L \geq 2$. Namely, although the interval region defined by the relevant threshold values of γ change in dimension, at equilibrium we get the same market configurations as in Proposition 2. Figure 2 represents the case $q_H/q_L \geq 2$. The unique difference with respect with Figure 1 is that $q_H = 2.8$.

[24] Indeed, the positive effect of γ on the equilibrium price and market share is observed under both duopoly and monopoly.

Figure 2: $q_H/q_L \geq 2$



A comparison between Figure 1 and Figure 2 enables us to evaluate the consequences of increasing the quality gap between the two variants. Two forces are pushing towards opposite directions given that consumers value the environmental performance of the product and not only its intrinsic quality. On the one hand, as q_H/q_L increases, consumers tend to value more the intrinsic quality difference, thus rewarding the high quality-brown producer. On the other hand, the higher hedonic quality gap, which corresponds to a higher environmental quality gap, raises the social component of consumption thus contributing to favour the low quality-green producer. It is again the interaction between γ and b that determines which of these two forces prevails. When γ is relatively high, notice in Figure 2 that the area where the market is covered, both for the green monopoly and for the duopoly, tend to increase. *Ceteribus paribus*, an increase in the quality gap is reflected here in a higher level of effectiveness of relative preferences. On the contrary, for relatively low levels of γ, it is the intrinsic quality that dominates the environmental effects, and an increase in q_H/q_L tends to favour the brown producer. One can notice, for example, that the area where the price switch does not occur is larger in Figure 2.[25]

4 Some environmental policy implications

We evaluate the effect on the environmental damage when one firm is induced to improve its environmental quality, either by a policy, whatever it is, or by a voluntary program for emissions abatement.[26]

[25] An increase in q_H/q_L implies an upward shift of $\widetilde{\gamma}$, as it can be easily demonstrated.

[26] We focus on changes of the environmental damage due to changes of firms'environmental qualities. We depart from the literature on environmental policy instruments looking at total social welfare that typically focuses on taxation

Consistently with a large bulk of literature, when improving the environmental quality, the firm sacrifies the corresponding performance of the good. This trade-off between economic performance and environmental quality is viewed as a key feature of the environmental policy: since both governments at international level and consumers at local level call for cleaner technologies, firms are faced with the urgency to comply with stricter environmental norms.[27] Nevertheless, their abatement efforts at least in the short run penalize the economic performance. In our model, environmental quality and hedonic quality go along opposite directions so that the above evoked trade-off immediately emerges.

The total environmental damage deriving from global emissions (D) is defined as the sum of the environmental damage coming from the green firm $D^L = q_L x_L$, and that coming from the brown rival $D^H = q_H x_H$, where we remind that the hedonic qualities reflect the per-unit emissions of the goods, i.e. $q_L = e_L$ and $q_H = e_H$.[28] Formally, we analyse what happens when either firm improves its environmental quality given the environmental quality of the rival. The main findings can be explained by tracking down some typical effects that, borrowing from the literature on trade and environment, we can label *technique* effect and *composition* effect. The former effect indicates the reduction of damage deriving from adoption of green technologies, with a lowering in emissions for unit of output. The latter refers to the change of market share that each firm undergoes as a consequence of the different quality gap between variants.[29] In our model, the composition effect is moved by two drivers: a price competition driver and a social component of consumption driver. Changing the environmental quality of a variant affects the quality gap and thus the price competition taking place in the market. For example, increasing the environmental quality of the brown good reduces the quality gap, thereby making the price competition between firms fiercer. As a consequence of this, the brown firm expands its market share and steals consumers from the rival with an immediate increase in the corresponding damage. On the contrary, increasing the environmental quality of the green firm magnifies the hedonic quality gap between goods thereby softening the price competition in the market. In this case, the market share of the brown firm tends to decrease thus reducing the

and subsidies (see for instance Moraga-Gonzales and Padron-Fumero (2002), Lombardini-Riipinen (2005) and Deltas *et al.* (2013)). There is however a recent stream of literature supporting environmental/informative campaigns as a policy instrument to supplement and/or substitute traditional policies. See among others Sartzetakis *et al.* (2012) and Mantovani and Vergari (2013). See also Lambertini (2013) for a comprehensive analysis.

[27] The role of consumers in enhancing investment in cleaner technology has been recently recognized by the institutions. See the Energy Union Package (2015) on this.

[28] The environmental damage is usually taken to be quadratic in the level of emissions. Our assumption of a linear environmental damage allows us to simplify calculations and obtain analytically tractable expressions. However, the qualitative results of our paper do not change if we consider alternative specifications, even if that would imply resorting to tedious numerical simulations. See Lambertini 2013 for this assumption of linear damage.

[29] Typically, in the trade and the environment literature (see e.g. Copeland and Taylor, 1994, 2003), it is usual to distinguish three effects of trade liberalisation on the environment, following Grossman and Krueger (1993). The *scale effect* captures the impact on the level of economic activity, with the composition of total production unchanged. The *composition effect* indicates the change in the sectoral composition of production due to the impact of trade liberalisation on the country specialization. The *technique* effect reflects that trade liberalisation may lead to a change in the technologies adopted, with a lowering in emissions for unit of output.

corresponding damage, whereas the market share of the green firm can decrease.

From the equilibrium analysis, we know that different equilibrium configurations can emerge. Accordingly, we analyse the environmental properties of each equilibrium in turn.

We consider first the case of *uncovered duopoly*. We remind that, it takes place whenever the social component of consumption takes intermediate values (namely $\gamma \in \left(\max\{0, \underline{\gamma}\}, \min\{\overline{\gamma}, \widehat{\gamma}\}\right)$). The environmental damage is:

$$D_D = D_D^L + D_D^H = q_H \frac{b\,(2q_H + q_L) + \gamma\,(q_L - q_H) - c}{(4q_H - q_L)}.$$

Let us assume that the brown firm decides to reduce its per-unit emissions, while the green firm refrains from changing its quality variant. We keep the assumption that the brown firm always stays more pollutant than the green rival (namely $e_H > e_L$).

Proposition 3 *Consider the uncovered duopoly equilibrium. Increasing the environmental quality of the brown variant does not always reduce the environmental damage. Indeed, when the social component of consumption is sufficiently high, the damage coming from the green firm decreases with the environmental quality of the brown good. Still, the damage from the brown firm increases to such an extent to neutralize this reduction whenever the WTP for hedonic quality is low. In this circumstance, total damage increases with the environmental quality of the brown good.*

Proof. See Appendix. ■

For an intuition of the results stated in the above Proposition, notice that a reduction of q_H raises the equilibrium market share of the brown firm (as a lower quality calls for a lower price and in turn a higher quantity) while decreasing that of the green producer (the consumption coming from the moral motivation is increasing in the environmental quality gap) when the social component of consumption is rather high. In this case, the *composition effect* occurs with the brown firm stealing consumers from the green rival. Thus, the effect on the damage coming from the green firm is clear-cut: it decreases as a result of improving the environmental quality of the brown good. As for the effect on the damage coming from the brown firm, this is ambiguous. On one hand, a direct effect is that the per-unit emissions decrease; but on the other hand the indirect effect of reducing q_H is that the market share of the brown firm increases. The first effect is independent of γ and b. The second effect instead increases with the social component of consumption γ and decreases with the WTP b: the higher is γ, and / or the lower is b, the more significant is the impact of the quality gap reduction on the consumption decisions. As a result, as long as γ is low relative to b, the direct effect of reducing q_H prevails, so that D_D^H decreases; for γ relatively high, in contrast, it is the indirect effect to prevail so that D_D^H increases.

Now, let us consider the alternative scenario where the green firm improves its environmental quality, the brown firm refraining from emissions abatement.

Proposition 4 *Consider the uncovered duopoly equilibrium. Improving the environmental quality of the green good reduces the damage coming from the brown firm to such an extent that even when the own green firm's damage increases, the total damage decreases.*

Proof. See the Appendix. ■

Improving the environmental quality of the green variant has always a positive effect on the damage of the brown rival, since it decreases. Indeed, a lower q_L widens the quality gap between variants so that the price competition softens and *ceteris paribus* the equilibrium price of the brown variant increases. As a consequence, the corresponding market share decreases like so the damage. The green firm instead can get a larger market share if the social component of consumption is very significant. Nevertheless, the net effect on total damage is clear-cut: it always decreases because the increase in the damage coming from the green producer is overcompensated by the reduction in damage deriving from the brown firm.

Consider next the *covered duopoly*. We remind that, it takes place whenever $\gamma \in (\widehat{\gamma}, b)$, that is a relevant interval as long as the WTP for hedonic quality is rather high (namely $b > \hat{b}$). The environmental damage is:

$$D_C = D_C^L + D_C^H = \frac{1}{b}\left[\left(q_L \frac{1}{2}(b+\gamma)\right) + \left(q_H \frac{1}{2}(b-\gamma)\right)\right] = \frac{1}{b}\left(\frac{1}{2}b(q_H + q_L) - \gamma \frac{1}{2}(q_H - q_L)\right).$$

Each component of damage (D_C^L and D_C^H) decreases linearly with the environmental qualities q_H and q_L. Interestingly, the composition effect does not play any role because the market share of each firm is independent of the rival's environmental quality. So, the damage coming from the producer i, namely D_C^i increases with q_i, while being independent of q_j, with $i, j = H, L$ and $i \neq j$. Further, the total damage decreases with γ, while being increasing in b. This is quite intuitive because under market coverage, *ceteris paribus*, the higher the market share of the brown good (increasing in b and decreasing in γ), the lower the corresponding market share of the less pollutant rival. So, we can state that:

Proposition 5 *In the covered duopoly equilibrium, improving the environmental quality of a variant, whatever it is, always reduces the environmental damage.*

It follows from the above that whenever the price competition between firms is particularly fierce (which is typically the case under market coverage), improving the environmental quality of either the brown or the green good entail the same qualitative effect on damage.

Consider finally the case when the social component of consumption γ is so high ($\gamma > \max\{\underline{\gamma}^M, \overline{\gamma}, b\}$) that the market is *monopolized by the green firm.* However, the brown good (not sold at equilibrium) remains a reference point for consumers. In the *uncovered monopoly*, $\gamma \in [\max\{\underline{\gamma}^M, \overline{\gamma}, b\}, \gamma^M)$, the environmental damage writes as

$$D_M = q_L \frac{bq_L - c + \gamma(q_H - q_L)}{2q_L} = \frac{1}{b}\left[\frac{1}{2}(bq_L - c + \gamma(q_H - q_L))\right].$$

Whenever the green firm improves its environmental quality, we find that

$$\frac{\partial D_M}{\partial q_L} = \left(-\frac{1}{2}\right) b^{-1} (\gamma - b) < 0$$

as $\gamma > b$ always holds. Therefore, the abatement effort by the green firm increases the damage as its market share enlarges. Rather, when improving the environmental quality of the brown good the environmental damage reduces unambiguously as:

$$\frac{\partial D_M}{\partial q_H} = \frac{1}{2} b^{-1} \gamma > 0.$$

At first sight, this finding can be counterintuitive: the brown firm plays a role in determining the damage, while being inactive in the market. However notice that an abatement effort could be undertaken by the brown firm with the aim of re-entering the market. This surprising result can be explained when taking into account that the market share of the green firm is affected by the quality produced by the brown rival: the more pollutant the brown good, the larger the market share of the green producer and thus the higher the corresponding damage. This implies that an abatement effort by the brown firm dominates that coming from the green firm in terms of damage.

In the *covered monopoly*, $\gamma > \gamma^M$, the damage coincides with the per-unit emissions of the green good, q_L. In this case, the brown firm no longer plays a role in determining the damage since under market coverage there is no room for entry.[30]

Proposition 6 *Under monopoly, whenever the market is uncovered, improving the environmental quality of the green (resp. brown) firm increases (resp. reduces) the total damage. When the market in covered, the damage increases with the environmental quality of the green variant, the brown producer ceasing to play a role.*

Although we have developed a very stylized analysis, we find that under duopoly, the abatement coming from the green firm is preferred over that coming from the brown since the former unambiguously reduces damage, while the latter can cause an increase of it. However, the same statement no longer holds when considering the monopoly case. Indeed, under monopoly, inducing the brown firm to improve its environmental quality reduces the damage, which rather increases when an effort is undertaken by the green firm.

5 Conclusions

In this paper, we have considered a situation in which a "clean" and a "dirty" firm compete in the market by offering two differentiated products that differently satisfy a social norm. We have assumed that there exist two sources of differentiation: the performance of the good determines its *hedonic*

[30] In a way, this result is reminiscent of the natural monopoly property.

quality, while the polluting emissions set its *environmental quality*. Furthermore, the high (resp. low) hedonic quality variant is less (resp. more) complying with the norm compared with the alternative. Therefore, an environmentally friendly good satisfies the consumers' desire to stand out as a *good citizen*, however leaving them unsatisfied due to poor performance. Our findings can be summarized as follows. First of all, our model departs from a traditional setting of vertical differentiation, belonging rather to a hybrid category of product differentiation where goods can be either vertically or horizontally differentiated depending on the social component of consumption. As a result of this, the traditional ranking of prices no longer holds and a price switch can emerge, with the price of the low hedonic quality variant being higher than the alternative good. This price switch effect can emerge as a consequence of a quality switch so that all consumers would prefer the green good to the brown alternative, if the variants would be sold at the same price. In this case, the mechanism underlying the price switch directly flows from the vertical differentiation approach, where the green variant is intended as a high-quality variant. Otherwise, the price switch emerges in a setting where only some consumers would prefer the green good to the brown product, if sold at the same price. In this case, the switch can no longer be attributed to a vertical differentiation mechanism: the defining property of competition is here rather ascribable to the horizontal differentiation.

Further, when the social component of consumption is strong, the market can be monopolized by the green producer. It is worth noting that this monopolization effect is never observed in a vertically differentiated market where the lower bound of the market is nil. Typically, in this situation there is always room in the market for two firms, as a natural monopoly setting requires the market to be covered. Furthermore, in a traditional vertically differentiated framework, the coverage of the market can never be observed due to the lower bound above evoked: when the lowest willingness to pay is nil, no firm can find it profitable to cover the market at equilibrium as this choice would require to set a nil price at equilibrium.

From the above considerations, it derives that the social dimension of consumption provides the green producer with an incentive to specialize in green production: the green firm can benefit from a price premium or even monopolize the market for values of γ sufficiently high. As a such, these preferences represent a market-based mechanism for firms to produce green goods and escape from the penalty deriving from the consumers' attitude toward brown products. An immediate consequence of this statement is that, contrary to what is somehow argued, consumers may have a role in reducing pollution. Nesting the conflict between the social component of consumption and the individual-rationality-based motive in the traditional utility function enables to show how this role can be carried out. Moreover, taking into account this consumers' attitude toward green goods sheds light on the effectiveness of climate policy measures when they do not involve all firms in the market. Under a trade-off between hedonic quality and environmental quality, our analysis shows that the effect of reducing emissions on environmental damage is not clear-cut as it changes with the firm undertaking emissions' abatement and the market structure arising at equilibrium.

Appendix

Proof of Lemma 1

First, observe that the interval $[\max\{0,\underline{\gamma}\},\max\{\overline{\gamma},b\})$ is non-empty for $b>\underline{b}$ given that $\underline{\gamma}>0 \iff b<b_0$ with $b_0>\underline{b}$, $\overline{\gamma}>\underline{\gamma} \iff b>\underline{b}$ and $\overline{\gamma}>b \iff b<\widehat{b}$. Notice also that the interval $[\widehat{\gamma},b)$ is non-empty only for $b>\widehat{b}$, given that $\widehat{\gamma}<b \iff b>\widehat{b}$. Secondly, following the previous discussion, equilibrium candidates (8) and (9) verify $p_L^*>c$, $p_H^*>0$ and $0<\theta_L^*<\theta_H^*<b$ only when $\gamma\in[\max\{0,\underline{\gamma}\},\min\{\overline{\gamma},\widehat{\gamma}\})$, where:

$$\begin{aligned}\theta_L^* &= \frac{2cq_H-(q_H-q_L)\left[2\gamma q_H-(b+\gamma)q_L\right]}{(4q_H-q_L)\,q_L},\\ \theta_H^* &= \frac{(q_H-q_L)\left[(2b+3\gamma)q_H-(b+\gamma)q_L\right]-cq_H}{(4q_H-q_L)\,(q_H-q_L)}.\end{aligned}$$

Indeed, for $\gamma\geq\widehat{\gamma}$ (which is possible only when $b\geq\widehat{b}$), then $\theta_L^*\leq 0$ and the market is covered. However, an interior duopoly solution with covered market cannot be sustained at equilibrium. In order to prove it, assume that the demand for the low quality good starts at zero. This means that $x_L\equiv\theta_H$. Solving the corresponding *f.o.c.s* for the modified profit functions, the candidate equilibrium prices are

$$\begin{aligned}p_H^{'} &= \frac{1}{3}[c+2(b-\gamma)\,(q_H-q_L)],\\ p_L^{'} &= \frac{1}{3}[2c+(b+2\gamma)\,(q_H-q_L)].\end{aligned}$$

Now we can substitute into (1) and (2) and check that $\theta_L^{'}<0<\theta_H^{'}<b$, together with $p_H^{'}>0$, $p_L^{'}>c$. Algebraic calculations reveal that:

$$\begin{aligned}\theta_L^{'} &\equiv \frac{2c+(b-\gamma)\,(q_H-q_L)}{3q_L}<0\Leftrightarrow\gamma>\frac{2c+(b-\gamma)\,(q_H-q_L)}{3q_L},\\ \theta_H^{'} &\equiv \frac{1}{3}(b+2\gamma-\frac{c}{q_H-q_L})>0\Leftrightarrow\gamma<b+\frac{c}{2\,(q_H-q_L)}.\end{aligned}$$

Nonetheless, the two conditions cannot be simultaneously satisfied given that

$$\frac{2c+(b-\gamma)\,(q_H-q_L)}{3q_L}>b+\frac{c}{2\,(q_H-q_L)},$$

as it can be easily ascertained. In such a case, therefore, a duopoly with the market *covered at the limit* becomes the equilibrium candidate. This equilibrium configuration is characterized by constrained price competition. As the market is covered at the limit, the indifferent consumer θ_L defined in (1) is set equal to zero, and demand functions are defined as $x_L=\theta_H$ and $x_H=b-\theta_H$. Accordingly, the equilibrium price of the green good is now given by:

$$p_L^C=\gamma\,(q_H-q_L)\,,$$

and it always hold that $p_L^C > c$. Therefore, inserting such a value in the best reply of the high quality firm and solving, we obtain:

$$p_H^C = \frac{(b-\gamma)(q_H - q_L)}{2}.$$

The optimal price of the brown firm p_H^C is strictly positive *iff* $\gamma < b$. Hence, when $\gamma \geq \widehat{\gamma}$, there is still room for both producers and the market is covered at the limit only when $\gamma < b$, as it can also be observed from $0 = \theta_L^C < \theta_H^C < b$, where $\theta_H^C = (b+\gamma)/2$.

Proof of Remark 1

At the interior duopoly equilibrium we find that:

$$p_L^* \gtreqless p_H^* \iff \gamma \gtreqless \frac{b(2q_H^2 - 3q_H q_L + q_L^2) - cq_H}{(q_H - q_L)(5q_H - q_L)} \equiv \widetilde{\gamma}.$$

Moreover, it is straightforward to find that $\widetilde{\gamma} \in (0, \min\{\overline{\gamma}, \widehat{\gamma}\})$ when $q_H/q_L \in (1,2)$. In such a case, then, the price charge charge by the green producer is higher than that charged by the brown producer when $\gamma \in (\widetilde{\gamma}, \min\{\overline{\gamma}, \widehat{\gamma}\})$. The opposite holds in $\gamma \in (0, \widetilde{\gamma}]$.

Consider now the covered duopoly at the limit, which holds when $\gamma > \widehat{\gamma}$ and $b > \widehat{b}$. We easily obtain that:

$$p_H^C > p_L^C \iff \gamma < \frac{b}{3} \equiv \widetilde{\gamma}'.$$

However, it is immediate to find that:

$$\widehat{\gamma} - \widetilde{\gamma}' = \frac{2\left[3cq_H - b(q_H - q_L)(q_H - 2q_L)\right]}{3(q_H - q_L)(2q_H - q_L)} > 0$$

given that we are limiting our attention to the case where $q_H/q_L \in (1,2)$. When the duopoly is covered at the limit, we get that $p_H^C < p_L^C$.

Proof of Remark 2

First of all, we insert p_L^* in $b_D(p_L)$ and impose $\gamma = \widetilde{\gamma}$ to find that:

$$\gamma^H > \gamma^L(p_L^*|_{\gamma=\widetilde{\gamma}}) \iff b \geq \frac{4cq_H}{(q_H + q_L)(3q_H + q_L)} \equiv b_D^*.$$

In such a case, moreover,

$$x_L(p_H^* = p_L^*) > 0 \iff \gamma > \frac{2cq_H + b(q_H - q_L)q_L}{2q_H^2 + 5q_H q_L - q_L^2} \equiv \gamma_{ID}^L,$$

where additional subscript ID stands for *Internal Duopoly*. It is immediate so show that $\underline{b} < b_D^* < b_0$ and that $\gamma^H > \gamma_{ID}^L$ when the duopoly is uncovered, *i.e.* in $\gamma \in [\max\{0, \underline{\gamma}\}, \min\{\overline{\gamma}, \widehat{\gamma}\})$.

On the other hand, when the market is covered at the limit, $x_L(p_H^C = p_L^C) > 0 \iff \gamma > 0$ and obviously no vertical hedonic differentiation prevails when γ is relatively high, *i.e.* in $\gamma \in [\widehat{\gamma}, b)$.

All in all, under the conditions sustaining a duopoly (both covered and uncovered), market competition between the green and the brown producer can be described by either horizontal or vertical differentiation. In particular, when $\gamma \in [\max\{0, \underline{\gamma}\}, \gamma_{ID}^{L})$, then hedonic vertical differentiation prevails, as the social component of consumption is very weak. For $\gamma \in [\gamma_{ID}^{L}, \gamma^{H})$ horizontal differentiation prevails as both firms would obtain a positive market share even when charging the same price. It is also possible to demonstrate that $\widetilde{\gamma} \in [\gamma_{ID}^{L}, \gamma^{H})$, thus revealing that the price switch occurs when products are perceived as horizontally differentiated. Finally, $\gamma \in [\gamma^{H}, \max\{\overline{\gamma}, b\})$, the duopoly equilibrium is characterized by environmental vertical differentiation, given that consumers attach a high value to the environmental performance of the product.

Proof of Lemma 2

The proof aims at demonstrating that, when $\gamma > \max\{\underline{\gamma}^{M}, \overline{\gamma}, b\}$, two conditions are simultaneously verified: *(i)* the brown firm is not active in the market, neither at the duopoly nor at the monopoly equilibrium; *(ii)* the equilibrium price charged by the green firm when it holds a monopoly position is higher than its marginal cost. First, notice that:

$$\max\{\underline{\gamma}^{M}, \overline{\gamma}, b\} = \begin{cases} \underline{\gamma}^{M} \text{ if } b \leq \underline{b}, \\ \overline{\gamma} \text{ if } b \in \left(\underline{b}, \widehat{b}\right), \\ b \text{ if } b \geq \widehat{b}. \end{cases}$$

Let us start from the brown firm. At the internal duopoly equilibrium, $p_H^* \geq 0 \iff \gamma \leq \overline{\gamma}$, as we know from (11). When $\gamma > \overline{\gamma}$, then $p_H^* < 0$ and the brown firm would stop producing. Consider now $\gamma \in (\overline{\gamma}, \underline{\gamma})$, which holds in $b \in [0, \underline{b}]$. Following (10), there exists the possibility for brown producer to monopolize the market, given that $p_L^* < c$. In such a case, its profit would be $\pi_H^M = p_H \{b - [p_H/q_H + \gamma (q_H - q_L)/q_H]\}$. We compute the equilibrium price p_H^M and find that:

$$p_H^M = \frac{bq_H - \gamma(q_H - q_L)}{2} > 0 \iff \gamma < \frac{bq_H}{(q_H - q_L)} \equiv \overline{\gamma}^{M}.$$

However, $\overline{\gamma}^{M} < \overline{\gamma}$ in $b \in [0, \underline{b}]$. This implies that $p_H^M < 0$ in $\gamma > \overline{\gamma}$. The brown monopoly is therefore excluded from the market when $\gamma \in (\overline{\gamma}, \underline{\gamma})$. Finally, from the demonstration of Lemma 1, we know that, when the market is a duopoly covered at the limit, then $p_H^C \geq 0$ when $\gamma \leq b$. We need to impose therefore $\gamma > b$ to remove the possibility for the brown producer to be present in the covered duopoly at the limit. To sum up, parametric restrictions ensuring that the brown firm is not active in the market boil down to $\gamma > \max\{\overline{\gamma}, b\}$.

As for the green producer, in absence of the brown rival it would obtain monopoly profit $\pi_L^M = (p_L - c)[bq_L - p_L + \gamma (q_H - q_L)]/q_L$. The resulting equilibrium price is:

$$p_L^M = \frac{1}{2}[c + \gamma (q_H - q_L) + bq_L] \geq c \iff \gamma \geq \frac{c - bq_L}{q_H - q_L} \equiv \underline{\gamma}^{M}.$$

We have to introduce therefore the additional condition $\gamma \geq \underline{\gamma}^M$. As we notice above, $\max\{\underline{\gamma}^M, \overline{\gamma}, b\} = \underline{\gamma}^M$ if $b \in [0, \underline{b}]$. Moreover, we have to verify that $0 < \theta_L^M < b$. We can easily find that:

$$0 \quad < \quad \theta_L^M \equiv \frac{c - \gamma q_H + (b+\gamma) q_L}{2 q_L} \iff \gamma < \frac{c + b q_L}{q_H - q_L} \equiv \gamma_M,$$
$$\theta_L^M \quad \leq \quad b \iff \gamma \geq \frac{c - b q_L}{q_H - q_L} \equiv \underline{\gamma}^M.$$

This verifies that the market is characterized at equilibrium by the monopoly position held by the green producer when $\gamma > \max\{\underline{\gamma}^M, \overline{\gamma}, b\}$. Moreover, at this green monopoly, the market is uncovered if $\gamma < \gamma_M$, with $\gamma_M \geq \max\{\underline{\gamma}^M, \overline{\gamma}, b\}$, and covered when $\gamma \geq \gamma^M$.

Proof of Lemma 3

Two conditions have to simultaneously hold when $\gamma < \min\{\underline{\gamma}, \overline{\gamma}^M\}$. First, the green firm can not be active in the market. As we know from (10), $p_L^* < c$ when $\gamma < \underline{\gamma}$. Recall that such an interval region is valid only when $b \in [0, b_0)$, as it can be seen from (12). Second, the price charged by the brown firm when it acts as a monopolist has to be positive. From the demonstration of Lemma 2, we obtained that $p_H^M > 0$ when $\gamma < \overline{\gamma}^M$. This always hold in $b \in (\underline{b}, b_0]$, where it is immediate to demonstrate that $\underline{\gamma} < \overline{\gamma}^M$. In $b \in [0, \underline{b}]$, on the contrary, $\overline{\gamma}^M < \underline{\gamma}$, and therefore in such an interval region we have to impose the additional condition that $\gamma < \overline{\gamma}^M$ for the price charged by the brown monopolist, p_H^M, to be positive. To sum up, when $b \in [0, b_0)$, the only firm in the market is the brown one when $\gamma < \min\{\underline{\gamma}, \overline{\gamma}^M\}$.

Proof of Lemma 4

From Lemmata (1-3), we can identify an interval region where the unique candidate at equilibrium is the absence of producers. From (13), we know that $\overline{\gamma} < \underline{\gamma}$ when $b \in [0, \underline{b}]$, thus complicating our analysis. Consider first $\gamma < \overline{\gamma}$ $(< \underline{\gamma})$. Firm L can not be active at the internal duopoly, given that, from (10), $p_L^* < 0$ when $\gamma < \underline{\gamma}$. The brown monopoly, however, can be sustained at equilibrium only when $p_H^M > 0 \iff \gamma < \overline{\gamma}^M$, as we found in the proof of Lemma 2. Given that $\overline{\gamma}^M < \overline{\gamma}$ in $b \in [0, \underline{b}]$, it follows that no producer is active in $\gamma \in (\overline{\gamma}^M, \overline{\gamma})$. Consider now $\gamma \in [\overline{\gamma}, \underline{\gamma})$. In this region, both $p_L^* < c$ and $p_H^* < 0$. In the proof of Lemma 2, we demonstrated that a brown monopoly does not exist, as $\gamma > \overline{\gamma}^M$ and therefore $p_H^M < 0$. However, neither the green monopoly can hold at equilibrium, as $p_L^M \geq c$ only when $\gamma \geq \underline{\gamma}^M > \underline{\gamma}$. A similar reasoning can be applied when $\gamma \geq \underline{\gamma}$, where $p_H^* < 0$ and the green monopoly holds at equilibrium for $\gamma \geq \underline{\gamma}^M > \underline{\gamma}$. To sum up, no firm is active in the market when $\gamma \in (\overline{\gamma}^M, \underline{\gamma}^M)$.

Equilibrium analysis for $q_H/q_L \geq 2$:

From the equilibrium analysis performed in Section 3, we know that $\widehat{\gamma} > \overline{\gamma} \iff b < \widehat{b}$, $\widetilde{\gamma} < \overline{\gamma}$ and $\overline{\gamma} > \underline{\gamma} \iff b > \underline{b}$. However, when $q_H/q_L \geq 2$ and additional interval region takes place, given that

$$\widehat{\gamma} > \widetilde{\gamma} \begin{cases} \text{always when } q_H/q_L \in (1,2) \\ \iff b < \widetilde{b} \equiv \dfrac{3cq_H}{(q_H - 2q_L)(q_H - q_L)} \text{ when } q_H/q_L \geq 2 \end{cases}.$$

The complete ranking is as follows:

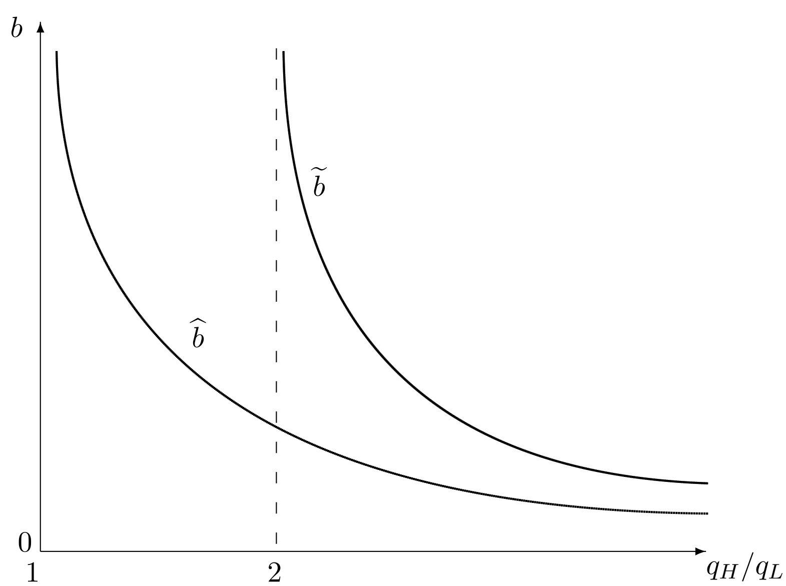
1. $b \in (0, \widehat{b})$: $\widetilde{\gamma} < \overline{\gamma} < \widehat{\gamma}$, where $\widehat{\gamma}$ will not be considered as the equilibrium will change when $\gamma \geq \overline{\gamma}$, given that the brown producer cannot charge a positive price in the market, as we already know (see Lemma 2).

2. $b \geq \widehat{b}$ when $q_H/q_L \in (1,2)$, and $b \in [\widehat{b}, \widetilde{b})$ when $q_H/q_L \geq 2$: $\widetilde{\gamma} < \widehat{\gamma} < \overline{\gamma}$, where $\overline{\gamma}$ will not be considered as we identified a covered market when $\gamma \geq \widehat{\gamma}$ (see Lemma 1).

3. $q_H/q_L \geq 2$ and $b \geq \widetilde{b}$, where $\widehat{\gamma} < \widetilde{\gamma} < \overline{\gamma}$, and here both $\widetilde{\gamma}$ and $\overline{\gamma}$ will not make sense as they are referred to an internal equilibrium which no longer holds when $\gamma \geq \widehat{\gamma}$.

Figure A represents the aforementioned ranking; it has been plotted by fixing $c = 1$ and $q_L = 1$.

Figure A: Threshold Values of b



We focus on the region where $q_H/q_L \geq 2$ and $b \geq \widetilde{b}$, as the remaining interval region has already been analyzed in the main text. The relevant ranking is here $\widehat{\gamma} < \widetilde{\gamma} < \overline{\gamma}$. Two cases have to be considered:

1. In $\gamma < \widehat{\gamma}$ we have an uncovered duopoly without price switch, given that now $\widehat{\gamma} < \widetilde{\gamma}$.

2. When $\gamma \geq \widehat{\gamma}$, then we have a covered duopoly in $\gamma \in [\widehat{\gamma}, b)$ and a covered green monopoly when $\gamma \geq b$. In this interval region, in fact, $\gamma_M < b$, as it can be demonstrated by combining

$$\gamma_M > b \iff b < \frac{c}{q_H - 2q_L} \equiv b^M$$

with the fact that $b^M < \widetilde{b}$. Hence, an uncovered green monopoly cannot be obtained at equilibrium. As for the covered duopoly, we find that the price switch occurs in $\gamma \in [\widetilde{\gamma}', b)$, given that:

$$\begin{aligned} (i)\ p_H^C &> p_L^C \iff \gamma < \frac{b}{3} \equiv \widetilde{\gamma}', \\ (ii)\ \widetilde{\gamma}' &> \widehat{\gamma} \iff b \geq \widetilde{b}. \end{aligned}$$

In $\gamma \in [\widehat{\gamma}, \widetilde{\gamma}')$, we discover the existence of a covered duopoly at the limit *without* price switch.

Proof of Proposition 3

In the unconstrained equilibrium, the equilibrium environmental damage is:

$$\begin{aligned} D_D &= D_D^L + D_D^H = \frac{(2bq_H - c + bq_L - \gamma q_H + \gamma q_L)\, q_H}{(4q_H - q_L)}, \text{ with} \\ D_D^L &= q_L \frac{\left(cq_L - 2cq_H + bq_H q_L - 2\gamma q_H q_L - bq_L^2 + 2\gamma q_H^2\right) q_H}{b\,(q_L - q_H)\,(q_L - 4q_H)\, q_L}, \text{ and} \\ D_D^H &= q_H \frac{\left(2bq_H q_L - cq_H - 4\gamma q_H q_L - 2bq_H^2 + 3\gamma q_H^2 + \gamma q_L^2\right)}{b\,(q_H - q_L)\,(q_L - 4q_H)}. \end{aligned}$$

We proceed by studying the sign of the partial derivatives with respect to q_H.

$$\frac{\partial D_D^L}{\partial q_H} = \frac{\partial q_L}{\partial q_H} x_L + \frac{\partial x_L}{\partial q_H} q_L$$

so that the sign of $\dfrac{\partial D_D^L}{\partial q_H}$ coincides with the sign of $\dfrac{\partial x_L}{\partial q_H}$, given that $\dfrac{\partial q_L}{\partial q_H} x_L = 0$. Then,

$$\begin{aligned} \frac{\partial x_L}{\partial q_H} &= \frac{q_L \left[c\left(6q_H^2 - 4q_H q_L + q_L^2\right) - bq_L\,(q_H - q_L)^2\right] + 4\gamma q_H\,(2q_H - q_L)\,(q_H - q_L)^2}{(q_H - q_L)^2\,(4q_H - q_L)^2\, q_L} > 0 \\ &\iff \gamma > \gamma_L \end{aligned}$$

with $\gamma_L \equiv \dfrac{bq_L^2\,(q_L - q_H)^2 - q_L c\left(6q_H^2 - 4q_H q_L + q_L^2\right)}{4q_H\,(2q_H - q_L)\,(q_L - q_H)^2}$ and $\gamma_L < \overline{\gamma}$.

$$\frac{\partial D_D^H}{\partial q_H} = \frac{\partial q_H}{\partial q_H} x_H + \frac{\partial x_H}{\partial q_H} q_H = x_H + \frac{\partial x_H}{\partial q_H} q_H,$$

where $\frac{\partial x_H}{\partial q_H} < 0$. Then the sign of $\frac{\partial D_D^H}{\partial q_H}$ is ambiguous. Direct computations reveal that

$$\begin{aligned}\frac{\partial D_D^H}{\partial q_H} &= \frac{q_H\left[4b\left(2q_H - q_L\right)\left(q_H - q_L\right)^2 - c\left(5q_H - 2q_L\right)q_L\right] - \gamma\left(12q_H^2 + q_L^2 - 6q_Hq_L\right)\left(q_H - q_L\right)^2}{\left(q_H - q_L\right)^2\left(4q_H - q_L\right)^2} > 0 \\ &\iff \gamma < \gamma_H\end{aligned}$$

where $\gamma_H \equiv \frac{q_H\left[4b\left(2q_H - q_L\right)\left(q_H - q_L\right)^2 - c\left(5q_H - 2q_L\right)q_L\right]}{\left(12q_H^2 + q_L^2 - 6q_Hq_L\right)\left(q_H - q_L\right)^2}$ and $\gamma_H \in (\gamma_L, \overline{\gamma})$. Finally,

$$\frac{\partial D_D}{\partial q_H} = \frac{\partial D_D^L}{\partial q_H} + \frac{\partial D_D^H}{\partial q_H} = \frac{\partial x_L}{\partial q_H}q_L + x_H + \frac{\partial x_H}{\partial q_H}q_H.$$

Again *a priori* the sign is ambiguous. Direct computations reveal that

$$\frac{\partial D_D}{\partial q_H} = \frac{cq_L - 4bq_Hq_L + 8bq_H^2 - bq_L^2 - \gamma\left(4q_H^2 + q_L^2 - 2q_Hq_L\right)}{\left(4q_H - q_L\right)^2} > 0 \iff \gamma < \gamma_D$$

with $\gamma_D \equiv \frac{cq_L + 8bq_H^2 - bq_L^2 - 4bq_Hq_L}{\left(4q_H^2 + q_L^2 - 2q_Hq_L\right)}$ and $\gamma_D > \gamma_H > \gamma_L$. Also $\overline{\gamma} - \gamma_D > 0 \iff b < b_D$, where $b_D \equiv \frac{c\left(q_H^2 - q_Hq_L + q_L^2\right)}{\left(4q_H + q_L\right)\left(q_H - q_L\right)^2}$ and $b_D \in [\underline{b}, \hat{b}]$. Summing up, we find the following ranking:

- for $b > b_D$, we have that $\gamma_L < \gamma_H < \overline{\gamma} < \gamma_D$;
- for $b \in (\underline{b}, b_D)$, we have that $\gamma_L < \gamma_H < \gamma_D < \overline{\gamma}$.

Thus, for $\gamma \in (\gamma_D, \overline{\gamma})$, the sign of the derivatives are such that: $\frac{\partial D_D^L}{\partial q_H} > 0$, $\frac{\partial D_D^H}{\partial q_H} < 0$, $\frac{\partial D_D}{\partial q_H} < 0$.

Proof of Proposition 4

First, notice that $\frac{\partial D_D^H}{\partial q_L} = \frac{\partial q_H}{\partial q_L}x_H + \frac{\partial x_H}{\partial q_L}q_H$. As $\frac{\partial q_H}{\partial q_L}x_H = 0$, the sign of $\frac{\partial D_D^H}{\partial q_L}$ is the same as the sign of

$$\frac{\partial x_H}{\partial q_L} = \frac{q_H\left[c\left(5q_H - 2q_L\right) + 2b\left(q_H - q_L\right)^2 + \gamma\left(q_H - q_L\right)^2\right]}{\left(q_H - q_L\right)^2\left(4q_H - 4q_L\right)^2} > 0.$$

Then, $\frac{\partial D_D^L}{\partial q_L} = \frac{\partial q_L}{\partial q_L}x_L + \frac{\partial x_L}{\partial q_L}q_L = x_L + \frac{\partial x_L}{\partial q_L}q_L$. The sign of $\frac{\partial x_L}{\partial q_L}$ is ambiguous, so it is the sign of $\frac{\partial D_D^L}{\partial q_L}$. Direct computations show that

$$\frac{\partial D_D^L}{\partial q_L} = \frac{q_H\left[c\left(4q_Hq_L - 6q_H^2 - q_L^2\right) + 4bq_H\left(q_H - q_L\right)^2 + 2\gamma q_H\left(q_H - q_L\right)^2\right]}{\left(q_H - q_L\right)^2\left(4q_H - q_L\right)^2} > 0 \iff \gamma > \gamma_L^G.$$

with $\gamma_L^G \equiv \dfrac{c\left(6q_H^2+q_L^2-4q_Hq_L\right)-4bq_H\left(q_H-q_L\right)^2}{2q_H\left(q_H-q_L\right)^2}$. Finally,

$$\frac{\partial D_D}{\partial q_L}=\frac{\left(6bq_H-c+3\gamma q_H\right)q_H}{\left(4q_H-q_L\right)^2}>0 \iff \gamma>\gamma_D^G.$$

with $\gamma_D^G \equiv \dfrac{c-6bq_H}{3q_H}$.

Comparing the relevant thresholds, we find that: $\gamma_L^G-\gamma_D^G=\frac{1}{6}\left(q_H-q_L\right)^{-2}q_H^{-1}\left(4q_H-q_L\right)^2c>0$, $\overline{\gamma}-\gamma_D^G=\dfrac{\left(4q_H-q_L\right)\left[6q_Hb\left(q_L-q_H\right)-cq_L\right]}{3\left(q_H-q_L\right)\left(3q_H-q_L\right)q_H}>0$, $\gamma_D^G-\underline{\gamma}=\dfrac{\left(3bq_L-3bq_H-c\right)\left(4q_H-q_L\right)}{6\left(q_H-q_L\right)q_H}<0$ and $\gamma_L^G-\overline{\gamma}=\dfrac{c\left(4q_H^2-3q_Hq_L+q_L^2\right)-4bq_H\left(q_H-q_L\right)^2}{2\left(q_H-q_L\right)^2\left(3q_H-q_L\right)q_H}\left(q_L-4q_H\right)>0 \iff b<\dfrac{c\left(4q_H^2-3q_Hq_L+q_L^2\right)}{4q_H\left(q_H-q_L\right)^2}\equiv$ b_G, with $b_G-\widehat{b}=\frac{1}{4}\left(q_L-q_H\right)^{-2}q_H^{-1}\left(q_L-3q_H\right)cq_L<0$ and $b_G-\underline{b}=\dfrac{\left(3q_H-q_L\right)^2cq_L}{4\left(q_H-q_L\right)^2\left(q_H+q_L\right)q_H}>0$. Summing up, the following ranking holds (and the proof comes from looking at the signs of the above derivatives in the proper parameters' ranges):

- for $b<b_G$, $\gamma_D^G<\underline{\gamma}<\overline{\gamma}<\gamma_L^G$;
- for $b>b_G$, $\gamma_D^G<\underline{\gamma}<\overline{\gamma}<\gamma_L^G$.

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Alma Mater Studiorum - Università di Bologna
DEPARTMENT OF ECONOMICS

Strada Maggiore 45
40125 Bologna - Italy
Tel. +39 051 2092604
Fax +39 051 2092664
http://www.dse.unibo.it