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Is Environmentalism the Right Strategy to Decarbonize the World?*

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Abstract

We study how the supply of environmentalism, which is defined by psychic benefits (costs) associated with the purchase of high-environmental (low-environmental) qualities, affects the way firms choose their prices and products and the ensuing consequences for the global level of pollution. Contrary to general belief, a high supply of environmentalism does not necessarily give rise to a better environmental outcome because it endows the green firms with more market power which they use to charge higher prices. Nonetheless, environmentalism can be used to effectively complement more traditional policy instruments such as a minimum environmental standard.

Keywords: environmentalism, psychic costs and benefits, vertical product differentiation, environmental policy

JEL Classification: D11, L13, Q50

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1 Introduction

Most debates about the environmental question take the view that consumers' behavior must change if the world is to transition to a cleaner society. A more deeply rooted environmental consciousness would encourage consumers to shift from brown to green products. The change in individuals' consumption choices would then spark a major drop in emissions. We refer to the various doctrines competing to shape the consumer side as *environmentalism* or *green consumerism*.

Firms, responding to these new concerns, are paying more attention to the environmental characteristics of their products. More specifically, a product is now viewed as a bundle of attributes that are hedonic as well as environmental. For example, a car is judged by consumers for its standard performance (safety, comfort, power and reliability) and also for its environmental performance (e.g., its CO_2 emissions). It is significant that environmentally friendly firms are often producers of goods with high hedonic attributes. For example, the Group BMW is ranked first in the "Automobiles" category of the Dow Jones Sustainability Index. In Europe, BMW has reduced its CO_2 emissions by around 42 percent between 1995 and 2019. Since this company aims to reduce emissions by a further 80 percent by 2030, BMW's CO_2 emissions will then be less than 10 percent of what they were in 2006 (Automotive World, November 2020). In a totally different industry, Kering—a global luxury group managing the development of a series of prestigious houses in fashion, leather goods, jewelry and watches—is among the top 10 of the most sustainable companies in the world (Corporate Knights' annual Global 100 ranking, 2020).

Beauty products are currently evaluated not only on their coverage and fragrance but also on their toxicity and whether they were tested on animals. To illustrate, Estée Lauder Companies—a global leader in prestige beauty products, selling more than 25 brands in 150 countries—commits to achieving two goals: sourcing 100 percent renewable electricity, and also producing net zero carbon emissions (Citizenship & Sustainability Report, 2020). We could easily make this list longer to illustrate that producers of high-quality goods are striving to supply goods that are also environmentally friendly. To be sure, this trend to align the hedonic and the environmental attributes is relatively recent. For many years, these features were not in sync; the more environmentally friendly goods often came at the expense of high performance. To mention just one example, it took a lot of manual effort to drive the initial prototypes of hybrid and electric vehicles, which were also noisy and uncomfortable.[1] In addition, there were few charging stations and the cars had limited range, two significant drawbacks.[2]

[1] For more information, visit https://www.energy.gov/articles/history-electric-car.

[2] The above anecdotal evidence is somehow related to the so-called environmental Kuznets curve (EKC) that states environmental degradation first rises and then falls with increasing income per capita. The empirical evidence is mixed. For example, the EKC is more likely to hold in sectors where pollution is local rather than global (Dinda, 2004; Stern, 2004). Moreover, its robustness is also country-specific (Churchill *et al.*, 2018). However, it seems hard to draw clear-cut conclusions. It seems equally clear that the EKC is not purely hypothetical. This points in the same direction as the

Both the hedonic and the environmental attributes together determine the *intrinsic* part of a good. With environmentalism present, the consumer who buys a green product enjoys its intrinsic element but also enjoys a *psychic benefit*, a non-pecuniary feeling of being a "good citizen." By contrast, when the consumer buys a brown product, she pays a *psychic cost*, a non-pecuniary feeling of shame or guilt (Conrad, 2005; Glaeser, 2014). In this case, an *extrinsic* component, related to the level of environmentalism in the public sphere, is added to the consumer decision (Kahn, 2007; Carlsson *et al.*, 2010; Allcott, 2011; Pinto *et al.*, 2014). Whereas the intrinsic component is chosen by firms, the extrinsic one is conferred on the firms by the public at large. Equally important, different individuals assign their own ranking of importance to a value system, in this case, environmentalism. Thus the benefits and costs vary among consumers. In line with the foregoing discussion, we assume that preferences about hedonic and environmental attributes are aligned, that is, the green product embodies more hedonic attributes than the brown one. However, we will also briefly discuss the case where preferences are misaligned.

Since the empirical literature on the consequences of green consumerism is meager, we find it meaningful to start with a theory-based investigation. The classical approach in environmental economics is to consider a market in which firms produce a vertically differentiated good—with hedonic and environmental attributes chosen by producers—for consumers who are willing to pay more for the green variants than for the brown (see the related literature section). However, this modeling strategy fails to capture the various factors that affect consumer choices in a context where cultural, political and social values interact with standard preferences. That said, as Stigler and Becker (1977) warn, care is needed when considering deviations from standard preferences. Otherwise, one runs the risk of providing "microeconomic foundations" to almost any prediction or recommendation policy. We therefore consider a *minimal deviation* from a well-established model by adding individualized psychic costs and benefits to the preferences of rational consumers.

We consider a two-stage setting in which firms, selling the green and brown variants of a given product, choose the environmental attribute of their variant first and the price second. The market outcome is given by a subgame perfect Nash equilibrium. Given the qualities chosen by firms, we first study the ensuing price subgame. In the quality stage, firms anticipate accurately what the equilibrium prices will be while consumer choices are now driven by both firms' quality and price decisions. The marginal production cost increases with quality because producing a more eco-friendly good without reducing its performance often requires more expensive inputs and better management practices. We also assume that improving the environmental quality implies additional overhead expenditures such as R&D and capital goods.

Our main findings may be summarized as follows. Environmentalism generates the expected *positive*

evidence discussed in the text.

effect on the environment *only* when hedonic and environmental attribute are misaligned. In this case, environmentalism fosters the entry of the green variant in a market which is otherwise supplied by the brown variant. In contrast, when attributes are aligned, environmentalism generates *unexpected* effects. In particular, at the price stage, when environmentalism is weak, price competition is relatively tough. The brown firm's entry to the market can be deterred by the green firm. Indeed, consumers are not heterogeneous enough for the green firm to charge a price high enough for the brown firm to enter. As environmentalism grows, however, consumers become more heterogeneous, which provides the green firm with enough market power to set a high price, enabling the brown firm to sell its product. Once both firms are active, a loftier environmental ideology eases price competition even further so that both firms end up charging higher prices. But, because the green costs relatively more than its rival, more consumers buy brown than green, which raises the global level of pollution. This suggests that *environmentalism consciousness needs not be good per se.*

As for the quality subgame, we show the existence and uniqueness (up to a permutation of firms' names) of an equilibrium. When the level of environmentalism is low, only one firm invests in quality while the other acts as a potential entrant. As the level of environmentalism rises above some threshold, consumers become heterogeneous enough for the incumbent to raise its price. This allows the second firm to enter the market by supplying a product of inferior environmental quality to that provided by the incumbent. The odd consequence is that the environmental performance of the market outcome decreases.

These results should not come as a surprise because they point in the same direction as the Jevons paradox, which generates heated debates in environmental economics (Alcott, 2005). According to this paradox, energy-saving policies may increase rather than decrease energy consumption. It is customary in this literature to distinguish between direct and indirect rebound effects. The former are often obtained under a ceteris paribus assumption, whereas the latter accounts for the endogeneity of several variables. Although checking the empirical relevance of this paradox is difficult, the best empirical works suggest the existence of effects consistent with Jevons paradox (Sorell, 2009; Churchill *et al.*, 2018). In a way, the results summarized above point in the same direction as indirect rebound effects. Indeed, although environmentalism is always desirable at the prevailing prices, this need not be so when it is recognized that firms respond to changes in environmental ideology by choosing new prices and products in an oligopolistic market. Our paper determines under which circumstances environmentalism generates a "good" or "bad" market outcome.

At the current stage of development, given the growing number of sectors where the hedonic attributes of goods do not come at the expense of the environment, environmentalism cannot be the only weapon that would drastically improve the current level of pollution. Nevertheless, when combined with specific policy vehicles, environmentalism can deliver its expected positive effects. It is therefore crucial to identify the instruments whose effects are magnified by green consumerism. We then use our baseline model to study the effects of the two instruments that occupy center stage in policy debates, i.e., a minimum environmental standard, and the development of green technologies. First, we show that the health of the environment rises with the minimum standard. In addition, environmentalism and a minimum environmental standard complement each other in a way that leads to a more ecological consumption pattern. Second, we find that the use of greener technologies leads to healthier environment through the more eco-friendly qualities and bigger market share for the green variant of the product.

Our answer to the question posed by the title of the paper is therefore that environmentalism can have opposite effects. On the one hand, when the hedonic and the environmental attributes are misaligned, environmentalism enables the green firm to gain a growing market share, which has a positive effect on the environment. On the other hand, when attributes are aligned, the green firm uses its greater market power to raise price in a way that leads consumers to buy more brown product at the expense of the green one. In a nutshell, *green consumerism fosters a better environmental outcome when the high quality product is the brown one, but it generates perverse effects when the high quality product is the green one.*

A last remark is in order. Solving the vertically differentiated oligopoly problem for several products is notoriously hard. We chose to work with a duopoly as we did not want to sidetrack our analysis with considerations foreign to our main purpose. Yet it is legitimate to wonder what our main findings would be in a market with several firms. We show in Appendix A Material that the main findings hold true when the market involves an arbitrary number of firms supplying products with different environmentally friendly qualities. Specifically, when the hedonic and environmental attributes are aligned, a higher level of environmentalism relaxes competition, which allows the entry of firms at the low end of the environmental quality range.

Related literature. When some consumers are willing to pay more than others to consume less-polluting goods, the analysis of environmental quality is amenable to settings with vertically differentiated products, such as those developed in industrial economics (Tirole, 1988; Belleflamme and Peitz, 2015). These models have been applied successfully to environmental quality competition. The entry point of this literature is that environmentally aware consumers perceive products as being vertically differentiated on the basis of their environmental impact. The main message is clear: when consumers care about the ecological footprint of their own consumption, firms segment the market by supplying green and brown variants of the same good, which are sold at high and low prices. This idea has been developed along several dimensions: (i) the emission of pollutants (Moraga Gonzales and Padron-Fumero, 2002), (ii) firms' abatement effort (Arora and Gangopadhyay, 1995; Rodriguez-Ibeas *et al.*, 2003; Bansal, 2008; Karakosta, 2018), and (iii) the degree of corporate social responsibility adopted by firms (Garcia-Gallego and Georgantis, 2009; Doni and Ricciuti, 2013; Ambec and De Donder, 2020). Closer to us, Eriksson (2004) who uses a product differentiation setting to show that green consumerism cannot replace environmental regulation.

In a different strand of literature, consumers internalize partially the environmental damages generated by the consumption of polluting goods (Cremer and Thisse, 1999; Bansal and Gangopadhyay, 2003; Amacher *et al.*, 2004; Lombardini 2005). Fuelled by empirical analysis that shows that consumers attribute a symbolic value to clean goods (Heffner *et al.*, 2007; Sexton and Sexton, 2014), Ben-Elhadj and Tarola (2014) assume that consumers choose green products not only to satisfy material needs but also to obtain a socially worthy position along a social ladder. The merit of these contributions is to open the door to psychological and sociological considerations that are likely to affect the preferences of environment-friendly consumers.

The paper is organized as follows. The model is presented in Section 2. Section 3 characterizes the equilibrium of any price subgame. In Section 4, we solve the quality game. Section 5 focusses on how the supply of environmentalism affect the environmental surplus and social welfare generated by the market equilibrium and discusses the properties of the second best social optimum in which a planner chooses qualities and compare these outcomes to the market solution. In Section 6, we discuss the combination of environmentalism with various standard policy instruments. Section 7 concludes.

2 The model

Preferences. We consider a market with a unit mass of heterogeneous consumers. In line with the literature, we assume that the product is indivisible (e.g., a durable) and that each consumer buys one unit of this product (perhaps because this product is a necessity good), so that the whole market is covered. The product has two attributes. The first one determines its hedonic quality. The other concerns its emission intensity per unit of production and/or consumption, which we call environmental quality. Firm G supplies the green product while firm B offers the brown one, meaning that the environmental quality of G is higher than that of B. However, the hedonic quality of G can be higher or lower than that of B. In this paper, we assume that product G embodies both the higher environmental and hedonic attributes. Thus, denoting respectively by q_G and q_B the variants supplied by firms G and B, we have $q_G > q_B$. We will briefly comment on the alternative case where $q_B > q_G$ because the hedonic quality of B is much superior to that of G.

Moreover, each product pertains to a reference group to which a consumer relates, or aspires to relate, herself through the product she consumes. The reference group is formed here by those consumers who buy the green product. Belonging to this group confers a psychic benefit to its members that translates into a higher utility. This *psychic benefit* $\psi_G > 0$ is the concrete form taken by the impact environmentalism on individual preferences. By contrast, very much like Groucho Marx who did not want to belong to a club that will accept him as a member, a consumer who buys brown suffers a negative effect – under the form of shame or guiltiness – that reduces her welfare. This is because buying a polluting product is perceived as a negative action that excludes her from the reference group. Consequently, the *psychic cost* $\psi_B < 0$ the consumer bears makes her worse off. Like the psychic benefit, it is individual-specific. Psychic benefit and psychic cost represent the extrinsic component of the good.

Formally, consumers are endowed with pro-environmental preferences. We follow the literature and assume that a (θ_1, θ_2)-consumer is endowed with a linear indirect utility (Neven and Thisse, 1990; Vandenbosch and Weinberg, 1995: Lauga and Ofek, 2011):

$$V(\theta_1, \theta_2) = \begin{cases} \theta_1 q_G + \theta_2 \psi_G - p_G, & \text{if she consumes } G \\ \theta_1 q_B + \theta_2 \psi_B - p_B, & \text{if she consumes } B \\ -\infty, & \text{otherwise} \end{cases} \tag{1}$$

where $\theta_1 \geq 0$ refers to the heterogeneity of consumers' willingness-to-pay for the environmental quality q_i, while $\theta_2 \geq 0$ measures the idiosyncratic evaluation of the psychic benefit (resp., cost) that a consumer enjoys (resp., bears) when she is (resp., is not) a member of the reference group. This modeling approach may be viewed as a crude, but natural, way to capture the idea that the pursuit of socially positive values affects differently the well-being of different groups' members. Since consumers are free to choose which product to buy, the group they belong to is the outcome of individual utility maximization. Note also that (1) implies that a consumer with a high (resp., low) psychic benefit for being green also faces a high (resp., low) psychic cost when she is brown, which seems reasonable.

Models of vertical differentiation typically assume that consumers are heterogeneous in a single attribute (Tirole, 1988; Belleflamme and Peitz, 2015; Gabszewicz and Tarola, 2018). Since products are here characterized by two attributes, it seems natural to consider a setting in which consumers are heterogeneous along the two characteristics. However, the few attempts made to develop two-dimensional models of product differentiation show that working with those settings become quickly very cumbersome from the analytical point of view. Since the focus of this paper is on the role of environmentalism, we assume with Garella and Lambertini (2014) that consumers are homogeneous in their attitude toward the hedonic component of products, that is, the distribution of θ_1 is atomic with a unit mass point at $\theta = 1$. As a result, consumers have a higher willingness-to-pay for green than for brown. Using an a non-atomic distribution is unlikely to affect the nature of our findings since the green product is dominant in the two attributes. Note also that the first attribute of a product, which is given by its environmental quality, is a continuous variable.

In (1), the second component is given by a binary variable that refers to the group the consumer belongs to: $\psi_G = \beta > 0$ and $\psi_B = -\beta$ where β measures what we call the *environmental ideology*. That said, we may rewrite preferences (1) as follows:

$$V(\theta) = \begin{cases} q_G + \beta\theta - p_G, \\ q_B - \beta\theta - p_B. \end{cases} \tag{2}$$

Thus, things work as if a θ-consumer were to pay the price $p_G - \beta\theta$ for the green product and $p_B + \beta\theta$ for the brown. These prices are consumer-specific but they also vary with the supply of environmentalism. By contrast, β is common to all. Since a higher supply of environmentalism makes the greens better-off and the browns worse-off, *the environmental ideology β affects consumers' willingness-to-pay*, hence firms' behavior on the market. Clearly, a consumer characterized by a higher θ has a higher willingness-to-pay for green and a lower one for brown.

Two remarks are in order. First, by assuming linear utilities, (1) and (2) remain in the tradition of standard models of product differentiation. It might seem more reasonable to consider a setting in which consumers' welfare varies with the size of the group she belongs to. It is worth stressing that the findings obtained in the next sections hold true (up to some new numerical coefficients) if the psychic benefit of a θ-consumer is given by θn_G and her psychic cost by θn_B where n_i is the mass of consumers who purchase product i. In this context, consumers, and not only firms, are involved in a game-theoretic framework in which they must choose which firm to patronize. The elements of the resulting partition may then be viewed as the equilibrium networks or groups of consumers generated by a pair of qualities and a price system. Even in this case, our setting differs from the few models of vertical product differentiation with consumption externalities, such as Brécard (2013), because environmentalism implies that the group a consumer belongs to affects her welfare in opposite ways. Moreover, we assume that being a member of a group generates a (dis)satisfaction that is consumer-specific. Therefore, we may safely conclude that our setting is *not* another model of product differentiation with network externalities. Additional evidence can be found in the dissimilarities between several of our results with those obtained in the literature.

Second, in line with the literature we assume that the parameter θ is uniformly distributed over the interval $[0, 1]$. However, our analysis can readily be extended to any interval $[a, b]$ with $0 \leq a < b$ by rescaling the corresponding attribute. Furthermore, in (2) the qualities q_G and q_B can be weighted by a coefficient $\alpha > 0$ that reflects their relative value in consumer preferences. To ease the burden of notation, we set $\alpha = 1$. Hence, a lower β also means that the intrinsic qualities per se matter more to consumers than the environmental ideology. Given these normalizations, a high or a low value of β should not be interpreted in too a restrictive way.

Demands and costs. Substituting (2) into $V_G(\theta) = V_B(\theta)$ and solving for θ yields the consumer $\bar{\theta}$ indifferent between buying G or B at prices $p_G > 0$ and $p_B > 0$:

$$\bar{\theta} = \frac{(p_G - p_B) - (q_G - q_B)}{2\beta}. \tag{3}$$

How consumers are allocated between green and brown depends on the price gap $p_G - p_B$ and the quality gap $q_G - q_B$: when attributes are aligned, the larger the former (resp. the latter), the smaller (resp., the larger) the green product's market share. When $\bar{\theta} > 0$, *at given prices and qualities, a loftier environmental ideology leads more consumers to buy green.* This is precisely the effect expected by many activists and NGOs.

In (3), we implicitly assume that the marginal consumer $\bar{\theta}$ belongs to the open interval $(0, 1)$. However, it should be clear that the right-and-side of (3) may be smaller than 0 or larger than 1. Consequently, the equilibrium value of $\bar{\theta}$ that must be used to determine firms' market demands $D_G = 1 - \bar{\theta}$ and $D_B = \bar{\theta}$ are given by the following expression:

$$\bar{\theta}(p_G, p_B; q_G, q_B) = \max \left\{ 0, \min \left\{ \frac{(p_G - p_B) - (q_G - q_B)}{2\beta}, 1 \right\} \right\}. \tag{4}$$

Let us now come to firms' cost. We assume that firms can improve the ecological footprint of their products, without scarifying the hedonic attribute which is kept fixed. The firms' choice of a better environmental quality gives rise to specific expenditures, such as R&D and capital goods, which typically have the nature of endogenous overhead expenditures. Therefore, it seems reasonable to assume that most of the burden of quality improvement falls on fixed costs $F(q)$ (Ronnen, 1991; Motta, 1993). Nevertheless, marginal costs $c(q)$, which are constant with respect to output, are likely to increase with quality because producing a better environmental quality without changing the corresponding performance typically requires more expensive inputs (Lauga and Ofek, 2011).

Since a steady improvement of the environmental quality is likely to require more and more investment in R&D and capital, the function F is also strictly convex in q. In line with the literature, we assume that fixed costs are quadratic in q, i.e., $F(q) = q^2/2$. We also assume that the quality marginal cost is proportional to the chosen quality, i.e., $c(q) = cq$ where c is a positive constant. In what follows, we assume that *both firms have access to the same technology described by the marginal cost cq and the fixed cost $q^2/2$*, which both depend on the quality q. Also, in our setting, developing new technologies that allow producing greener products at lower costs does not generate additional pollutants because the possible damages caused by such technologies are taken into account in the environmental qualities supplied by firms.

The profit function of firm $i = G, B$ is then as follows:

$$\pi_i(p_G, p_B; q_G, q_B) = (p_i - cq_i) D_i(p_G, p_B; q_G, q_B) - \frac{q_i^2}{2}, \qquad i = G, B.$$

Competition between firms is modeled as a two-stage game. Let $\bar{q}$ be the highest environmental quality that can be produced under the current technology, while the minimal quality is normalized to 0. At the first stage, firms choose the ecological footprint of their products, which determines the overall quality of their product along the spectrum of technologically feasible qualities given by the interval $[0, \bar{q}]$. At the second stage, firms compete in prices with $p_G \geq cq_G$ and $p_B \geq cq_B$. The fixed costs and are sunk at the price competition stage of the game. The market outcome is given by a subgame perfect Nash equilibrium. For this equilibrium to be consistent with the above demand functions, it must be that $q_G > q_B$. As usual, the game is solved by backward induction.

Let us make a pause in order to discuss what makes vertical product differentiation different from horizontal product differentiation. The distinctive feature of the former is the "finiteness property," which states that only a limited number of firms can survive in equilibrium. More specifically, the market equilibrium involves a maximal number of firms whose value depends on the degree of consumer heterogeneity even when fixed costs are arbitrarily small. Since $q - c(q)$ stands for the social value of quality q, this property holds if and only if consumers agree on the ranking of all products when each quality q is priced at its marginal cost $c(q)$. Otherwise, a firm can always sell its output to the consumers who rank its product first because these consumers are willing to pay a price that slightly exceeds the product's marginal cost (Shaked and Sutton, 1983; Anderson *et al.*, 1992; Gabszewicz and Tarola, 2018). In our setting, all consumers prefer green to brown when $p_i = cq_i$, that is,

$$q_G + \beta\theta - cq_G > q_B - \beta\theta - cq_B$$

holds for all $\theta \in [0, 1]$. The most binding condition arises at $\theta = 0$, which means $(1 - c)(q_G - q_B) > 0$. For this to hold, it must be that $c < 1$.

3 How does price competition affect the consumption of the green and brown products?

In order to determine how environmentalism affect firms' behavior and the level of pollution generated by the consumption of goods differentiated by their environmental qualities, we need a benchmark case that describes the market outcome when consumers' choices are unaffected by social considerations, i.e., $\beta = 0$.

3.1 Price competition in the absence of environmentalism

By setting $\beta = 0$ in (2), we obtain the benchmark case in which consumers care only about their own choices. We have a standard setting in which two firms selling a vertically differentiated product and producing at different marginal costs compete in prices. Studying the case where $\beta = 0$ is worth doing because it allows us to determine how the market outcome is affected by environmentalism.

Since consumers are homogeneous when $\beta = 0$, firms compete in prices under different marginal costs. Consequently, they undercut each other until one firm reaches its marginal cost. In the presence of a price tie, it is natural to assume that the price tie is broken in favor of the firm with the lower marginal cost since this firm is able to further lower its price. Since all consumers prefer to buy G when both products are priced at their marginal costs, firm G can undercut firm B until its price is equal to

$$p_G^*(q_G, q_B) = q_G - (1-c)q_B > cq_G, \tag{5}$$

while $p_B^*(q_G, q_B) = cq_B$, and thus the green firm supplies the entire market. The above pair of prices is a Nash equilibrium of the price subgame.

Thus, in the absence of environmentalism ($\beta = 0$), all consumers buy from the green firm, which sets a price above its marginal cost. This firm sets a price such that consumers are indifferent between the two products, whereas the other firm prices at marginal cost. This shows the main implication of using an atomic distribution for quality: there is no equilibrium in which both firms share the market and earn positive profits. As shown below, this ceases to hold when β is positive.

3.2 Price competition in the presence of environmentalism

When $\beta > 0$, a θ-consumer considers the following "quality indices" before making her purchasing decision:

$$Q_G(\theta) \equiv q_G + \beta\theta > q_G \qquad Q_B(\theta) \equiv q_B - \beta\theta < q_B.$$

Observe that q_G and q_B are firm-specific, while $Q_G(\theta)$ and $Q_B(\theta)$ are consumer-specific. This difference is a distinctive feature of our model. In addition, raising β means that Q_G increases whereas Q_B decreases, even when q_G and q_B do not change. So, everything else, a higher environmental concern strengthens the market power of the green firm relative to the brown firm by magnifying the quality difference $q_G - q_B$.

Since the profit function π_i is concave in p_i, applying the first-order condition yields the following equilibrium prices when both firms share the market ($0 < \bar{\theta} < 1$):

$$p_G^*(q_G, q_B) = \frac{1}{3}\left(2cq_G + cq_B + (q_G - q_B) + 4\beta\right), \qquad p_B^*(q_G, q_B) = \frac{1}{3}\left(cq_G + 2cq_B - (q_G - q_B) + 2\beta\right). \tag{6}$$

Whereas $p_G^*(q_G, q_B) > cq_G$ always holds, $p_B^*(q_G, q_B) > cq_B$ if and only if $\beta > \beta_L \equiv (1-c)(q_G - q_B)/2$. Otherwise, firm G charges the limit price and firm B remains out of business, a result that typically arises in vertical differentiation models when consumer heterogeneity is low (Gabszewicz and Thisse, 1979; Wauthy, 1996). Assume now that β satisfies the above condition, so that firms G and B share the market. In this case, both prices increase with the intensity of environmental ideology ($\beta \uparrow$) because psychic costs and benefits rise. Stated differently, *environmentalism relaxes competition at the price stage*. However, the green firm's price grows faster than the brown firm's with β because more environmental ideology renders the green product even more attractive as $Q_G - Q_B$ becomes wider. Furthermore, p_G^* increases while p_B^* decreases with the quality gap $q_G - q_B$. Indeed, when the quality gap widens, the environmental ideology strengthens the green product's attractiveness, which incentivizes firm B to lower its price to restore its market share. This differs from what we observe in standard models of vertical differentiation where both prices increase with the quality gap.

Furthermore, the price differential is given by

$$p_G^*(q_G, q_B) - p_B^*(q_G, q_B) = \frac{1}{3}\left((2+c)(q_G - q_B) + 2\beta\right) > 0. \tag{7}$$

Hence, a wider quality gap leads to a wider price differential because p_G^* increases while p_B^* decreases with $q_G - q_B$. Plugging $p_G^*(q_G, q_B)$ and $p_B^*(q_G, q_B)$ into (4), we get the following expression for the marginal consumer at the equilibrium prices:

$$\bar{\theta}(q_G, q_B) = \frac{(1-c)(q_B - q_G)}{6\beta} + \frac{1}{3}, \tag{8}$$

Since $q_G > q_B$, a higher environmental concern allows the brown firm to capture a bigger market share because its rival builds on the resulting higher psychic costs and benefits to charge a much higher price. However, the green firm is always able to retain a market share that exceeds 2/3, which reflects its quality advantage.

3.3 The impact of environmental ideology on market prices

However, the level of environmental ideology must exceed the cutoff β_B to generate this positive effect. This may explain why the global ecological footprint is unaffected by a mild environmental concern.

When $\beta = 0$, we have seen that firm G serves the whole market. When β becomes positive, we still have $\bar{\theta}(q_G, q_B) = 0$ until the threshold $\beta_G \equiv (1-c)(q_G - q_B)/2 > 0$ is reached where the consumers at $\theta = 0$ are indifferent between the two products. When β rises above β_G, both the psychic benefits of the greens and the psychic costs of the brown rises. As shown by (8), $\bar{\theta}(q_G, q_B)$ becomes positive. Therefore, product B is sold to the consumers belonging to $[0, \bar{\theta}(q_G, q_B)]$. Why do some consumers now choose to buy the brown product? As β increases, both prices increase but p_G^* increases faster than p_B^*. When the price gap is wide enough, this induces the low θ-consumers to buy B. In other words, a sufficiently strong environmental ideology allows the brown product to enter the market. By implication, *a more environment-friendly population ends up with a worse ecological footprint*, the reason being that this social motivation exacerbates the perceived quality difference $Q_G - Q_B$, which in turn leads firm G, hence firm B, to charge higher prices.[3]

[3]Note also that this price escalation tends to reduce consumers' real income, which may incite them to buy cheap, but dirty, goods on other markets.

Furthermore, β_G increases with $q_G - q_B$. Therefore, a shock that improves the environmental quality of B makes it easier for this product to enter the market. Clearly, the entry of B raises the global level of pollution.

The next proposition provides a summary.

Proposition 1. *When the degree of environmental ideology is low, the brown firm cannot enter the market. However, a sufficiently high value of $\beta > \beta_G$ leads to a higher level of pollution through the entry of the brown firm. Once this firm is in business, increasing β raises the level of pollution because fewer consumers buy green.*

This counterintuitive result shows that a social attitude that seems beneficial to the environment may generate perverse effects by raising disproportionately the market power of the green-high-quality firm. More specifically, this firm takes advantage of the growing psychic benefits associated with the consumption of the green product to raise its price at a level sufficiently high for the brown firm to enter the market or for more consumers to buy brown, even though the psychic costs associated with the consumption of brown also increase. It is noteworthy that Proposition 1 is not an artefact of working with a duopoly. In the Appendix A, we consider the case of $n \geq 2$ firms whose environmental qualities are given by $q_\kappa = \kappa q$ for $\kappa = 1, ..., n$ and $q > 0$. In this more general setting, we show that, as the environmental ideology spreads, firms enter sequentially from high to low environmental qualities because the incumbents enjoy more market power when the environmental ideology is loftier.

One remark about the robustness of Proposition 1 is in order.

Remark. Proposition 1 relies on the alignment of the hedonic and environmental attributes in a way that is worth highlighting. To see what happens when attributes are misaligned, let us assume that brown has a priori the quality advantage, that is, $q_B > q_G$. When $\beta = 0$, (2) shows that all consumers buy variant B. Clearly, the brown firm remains the only provider until the threshold $\beta_B \equiv (1-c)(q_B - q_G)/4$ is reached where the consumers at $\theta = 1$ are indifferent between the two products. Once β exceeds β_B, the green product can enter the market from above. In other words, the consumers with the highest environmental concern shift from brown to green. The marginal consumer is still given by (4) while the demand system remains the same because consumers characterized by high values of θ buy the green variant. Hence, at an interior equilibrium, the market prices are still given by (6). It then follows from (7) that $p_B^* > p_G^*$ if and only if $\beta < \bar{\beta} \equiv (2+c)(q_B - q_G)/2$ with $\beta_B < \bar{\beta}$. As a result, as β crosses β_B from below, the brown firm builds on its quality advantage to charge a price higher than the green firm provided that $\beta < \bar{\beta}$. Less expected, however, when $\beta > \bar{\beta}$ the green firm is able to set a higher price than its rival because green consumerism reverses, at least partially, the quality advantage of firm B. Since (8) remains valid, we may conclude as follows: *despite its quality disadvantage, environmentalism allows the green firm to capture a expanding market share*. However, the green firm cannot drive brown out of business because its market share is bounded above by 2/3. This discussion shows that our setting is flexible enough to uncover different aspects of environmentalism. In what follows, we will refrain from studying this case in detail and will focus on the sole case where hedonic and environmental attributes are aligned ($q_G > q_B$) because it tends to fit better what happens on a growing number of markets, but also because it generates less expected results.

4 The environmental qualities supplied by the market

We may wonder whether these findings of Proposition 1 are caused by the assumption of fixed environmental qualities. In other words, quality competition could lead to a better environmental outcome? To answer this question, we must determine how firms choose their qualities in a strategic context. We now turn our attention to the first stage of the game. Since our focus is mainly on the environmental impact of the goods, we assume that, at this stage, firms invest only in the environmental attribute of their goods. Since the hedonic attribute is kept fixed, changing the environmental characteristics generates a direct and proportional change in quality q_i in the interval $[0, \bar{q}]$.

4.1 The case of a high supply of environmentalism

Duopoly models of vertical differentiation are characterized by interior equilibria where the two firms share the market or by corner equilibria where the high-quality firm secures the entire market (Anderson *et al.*, 1992; Gabszewicz and Tarola, 2018).

4.1.1 Interior equilibrium

A quality equilibrium (q_G^*, q_B^*) is said to be *interior* when $0 < \bar{\theta}(q_G^*, q_B^*) < 1$, so that two firms enter the market. Assume that such an quality equilibrium exists. Plugging the prices (6) into firms' profit functions yields the payoffs of the first-stage game:

$$\pi_G^*(q_G, q_B) = \frac{\left[4\beta + k^{1/2}\left(q_G - q_B\right)\right]^2}{18\beta} - \frac{1}{2}q_G^2, \qquad \pi_B^*(q_G, q_B) = \frac{\left[2\beta - k^{1/2}\left(q_G - q_B\right)\right]^2}{18\beta} - \frac{1}{2}q_B^2. \tag{9}$$

where $k \equiv (1-c)^2 > 0$.

Note here a first difference with standard models of vertical differentiation where a wider quality gap implies higher profits for both firms. While the green firm's profits always rise as the quality gap widens, this holds true for the brown firm if and only if $k^{1/2}\left(q_G - q_B\right)/2$ remains smaller than β. The impact of environmental ideology on profits is similar: the green firm's profits always increase with β whereas the brown firm's first decrease and then decrease. This is because psychic benefits and costs both rise but also diverge more and more.

Since the function π_i is quadratic in q_i, then π_i is strictly concave in q_i if and only if the coefficient of q_i^2 in the function (9) is negative, that is

$$\beta > \frac{k}{9}. \tag{10}$$

In this case, the function π_i is continuous and strictly concave on the compact interval $[0, \bar{q}]$, which implies that the quality game has a Nash equilibrium.

The first-order conditions with respect to qualities yield the following best-reply functions:

$$q_G^* (q_B) = \min \left\{ \max \left\{ 0, \frac{k^{1/2}(4\beta - k^{1/2} q_B)}{9\beta - k} \right\}, \bar{q} \right\}, \qquad q_B^* (q_G) = \min \left\{ \max \left\{ 0, \frac{k^{1/2}(2\beta - k^{1/2} q_G)}{9\beta - k} \right\}, \bar{q} \right\}. \tag{11a}$$

When (10) holds, qualities are strategic substitutes, that is, when a firm increases (resp., decreases) the environmental quality of its product, its rival finds it profit-maximizing to decrease (resp., increase) its own quality. This concurs with the wide-spread idea that quality differentiation relaxes price competition.

The candidate equilibrium qualities are obtained by solving the system of linear equations (11a) whose unique solution is:

$$q_G^* = \frac{2k^{1/2}}{3} \frac{6\beta - k}{9\beta - 2k} > q_B^* = \frac{2k^{1/2}}{3} \frac{3\beta - k}{9\beta - 2k}. \tag{12}$$

Note that the average quality $(q_G^* + q_B^*)/2 = k^{1/2}/3$ is independent of β.

For (12) to be an interior quality equilibrium, q_G^* and q_B^* must satisfy the following conditions: (i) $\bar{q} > q_G^* > q_B^* > 0$, (ii) $\bar{\theta}(q_G^*, q_B^*) \in (0, 1)$, and (iii) $\pi_G^*(q_G^*, q_B^*) > \pi_B^*(q_G^*, q_B^*) > 0$.

First, it is readily verified that $q_G^* > q_B^*$ if and only if

$$\beta > \frac{2k}{9} \tag{13}$$

holds, while $q_B^* > 0$ if and only if[4]

$$\beta > \frac{k}{3}. \tag{14}$$

Clearly, (14) is more stringent than (10) and (13). Unless explicitly mentioned, we assume that this condition holds. Moreover, we have $q_G^* < \bar{q}$ because $q_B^* > 0$.

Second, the marginal consumer (8) at (12) is such that

$$\bar{\theta}(q_G^*, q_B^*) = \frac{3\beta - k}{9\beta - 2k}. \tag{15}$$

It is readily verified that $0 < \bar{\theta} < 1$ always holds under (14).

[4]Observe that $q_B^* > 0$ also holds when both the numerator and denominator of q_B^* are negative. This case is considered in Section 6.

Third, substituting (12) in (6), we obtain the equilibrium markups and profits:

$$p_G^*(q_G^*, q_B^*) - cq_G^* = \frac{2\beta\,(6\beta - k)}{9\beta - 2k}, \qquad p_B^*(q_G^*, q_B^*) - cq_B^* = \frac{2\beta\,(3\beta - k)}{9\beta - 2k}, \tag{16}$$

and

$$\pi_G^*(q_G^*, q_B^*) = \frac{2}{9}\frac{(6\beta - k)^2\,(9\beta - k)}{(9\beta - 2k)^2} \qquad \pi_B^*(q_G^*, q_B^*) = \frac{2}{9}\frac{(3\beta - k)^2\,(9\beta - k)}{(9\beta - 2k)^2}, \tag{17}$$

which are all positive by implication of (14). Observe also that both $\pi_G^*(q_G^*, q_B^*)$ and $\pi_B^*(q_G^*, q_B^*)$ raise with β, which confirms what we said in the foregoing, namely, *environmentalism endows firms with market power*. Since $\pi_G^*(q_G^*, q_B^*) - \pi_B^*(q_G^*, q_B^*) > 0$, each firm would like to be the quality leader at the equilibrium like in standard models of vertical differentiation.

Furthermore, since qualities are strategic substitutes, the quality space is endogenously bounded above by

$$q_G^*(0) = \frac{4k^{1/2}\beta}{9\beta - k} > 0.$$

We will see below that $k^{1/2}$ is another upper bound on q_G. Therefore, we set

$$\bar{q} = \max\left\{q_G^*(0), k^{1/2}\right\}. \tag{18}$$

Note that $\bar{q} = q_G^*(0)$ if and only if $\beta > k/5$.

To sum up, we have shown the following result: if $\beta > k/3$, there exists a unique (up to a permutation of firms' names) subgame perfect Nash equilibrium and both firms share the market.

Note that the average quality $(q_G^* + q_B^*)/2 = k^{1/2}/3$ is independent of β.

For (12) to be an interior quality equilibrium, q_G^* and q_B^* must satisfy the following conditions: (i) $\bar{q} > q_G^* > q_B^* > 0$, (ii) $\bar{\theta}(q_G^*, q_B^*) \in (0, 1)$, and (iii) $\pi_G^*(q_G^*, q_B^*) > \pi_B^*(q_G^*, q_B^*) > 0$.

First, it is readily verified that $q_G^* > q_B^*$ if and only if

$$\beta < \frac{2k}{9} \tag{19}$$

holds, while $q_B^* > 0$ if and only if[5]

$$\beta < \frac{k}{6}. \tag{20}$$

[5] Observe that $q_B^* > 0$ also holds when both the numerator and denominator of q_B^* are negative. This case is considered in Section 6.

4.1.2 Corner equilibrium

What happens to the market outcome when (14) does not hold? Plugging $q_B^* = 0$ in (11a) yields the corresponding equilibrium quality of the green product when $\beta = k/3$:

$$q_G^*(0) = \frac{4\beta k^{1/2}}{9\beta - k}. \tag{21}$$

while $\bar{\theta}(q_G^*(0), 0) = 0$. In this case, the green firm sets the highest price such that the consumers at $\theta = 0$ are indifferent between buying the green quality $q_G^*(0)$ or the brown quality $q_B^* = 0$ at price $p_B^* = cq_B^* = 0$. In other words, the green firm sets a price p_G such that

$$q_G^*(0) + \beta\theta - p_G = 0 - \beta\theta - 0,$$

holds for the consumers at $\theta = 0$ who are indifferent between G and B. Therefore, firm G chooses the *limit price* $p_G^*(q_G) = q_G^*(0)$, which agrees with (5), and its profits are given by

$$\pi_G(q_G^*(0), 0) = \frac{4\beta k(7\beta - k)}{(9\beta - k)^2}.$$

Since $\bar{\theta}(q_G^*(0), 0)$ increases with β, the green firm accurately anticipates that $\bar{\theta} = 0$ when $\beta < k/3$, while it will charge its limit price $p_G^* = q_G$. As a result, this firm's profit function is no longer given by (9), but by the following expression where we have set $p_G^* = q_G$:

$$\pi_G(q_G, 0) = k^{1/2} q_G - \frac{q_G^2}{2}. \tag{22}$$

It is then immediate that (22) is maximized at $q_G^* = k^{1/2}$ while the corresponding profits are equal to $\pi_G(k^{1/2}, 0) = k/2 > 0$.

It remains to check whether firm G prefers $k^{1/2}$ or $q_G^*(0)$ when $q_B^* = 0$. It is readily verified that

$$\pi_G(k^{1/2}, 0) - \pi_G(q_G^*(0), 0) = \frac{k}{2}\frac{(5\beta - k)^2}{(9\beta - k)^2} > 0, \tag{23}$$

so that $q_G^*(0)$ is not firm G's best reply against $q_B = 0$ for $\beta < k/3$. Therefore, the Nash equilibrium of the quality game is given by $(k^{1/2}, 0)$ for $\beta < k/3$. That the limit price $p_G = q_G^*$ is the green firm's Nash strategy when consumers are not very heterogeneous is in accordance with the literature on vertical differentiation (Gabszewicz and Thisse, 1979; Anderson *et al.*, 1992; Gabszewicz and Tarola, 2018). The limit price is larger than the marginal cost cq_G^* because $c < 1$, but lower than the monopoly price because G is constrained in its price choice by potential competition with B. The market now has the structure of a natural monopoly in the sense that it can sustain only one firm.

The expression (23) has another consequence: $(k^{1/2}, 0)$ is a Nash equilibrium over the interval $(k/3, \bar{\beta})$ with $\bar{\beta} > k/3$ (see Appendix B.1). Consequently, there exist two pure strategy equilibria given by the interior equilibrium (q_G^*, q_B^*) and the corner equilibrium $(k^{1/2}, 0)$ over this interval. So, we need a selection device to pin down one equilibrium.

Consider the following 2×2 game where the players are firms G and B whose strategy spaces are, respectively, $\{k^{1/2}, q_A^*\}$ and $\{0, q_B^*\}$. The corresponding payoff matrix is as follows:

$G \setminus B$	0	q_B^*
$k^{1/2}$	$\pi_G(k^{1/2}, 0), \pi_B(k^{1/2}, 0)$	$\pi_G\left(k^{1/2}, q_B^*\right), \pi_B\left(k^{1/2}, q_B^*\right)$
q_G^*	$\pi_G\left(q_G^*, 0\right), \pi_B\left(q_G^*, 0\right)$	$\pi_G(q_G^*, q_B^*), \pi_B(q_G^*, q_B^*)$

This game has two pure strategy Nash equilibria given by $(k^{1/2}, 0)$ and (q_A^*, q_B^*). No equilibrium Pareto-dominates the other because

$$\pi_G(k^{1/2}, 0) > \pi_G^*(q_G^*, q_B^*), \qquad \pi_B^*(q_G^*, q_B^*) > \pi_B(k^{1/2}, 0).$$

Standard refinements must be ruled out because they do not select among strict Nash equilibria such as ours. One noticeable exception is the concept of risk-dominance introduced by Harsanyi and Selten (1988), which extends the concept of Pareto-dominance. The argument goes as follows. The corner outcome (say) is a *risk-dominant equilibrium* if

$$\begin{aligned} & \left[\pi_G(k^{1/2}, 0) - \pi_G\left(q_G^*, 0\right)\right] \cdot \left[\pi_B(k^{1/2}, 0) - \pi_B\left(k^{1/2}, q_B^*\right)\right] \\ > \; & \left[\pi_G(q_G^*, q_B^*) - \pi_G\left(k^{1/2}, q_B^*\right)\right] \cdot \left[\pi_B(q_G^*, q_B^*) - \pi_B\left(q_G^*, 0\right)\right] \end{aligned} \tag{24}$$

holds. When the opposite inequality holds, the risk-dominant equilibrium is the interior outcome. In words, $\pi_G(k^{1/2}, 0) - \pi_G\left(q_G^*, 0\right)$ is the gain made by firm G when firm G predicts accurately that firm B will play 0 and best responds to this prediction by playing $k^{1/2}$, instead of predicting wrongly that firm B will play q_B^*. The same holds mutatis mutandis for firm B. By choosing a risk-dominant equilibrium, firms G and B maximize the product of their deviation losses.

The following lemma is proven in Appendix B.2.

Lemma 1. *On the interval $(k/3, \bar{\beta})$, the corner equilibrium $(k^{1/2}, 0)$ risk-dominates the interior equilibrium (q_G^*, q_B^*).*

4.2 The case of a low supply of environmentalism

It remains to discuss the case where $\beta < k/9$. When this inequality holds, we know that π_G (resp., π_B) is strictly convex in q_G (resp., q_B). Thus, regardless of the value of q_B, π_G is maximized at $q_G = 0$ or at $q_G = \bar{q}$ where (18) implies $\bar{q} = k^{1/2}$. The same holds for firm B. In other words, we have a 2×2 game where the two firms share the same strategy set $\{0, \bar{q}\}$.

Observe first that $(\bar{q}, \bar{q})$ cannot be an equilibrium because both firms make negative profits. Second, plugging $q_G = \bar{q}$ and $q_B = 0$ in (8) implies that $\bar{\theta}(\bar{q}, 0) = 0$. In this case, firm G chooses the limit price $p_G = \bar{q}$, so that its profits are given by

$$\pi_G(\bar{q}, 0) = k^{1/2}\bar{q} - \frac{1}{2}\bar{q}^2 = k/2 > 0.$$

Last, $(0, 0)$ is not a Nash equilibrium because firm G's best reply against $q_B = 0$ is $k^{1/2}$. As a result, $(k^{1/2}, 0)$ is the only Nash equilibrium of the quality game for $\beta < k/9$.

The following proposition summarizes the above findings.

Proposition 2. (i) *For $0 < \beta < k/3$, $(k^{1/2}, 0)$ is the only Nash equilibrium.* (ii) *For $k/3 < \beta < \bar{\beta} \simeq 0.410k$, $(k^{1/2}, 0)$ is the Nash equilibrium selected by the risk-dominance criterion.* (iii) *For $\beta > \bar{\beta}$, the two firms share the market at the qualities (q_G^*, q_B^*) and prices (p_G^*, p_B^*).*

This proposition confirms the idea that motivates this paper, i.e., environmentalism affects the market outcome but in ways that are hard to predict. More specifically, the supply of environmentalism has no impact on the equilibrium outcome and its environmental performance when it does not exceed the threshold $\bar{\beta}$. Consequently, *the environmental ideology must be strong enough to have an impact on the greenness of the economy.* Furthermore,the equilibrium strategy q_G^* at the interior equilibrium is such that

$$q_G^* = \frac{2k^{1/2}}{3}\frac{6\beta - k}{9\beta - 2k} < k^{1/2}.$$

As a result, in societies where the protection of the environment is not a significant concern ($\beta < \bar{\beta}$), market competition leads the green firm to invest more in environmental quality because it has less market power.

5 Environmentalism and the market

The general belief holds that a higher concern about the ecological implications of consumerism fosters a better environment through more selective consumers' choices. We saw above that this argument is too simplistic. First, it disregards the fact that consumers' choices are also influenced by the prices and qualities of the goods made available on the market. For example, when the brown product is cheaper than the green one, the consumers whose willingness-to-pay is low will purchase the brown one. More importantly, by changing consumers' incentives, environmentalism leads firms to revise their price and quality strategies in a way that need not reduce the carbon footprint generated by the consumption of the goods.

5.1 How the environmental ideology affects firms' qualities?

In what follows, we study the effect of a change in β, which captures the population's environmental ideology, on the market outcome.

(i) Assume first that $\beta > \bar{\beta}$. Totally differentiating the first-order conditions for the equilibrium qualities with respect to β yields the following expressions:

$$\begin{aligned} \text{sign}\frac{\mathrm{d}q_G^*}{\mathrm{d}\beta} &= \text{sign}\frac{\partial^2 \pi_G^*(q_G^*, q_B^*)}{\partial\beta\partial q_G} = \text{sign}(q_B^* - q_G^*), \\ \text{sign}\frac{\mathrm{d}q_B^*}{\mathrm{d}\beta} &= \text{sign}\frac{\partial^2 \pi_B^*(q_G^*, q_B^*)}{\partial\beta\partial q_B} = \text{sign}(q_G^* - q_B^*), \end{aligned}$$

so that

$$\frac{\mathrm{d}q_G^*}{\mathrm{d}\beta} < 0 \qquad \frac{\mathrm{d}q_B^*}{\mathrm{d}\beta} > 0.$$

In words, a hike in the degree of environmental ideology leads the brown firm to produce a better environmental quality whereas the green firm chooses to raise its emission of pollutants. Hence, a more environmental-friendly population does not leads both firms to choose better environmental qualities. On the contrary, the quality gap shrinks symmetrically about the average quality $k^{1/2}/3$. These findings are not straightforward because the literature suggests instead that firms have a taste for product differentiation that often leads them to move far apart (Tirole, 1988). However, we want to stress that firms' desire to differentiate their products does not mean that they want to choose maximal differentiation. In the above, even though the quality gap shrinks, firms G and B keep selling different qualities.

Consider first the impact of a higher environmental ideology ($\beta \uparrow$) on the equilibrium prices when qualities are given. As the psychic benefits and costs increase with β, firm G enjoys relatively more market power than firm B because the perceived quality gap $Q_G - Q_B$ widens with β. Furthermore, since $c < 1$, (7) implies that a change in the quality gap $q_G - q_B$ is associated with a less than proportional change in the price gap. Moreover, (8) shows that more consumers buy green when the quality gap shrinks ($\bar{\theta} \downarrow$). Combining these various effects allows the green firm to save on its investment expenditures by reducing its quality without reducing much its market share. Since the brown firm loses some market power relative to the green firm, the former strives to regain consumers by improving its own quality. Eventually, both the quality and price gaps end up being narrower after the rise in the supply of environmentalism. Hence, more consumers buy brown. It should be clear that the environmental consequences of these changes in firms' strategies are not easy to predict.

A standard argument of product differentiation theory would suggest that the impact of β on firms' profits is negative because products are less differentiated. Let us show that things are more involved than that.

Using (17), It is straightforward to check that $\mathrm{d}\pi_B^*(q_G^*, q_B^*)/\mathrm{d}\beta > 0$ always holds. However, $\mathrm{d}\pi_G^*(q_G^*, q_B^*)/\mathrm{d}\beta$ is positive if and only if $\beta > \hat{\beta} \equiv (\sqrt{17}/9 + 1)k > \bar{\beta}$ because $\pi_G^*(q_G^*, q_B^*) > k/2$ at $\hat{\beta}$. When $\beta \in (\bar{\beta}, \hat{\beta})$, firm G's profits decrease with β. Indeed, the higher psychic benefits associated with the consumption of the green variant do not endow firm G with enough market power to compensate this firm for the narrower quality gap that favors firm B.

In other words, *environmentalism is beneficial to both firms when* $\beta > \hat{\beta}$, an effect that environmental activists do not probably suspect. This is so because, when β is sufficiently large, higher psychic benefits and costs make consumers sufficiently heterogeneous to permit firms to charge higher prices. However, a higher β may be detrimental to the green firm for intermediate value of β because the wider heterogeneity of consumers does not compensate this firm for its shrinking market share.

(ii) We now come to the case where $0 < \beta < \bar{\beta}$. Proposition 2 implies that $q_G^* = k^{1/2}$ and $q_B^* = 0$. Therefore, the green quality does not depend on the environmentalism.

Thus, firms operating in a more environmental-friendly society need not choose better environmental qualities. More importantly, since $k^{1/2} > q_G^* > q_B^*$, *the market delivers the best ecological outcome when environmentalism is weak.*

5.2 Environmental surplus and social welfare

We now turn our attention to the impact of green consumerism on the environmental surplus and social welfare generated by the market equilibrium described in Proposition 2. More specifically, does a greener society incentivize firms to choose qualities and prices such that consumers' choices lead to a better environment and/or a higher social welfare? To assess the overall impact of a quality pair (q_G, q_B), we use two different criteria, i.e., the environmental surplus and the social welfare.

5.2.1 Environmental surplus

The environmental surplus (ES) measures the environmental impact of the consumption of the green and brown variants at the market outcome. It is is defined as the sum of the market shares of the two variants, weighted by the environmental quality of the corresponding product:

$$ES(q_G, q_B) \equiv EG(q_G, q_B) + EB(q_G, q_B) = [1 - \bar{\theta}(q_G, q_B)] \cdot q_G + \bar{\theta}(q_G, q_B) \cdot q_B.$$

Recall that we have normalized the best environmental quality to $\bar{q}$ and the worst to 0. As a result, the environmental surplus is minimized when all consumers purchase the quality $q = 0$, whereas ES reaches its highest value when all consumers buy the quality $\bar{q}$. The value of ES always increases when a growing number of consumers buy the green variant. By contrast, the opposite holds when more consumers purchase the brown variant. This highlights the role of the marginal consumer in evaluating the environmental surplus generated by a given quality pair (q_G, q_B). Furthermore, when firms change the environmental quality of their products, this has a direct effect on the environmental surplus, but also an indirect impact through the new value of the marginal consumer $\bar{\theta}$ since this one varies with q_G and q_B according to (15). Consequently, the impact of β on ES must account for several distinct effects.[6]

Assume a environmentalist society that evaluates the market outcome through the sole criterion ES. We only discuss the case where both firms share the market because the quality $k^{1/2}$ in independent of β for $\beta < \bar{\beta}$. It then follows from (15) that more consumers buy brown when β rises. Since q_G^* decreases with β, EG thus decreases. As for the brown variant, we have seen that its quality rises. Since the market share of firm B increases, the net impact on EB is positive. In sum, the impact of β on EG and EB are opposite. Comparing the variations of EG and EB shows that $|\mathrm{d}EG/\mathrm{d}\beta| > |\mathrm{d}EB/\mathrm{d}\beta|$ holds, which means that ES decreases when the environmental ideology is heightened (see Appendix C.1).

Since the green firm enjoys more significant psychic benefits, it is able to supply a *lower* quality sold at a *higher* price. These two effects incentivize more consumers to shift to brown. In addition, the brown firm supplies a better quality which should attract even more consumers away from firm G despite the higher psychic costs. The combination of all these effects allows firm B to raise its price, but not as much as its rival. The net negative effect on EG dominates the net positive effect on EB, so that *the environmental surplus associated with the market outcome decreases with* β.

Disregarding the costs generated by the supply of environmental qualities seems too extreme for the following two reasons. First, besides consumption, production often generates pollution. Second, increasing the environmental surplus at a monetary cost that exceeds the opportunity cost of money is obviously not socially desirable. This is why we find it more reasonable to consider the *net environmental surplus* defined as follows:

$$NES(q_G, q_B) = ES(q_G, q_B) - C(q_G, q_B),$$

where the total cost

$$C(q_G, q_B) = cq_G(1 - \bar{\theta}) + cq_B\bar{\theta} + \frac{1}{2}q_G^2 + \frac{1}{2}q_B^2,$$

is the *social cost* of producing the qualities q_G and q_B when the mass of green consumers is $1 - \bar{\theta}$ while $\bar{\theta}$ is the mass of brown consumers.

Recall that the average quality $(q_G^* + q_B^*)/2$ is independent of β. When q_G^* decreases by the amount $\Delta > 0$ while q_B^* increases by the same amount, the investment cost $q_G^2/2 + q_B^2/2$ decreases with β. Since the environmental surplus and the investment costs vary in the same direction, while $(1-\bar{\theta})cq_G^*$ and $\bar{\theta}q_B^*$ move in opposite directions, the impact of β on NES is a priori ambiguous. Nevertheless, Appendix C.1 shows that *the net environmental surplus decreases with the supply of environmentalism*, i.e., the

[6] Note that maximizing the environmental surplus is equivalent to minimizing the environmental damage $ED \equiv \bar{q} - ES$, which is often used in the literature.

drop in ES dominates the drop in costs.[7]

Summing up the above results, we have the following proposition.

Proposition 3. *Assume $\beta > \hat{\beta}$. Then, a higher supply of environmentalism makes firms better-off but worsens the (net) environmental surplus at the market outcome.*

The result, which clashes with mainstream pro-environmental claims, tells us something important: a greener society does not trigger a better ecological footprint because firms adjust their qualities in a way that may incite more consumers to purchase the brown variant, while the green firms reduces its environmental quality. This highlights once more the need to study how the market selects prices and qualities before evaluating the social desirability of environmentalism.

5.2.2 Social welfare

Since all consumers buy a single unit of the differentiated product, there is no deadweight loss. Therefore, prices have the nature of transfers from consumers to firms and need not be taken into account. The social welfare must account for the psychic benefits and costs. As indirect utilities are linear, the social benefit associated with the consumption of the green variant may be obtained by summing the gross indirect utilities across greens:

$$SG(q_G, q_B) \equiv \int_{\bar{\theta}}^{1} (q_G + \beta\theta)\mathrm{d}\theta = (1-\bar{\theta})q_G + \frac{\beta}{2}(1-\bar{\theta}^2),$$

while the social benefit generated across browns is similarly defined by

$$SB(q_G, q_B) \equiv \int_{0}^{\bar{\theta}} (q_B - \beta\theta)\mathrm{d}\theta = \bar{\theta}q_B - \frac{\beta}{2}\bar{\theta}^2.$$

The social welfare (SW) is then given by

$$SW(q_G, q_B) \equiv SG + SB - C(q_G, q_B). \tag{25}$$

Hence, *the social welfare encompasses the (net) environmental surplus.*

Observe that $SW = NES + \Psi(\beta)$ where the net psychic benefits is given by

$$\Psi(\beta) \equiv \beta/2 - \beta\bar{\theta}^2.$$

[7] In the foregoing, we assume that ES and C are directly comparable because consumers know the "true" social value of the environmental qualities. However, in a population formed by individuals having different attitudes toward the environment, finding a consensus on the value of environment might be problematic. One way out is consider $\lambda ES - C$ as the environmental surplus where the parameter λ is treated as the "shadow price" of environmental qualities. When these ones are endowed with a higher weight than costs ($\lambda > 1$), λES still decreases with β while the drop in λES still dominates the drop in C. Hence, $\lambda ES - C$ decreases with β even when λ takes on higher values.

As shown in Appendix C.2, the function Ψ is convex in β and the derivative of Ψ at $\beta = 2k/3$ is positive. Therefore, in response to a higher supply of environmentalism, firms adjust their qualities to raise the net psychic benefits at an increasing rate. To put if differently, *rather than reducing the ecological footprint, environmentalism incentivizes firms to choose qualities that make consumers psychologically better-off.*

Since NES decreases while Ψ increases with β, the impact of environmentalism on social welfare is a priori undetermined. We then proceed as follows.

Differentiating (25) twice shows that the social welfare function is convex in β (see Appendix C.3). Since SW has a positive intercept for all $k \in [0, 1]$ while the derivative of SW at $k/3$ is negative for all $k \in [0, 1]$, the function SW reaches its minimum at $\tilde{\beta} > k/3$. In other words, SW decreases over $(k/3, \tilde{\beta})$ and increases for $\beta > \tilde{\beta}$.

Hence, we have shown the following proposition.

Proposition 4. *As the level of environmentalism steadily rises, the social welfare at the market outcome first decreases and, then, increases.*

In other words, environmentalism delivers its expected effects when it reaches a sufficiently high level. However, the so-obtained welfare gains are not generated by a less polluted environment since the (net) environmental surplus goes down. Rather, these welfare gains stem from the additional benefits consumers enjoy by purchasing green. Once more, this result shows that greener consumerism is not *the* solution to our environmental problems. Quite unexpectedly, it may even worsen the outgoing situation because a higher supply of environmentalism affects firms' behavior in ways that are not necessarily easy to understand when strategic interactions between firms are ignored.

6 Environmental policies

In a way, the above findings are disappointing. This leads us to consider the following policy instruments: (i) a *minimum environmental standard* and (ii) the development of *green technologies*. We discuss their efficiency per se. Furthermore, when combined with these instruments, environmentalism might deliver its expected payoffs. Unless explicitly mentioned, we consider only the case of an interior equilibrium.

6.1 Minimum environmental standard

Assume that $\beta > 6k/9$, so that the quality equilibrium is interior and given by (12) at the unregulated market outcome. The minimum environmental quality standard (MQS) Q must be such that $Q > q_B^*$, for otherwise the MQS would not bind. Since profit functions are strictly concave, there exists a quality equilibrium (q_G^{**}, q_B^{**}) of the game where the strategy space of the brown firm is given by $[Q, \bar{q}]$. If

$q_B^{**} > Q$, q_B^{**} maximizes $\pi_B(q_G^{**}, q_B)$ over $[Q, \bar{q}]$. Since $\pi_B(q_G^{**}, q_B)$ is strictly concave over $[0, \bar{q}]$, $q_B^{**} > Q$ implies that q_B^{**} also maximizes $\pi_B(q_G^{**}, q_B)$ over $[0, \bar{q}]$. In this case, there would exist two interior quality equilibria, (q_G^*, q_B^*) and (q_G^{**}, q_B^{**}), which contradicts Proposition 2. Therefore, in equilibrium, it is profit-maximizing for the brown firm to supply the quality Q. It then follows from (11a) that the green firm chooses the quality

$$q_G^*(Q) = \frac{k^{1/2}(4\beta - k^{1/2}Q)}{9\beta - k}. \tag{26}$$

Hence, $(q_G^*(Q), Q)$ is the only candidate Nash equilibrium of the quality game where the strategy space of the brown firm is given by $[Q, \bar{q}]$. However, for $(q_G^*(Q), Q)$ to be a Nash equilibrium, the following conditions must be satisfied: (i) $q_G^*(Q) > Q$, (ii) $\pi_B(q_G^*(Q), Q) > 0$, and (iii) $0 < \bar{\theta}(q_G^*(Q), Q) < 1$.

First, $q_G^*(Q) > Q$ holds if and only if $Q < 4k^{1/2}/9 < \bar{q}$. In this case, the quality gap $q_G^*(Q) - Q$ shrinks as Q rises. It then follows from (6) that the green firm sets a lower price whereas the brown firm is able to charge a higher price in the ensuing price subgame.

Since $q_G^*(Q)$ decreases with Q and $Q > q_B^*$, we have $q_G^*(Q) < q_G^*$. Plugging $q_G^*(Q)$ and Q in (8) yields the marginal consumer

$$\bar{\theta}(q_G^*(Q), Q) = \frac{1}{2}\frac{6\beta - 2k + 3Qk^{1/2}}{9\beta - k}, \tag{27}$$

which increases with Q. Indeed, as Q rises, the quality of the green variant decreases, which makes B more attractive to a wider range of consumers. By contrast, raising Q renders the green variant relatively more attractive because its price decreases, so that more consumers buy green.

Second, differentiating twice the profit function $\pi_B(q_G^*(Q), Q)$ with respect to Q shows that the equilibrium profits of the brown firm are strictly concave in Q. Applying the first-order condition to π_B indicates that the maximizer $\bar{Q}$ of π_B is positive while the equation $\pi_B = 0$ has a unique positive solution Q_0. Since $\pi_B(0) > 0$, the function π_B increases over $(Q, \bar{Q})$ and decreases toward 0 over $(\bar{Q}, Q_0)$. Hence, the MQS Q must be lower than the two upper bounds $4k^{1/2}/9$ and Q_0. It can be shown that the binding condition is given by $Q_{\max} \equiv 4k^{1/2}/9 < Q_0$. Substituting $4k^{1/2}/9$ in (27) shows that $0 < \bar{\theta}(q_G^*(Q), Q) < 1$.

We now study the impact of the MQS Q on the environmental surplus $ES(q_G^*(Q), Q)$. As in Section 4, we consider separately EG and EB. Differentiating $EG(q_G^*(Q), Q)$ with respect to Q shows that the first-order condition has a single positive solution given by

$$Q_0 = \frac{4\beta}{k^{1/2}},$$

which is larger than $Q_{\max}$. Inspecting (26) and (27) shows that EG is strictly convex in Q. As a result, EG decreases on $(q_B^*, Q_{\max})$. Furthermore, since $\bar{\theta}^*(q_G^*(Q), Q)$ increases with Q, $EB = Q\bar{\theta}^*(q_G^*(Q), Q)$ increases on $(q_B^*, Q_{\max})$.

We now come to the total impact of the MQS on the environmental surplus:

$$ES(q_G^*(Q), Q) = \frac{1}{2}\frac{27\beta k^{1/2}Q^2 + (2k^2 + 54\beta^2 - 48\beta k)Q + 48\beta^2 k^{1/2}}{(9\beta - k)^2},$$

which is quadratic and convex in Q. Furthermore, solving the first-order condition yields the unique minimizer of ES:

$$\bar{Q} = \frac{-27\beta^2 + 24k\beta - k^2}{27\beta k^{1/2}},$$

which is positive at $\beta = k/3$ and smaller than $Q_{\max}$. Since

$$\bar{Q} > q_B^* \Leftrightarrow \beta < 2k/3,$$

we have the following proposition.

Proposition 5. *If $k/3 < \beta < 2k/3$, then the environmental surplus first decreases with the MQS over $(q_B^*, \bar{Q})$, and then increases over $(\bar{Q}, Q_{\max})$. If $\beta > 2k/3$, the environmental surplus increases with the MQS over $(q_B^*, Q_{\max})$.*

Hence, in a duopoly, implementing a MQS is a more effective strategy to reduce the volume of emissions than environmentalism.

Note that the average quality $(Q + q_G^*(Q))/2$ increases with Q and with β, while the quality gap shrinks with Q and β.

Furthermore, the cross-derivative of ES is given by

$$\frac{\partial^2 ES}{\partial Q \partial \beta} = -3k^{1/2}\frac{81Q\beta - 54k^{1/2}\beta + 9Qk - 2k^{3/2}}{(9\beta - k)^3} > 0.$$

Indeed, the numerator is negative at $\beta = k/3$, which is the minimum value of β, and negative at $Q = 4k^{1/2}/9$, which is the maximum value of Q. Since it is increasing in Q and decreasing in β, the numerator is always negative. That is, the MQS and environmentalism are complements: *environmentalism reinforces the positive effect of the MQS on the environmental surplus associated with the market outcome.*

6.2 Green technologies

It is widely accepted among policy-makers that the use of more environmental-friendly technologies is one of the main tools that should permit the development of a green society. Reformulating this idea in our setting amounts to assuming that firms have access to a technology that allows them to produce q_G and q_B at lower costs. We are agnostic about the reasons that explain the emergence of this new technology. In this section, our aim is instead to investigate the market and environmental effects of such a technology. More specifically, we consider a cost function, which we view as a reduced form for an abatement or replacement technology designed through innovations or governments subsidizes.

So far, we have assumed that production costs are given by $cq + q^2/2$. We start by assuming that firms' fixed costs decrease. Formally, the fixed production costs are now defined as follows:

$$F(q) = \frac{q^2}{2\gamma}, \tag{28}$$

where $\gamma > 0$ measures the *technological greenness* of the production technique: the higher γ, the lower the cost of designing the environmental quality q. Since we have normalized $\gamma = 1$ in the previous sections, we study how increasing γ above 1 affects the market outcome.

Fixed costs. Assume for the moment that both firms adopt the new technology described by (28). Following Section 4, it can be shown that, for $\beta > \bar{\beta}_\gamma \equiv \gamma\bar{\beta} = 0.410\gamma k/3$, the equilibrium qualities are given by

$$q_G^\gamma = \frac{2\gamma k^{1/2}}{3}\frac{6\beta - \gamma k}{9\beta - 2\gamma k} > q_B^\gamma = \frac{2\gamma k^{1/2}}{3}\frac{3\beta - \gamma k}{9\beta - 2\gamma k}, \tag{29}$$

which are both positive since $\beta > \bar{\beta}_\gamma$. When this inequality does not hold, we have a corner solution which involves only the green firm.

It is readily verified that the green quality increase with the degree of technological greenness. As for the brown one, the argument goes as follows. We have:

$$\frac{\mathrm{d}q_B^\gamma}{\mathrm{d}\gamma} = \frac{2}{3}k^{1/2}\frac{2k^2\gamma^2 + 9\beta\left(3\beta - 2k\gamma\right)}{\left(9\beta - 2k\gamma\right)^2}.$$

As the numerator of this expression is a quadratic and convex function of β which is positive at $\beta = 0$, the brown quality also increases with γ when $\beta > 0.526\gamma k$. Thus, *both environmental qualities increase with technological greenness* when the supply of environmentalism is sufficiently high. In this case, the green quality rises faster than the brown one. This is because the strict convexity of the fixed cost function implies that a higher technological greenness has a bigger impact on firm G than on firm B.

Furthermore, the average quality

$$\frac{q_G^\gamma + q_B^\gamma}{2} = \frac{\gamma k^{1/2}}{3},$$

increases with γ while the quality gap, hence the price differential, widens.

Moreover, it holds that

$$\bar{\theta}(q_G^\gamma, q_B^\gamma) = \frac{3\beta - \gamma k}{9\beta - 2\gamma k} > 0,$$

because $\beta > \gamma k/3$. Differentiating this expression with respect to γ shows that the market share of the green variant grows with γ.

Since the environmental surplus is given by

$$ES^{\gamma} = \frac{2}{3}k^{1/2}\gamma\frac{2k^2\gamma^2 - 18k\beta\gamma + 45\beta^2}{(9\beta - 2k\gamma)^2}.$$

The derivative of ES with respect to γ is equal to

$$\frac{\mathrm{d}ES^{\gamma}}{\mathrm{d}\gamma} = (15\beta - 2k\gamma)\frac{2k^2\gamma^2 - 12k\beta\gamma + 27\beta^2}{(9\beta - 2k\gamma)^3},$$

which is positive for all β and γ.

Moreover, the effect on net environmental surplus is also positive. Indeed, we have:

$$NES^{\gamma} = \frac{2}{9}\frac{k\gamma(3-k)\left(2k^2\gamma^2 + 9\beta(5\beta - 2k\gamma)\right)}{(9\beta - 2k\gamma)^2},$$

so that

$$\frac{\mathrm{d}NES^{\gamma}}{\mathrm{d}\gamma} = \frac{2}{9}k(3-k)(15\beta - 2k\gamma)\frac{2k^2\gamma^2 + 27\beta^2 - 12k\beta\gamma}{(9\beta - 2k\gamma)^3} > 0.$$

For the above findings to be meaningful, it must that the two firms adopt the new technology. But do they want to do so? Plugging (29) in (9) yields the following equilibrium profits:

$$\pi_G^{\gamma}(q_G^{\gamma}, q_B^{\gamma}) = \frac{2}{9}\frac{(9\beta - k\gamma^2)(6\beta - k\gamma)^2}{(9\beta - 2k\gamma)^2}, \qquad \pi_B^{\gamma}(q_G^{\gamma}, q_B^{\gamma}) = \frac{2}{9}\frac{(9\beta - k\gamma^2)(3\beta - k\gamma)^2}{(9\beta - 2k\gamma)^2}. \tag{30}$$

Differentiating these expressions with respect to γ shows that firm G's profits increase with γ. By contrast, firm B's profits decrease because $\beta > \gamma k/3$. As a result, it is not clear that firm B wants to adopt the new technology.

Consider a game prior to the quality game, where each firm chooses either to adopt or not to adopt the γ-technology. Lemma 2, proven in Appendix D, shows that both firms choose the γ-technology.

Lemma 2. *In the 2×2 game where firms chooses between the old and new technologies, adopting the new technology is a dominant strategy for each firm.*

Like in Section 4, when $\beta < \bar{\beta}_{\gamma}$, the market outcome is given by the corner equilibrium where firm G's strategy is given by $q_G = \gamma k^{1/2}$, which increases with γ, while firm B's strategy is still $q_B = 0$. Here too, technological greenness leads to a better environmental outcome.

We may thus conclude that β and γ affect the market outcome in opposite ways: whereas green consumerism has a negative direct impact on environmental qualities and surplus, technological greenness delivers positive effects.

Observe that

$$\frac{\partial^2 ES^\gamma}{\partial\beta\partial\gamma} = -36\beta\gamma k \frac{9\beta + k\gamma}{(9\beta - 2k\gamma)^4} < 0.$$

Hence, environmentalism weakens the positive effects of green technologies.

Marginal quality cost. We now investigate to the impact of a lower marginal quality cost. Since k decreases with c, a lower marginal quality cost amounts to a higher k.

Assume first that $\beta > \bar{\beta}$. Differentiating (12) with respect to k yields:

$$\frac{\mathrm{d}q_G^\gamma}{\mathrm{d}k} = \frac{1}{3k^{1/2}} \frac{54\beta^2 - 15k\beta + 2k^2}{(9\beta - 2k)^2}, \qquad \frac{\mathrm{d}q_B^\gamma}{\mathrm{d}k} = \frac{1}{3k^{1/2}} \frac{(3\beta - 2k)(9\beta - k)}{(9\beta - 2k)^2}.$$

The sign of $\mathrm{d}q_G^*/\mathrm{d}k$ is given by the sign of the numerator, which is a convex parabola of k. This parabola is positive at $k = 0$ and its minimum is reached at $k = 15/4\beta$. Plugging this value in the numerator shows that this one is always positive. Therefore, the green quality increases with k. As for the brown quality, it is immediate that $\mathrm{d}q_B^*/\mathrm{d}k$ is positive since $\beta > k/9$. In other words, the brown quality also increases with k. Consequently, the average quality rises when the marginal quality cost decreases.

Differentiating (15) with respect to k shows that more consumers buy the brown quality when k increases ($\bar{\theta} \uparrow$). Nevertheless, it is easy to show that the impact of k on the environmental surplus is positive. Furthermore, the net environmental surplus also increases with k.

Clearly, when $\beta < \bar{\beta}$, it is immediate that the equilibrium quality $k^{1/2}$ increases with k.

Summarizing yields the following proposition.

Proposition 6. *For all levels of environmental ideology, a greener technology leads to a better environmental outcome.*

Hence, unlike environmentalism, a higher technological greenness always leads the market to provide better environmental solutions.

7 Concluding remarks

Green consumerism is often presented as one of the main backbones of new environmental policies. However, very little is known about its impact on firms' decisions. This paper contributed to reduce such a lacunae. To this end, we have developed a simple and intuitive model that takes into account the psychic costs and benefits associated with the consumption of goods that generate different amounts of emissions. Using this setting has allowed us to show that the environmental ideology can be ineffective in curbing the damages generated by consumption in a market economy if it is not combined with other and more traditional policy tools. Thus, our findings suggest the need for policy initiatives that add to those aimed at promoting environmentalism. In particular, we find that the positive environmental effects generated by a minimum environmental standard may be reinforced by the environmental ideology.

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Appendix A

In this Appendix we extend the result of Proposition 1 to the market with $n \geq 2$ firms, while fixed production costs prevent n from becoming arbitrarily large. We assume that firms' qualities are given by $q_\kappa = \kappa q$ for $\kappa = 1, ..., n$ and $q > 0$. In other words, environmental qualities are ranked by increasing order ($q_1 < q_2 < ... < q_n$) and the difference between any two neighboring qualities is the same and equal to q. Hence, the top environmental quality is $q_n = nq$ while the bottom one is q. For simplicity, we also assume that $c = 0$. For this setting, we can prove the following result:

Proposition 1a. *There exist $n-1$ thresholds $\beta_1 > ... > \beta_\kappa > ... > \beta_{n-1}$ such that firm κ is active if and only if $\beta > \beta_\kappa$ for $\kappa = 1, ..., n-1$. Furthermore, when β increases, the active firms charge higher prices.*

Proof. A consumer of type θ who buys the κth quality has an indirect utility given by

$$V_\kappa(\theta) = q_\kappa - \beta\theta(n-\kappa) - p_\kappa, \qquad \text{for } \kappa = 1, ..., n$$

where $\beta\theta(n-\kappa)$ stands for the psychological cost the consumer bears for not consuming the best environmental quality q_n, while p_κ is the price of quality q_κ. In this case, firm κ competes directly with firm $\kappa - 1$ and firm $\kappa + 1$, while firm 1 (n) compete with firm 2 ($n-1$) only. Hence, the consumer θ_κ indifferent between buying qualities $q_{\kappa+1}$ or q_κ is given by the solution to the equation:

$$q_{\kappa+1} - p_{\kappa+1} - \beta\theta(n-(\kappa+1)) = q_\kappa - p_\kappa - \beta\theta(n-\kappa),$$

that is,

$$\theta_\kappa = \frac{p_{\kappa+1} - p_\kappa - q}{\beta}, \qquad \text{for } \kappa = 1, ..., n-1. \tag{A.1}$$

Assuming that types are uniformly distributed over $[0, 1]$ with a unit density, firm κ's demand is given by

$$D_\kappa \equiv \theta_\kappa - \theta_{\kappa-1} = \frac{p_{\kappa+1} - 2p_\kappa + p_{\kappa-1}}{\beta}, \qquad \text{for } \kappa = 2, ..., n-1.$$

As for firms 1 and n, their demands are, respectively, given by

$$D_1 = \theta_1 = \frac{p_2 - p_1 - q}{\beta}, \qquad D_n = 1 - \theta_{n-1} = 1 - \frac{p_n - p_{n-1} - q}{\beta}.$$

In the case of a duopoly ($n = 2$), θ_1 is identical to (3) where $G = 2$, $B = 1$ and $q = q_G - q_B$, apart from the denominator of (A.1) where β is replaced by 2β because the difference between the psychic benefit and the psychic cost is 2β whereas the difference in psychic costs between $q_{\kappa+1}$ and q_κ is β. Hence, the duopoly studied in Section 3 is a special case of our n-firm setting. In what follows, we show that the main properties of the price equilibrium obtained in Proposition 1 hold true for $n \geq 2$ firms. Since qualities are given, we may disregard the fixed production costs in the price game.

Profit functions are such that

$$\begin{aligned}
\pi_1 &= \theta_1 = p_1 \frac{p_2 - p_1 - q}{\beta}, \\
\pi_\kappa &= p_\kappa(\theta_\kappa - \theta_{\kappa-1}) = p_\kappa \frac{p_{\kappa+1} - 2p_\kappa + p_{\kappa-1}}{\beta}, \qquad \kappa = 2, ..., n-1 \\
\pi_n &= p_n(1 - \theta_{n-1}) = p_n \left(1 - \frac{p_n - p_{n-1} - q}{\beta}\right),
\end{aligned}$$

where π_κ is continuous and quasi-concave in p_κ for $\kappa = 1, ..., n$.

The 3-firm case. Assume $n = 3$. If the price equilibrium is interior, the first-order conditions are as follows:

$$p_2 - 2p_1 = q, \tag{A.2}$$

$$4p_2 - p_1 - p_3 = 0, \tag{A.3}$$

$$2p_3 - p_2 = q + \beta, \tag{A.4}$$

whose solution is

$$p_1^* = \frac{1}{12}\beta - \frac{1}{2}q, \qquad p_2^* = \frac{\beta}{6}, \qquad p_3^* = \frac{1}{2}q + \frac{7}{12}\beta, \tag{A.5}$$

which all increases with β. Note that

$$D_1(p_1^*, p_2^*) = \frac{1}{12}(\beta - 18q),$$

which increases with β. Moreover,

$$D_3(p_2^*, p_3^*) = \frac{q}{2\beta} + 7$$

decreases with β. Hence, *the spreading of environmental ideology widens the market share of the bottom quality and narrows down that of the top quality.* In other words, when the three firms operate, raising β leads to a market outcome that generates a higher level of pollution.

Since $p_1^* < p_2^* < p_3^*$, the equilibrium is interior if and only if $p_1^* > 0$, that is, $\beta > \beta_1 \equiv 6q$, where β_1 is the unique solution to $p_1^*(\beta) = 0$. In this case, it follows from (A.2) that firm 2 charges the limit price $p_2^* = p_{\text{lim}} = q$ while firm 3's best reply implies that $p_3^* = q + \beta/2$. Note also that (A.1) implies $\theta_1(p_1^*, p_2^*) = 0$ at these two prices.

Assume now that β crosses from β_1 above, so that p_3^* also decreases. Below some threshold, p_3^* becomes small enough for firm 2 to find it profitable to set a price smaller than q. In this case, the equilibrium prices of firms 2 and 3, denoted p_2^{**} and p_3^{**}, are given by the solution to the system of first-order conditions for these two firms:

$$p_3 - 2p_2 = q, \qquad 2p_3 - p_2 = q + \beta.$$

Solving yields

$$p_2^{**} = \frac{\beta - q}{3}, \qquad p_3^{**} = \frac{q + 2\beta}{3}, \tag{A.6}$$

which both decrease with β. Let $\beta_{\lim} = 4q$ be the solution to the equation $p_2^{**}(\beta) = q$. Clearly, $\beta_{\lim} \equiv 4q < \beta_1$, and thus firms 2 and 3 choose $p_2^* = q$ and $p_3^* = q + \beta/2$ for $\beta_{\lim} < \beta < \beta_1$.

When $< \beta < \beta_{\lim}$, firms 2 and 3 charge the prices (A.6) that both decrease with β. Since

$$\theta_2(p_2^{**}, p_3^{**}) = \frac{p_3^{**} - p_2^{**} - q}{\beta} = 1 - \frac{q}{\beta},$$

$\theta_2(p_2^{**}, p_3^{**}) = 0$ when $\beta = q$. In this case, we have $p_2^{**} = 0$ and $p_3^{**} = p_{\lim} \equiv q$. Set $\beta_2 \equiv q < \beta_{\lim} < \beta_1$. Hence, when β crosses β_2 from above, firms 1 and 2 are out of business while firm 3 supplies the whole market at the price $p_3^{**} = q$.

In sum, we have: assume that β decreases from a value larger than β_3. First, firm 1 exits the market when $\beta = \beta_3$ while firm 2 charges the limit price $p_{\lim} = q$. Firms 2 and 3 remain in business for $\beta_2 < \beta < \beta_3$. Then, firm 2 exits the market when $\beta = \beta_2$ while firm 3 remains in business charges the limit price $p_{\lim} = q$. Finally, firm 1 remains in business for all $\beta \geq 0$. In other words, we have: (i) when $\beta < q$, only the high-quality firm is in business; (ii) when $\beta < q < 6q$, both firms 2 and 3 are on the market; and (iii) when $\beta > 6q$, the 3 firms supply the market. To put it differently, a steadily growing environmental ideology allows firms with a decreasing environmental quality to enter sequentially the market.

Putting all the above results together, we have shown that *an economy characterized by a rising environmental ideology generates a market outcome whose environmental standard goes down.*

The n-firm case. Differentiating π_κ with respect to p_κ yields the following second-order difference equations for an interior equilibrium:

$$\begin{aligned} p_2 - 2p_1 &= q \\ 4p_\kappa - p_{\kappa-1} - p_{\kappa+1} &= 0, \qquad \kappa = 2, .., n-1 \\ 2p_n - p_{n-1} &= q + \beta \end{aligned} \tag{A.7}$$

The first and last equations are the same as (A.2) and (A.4) while (A.3) is a straightforward extension of (A.3).

The characteristic equation associated with (A.7) is

$$-Ab^{\kappa+1} + 4Ab^{\kappa} - Ab^{\kappa-1} = 0,$$

After simplification, we have the following quadratic equation:

$$-b^2 + 4b - 1 = 0$$

whose solutions are given by

$$b_1 = 2 + \sqrt{3} > 1 > b_2 = 2 - \sqrt{3} > 0.$$

Consequently, the solution to (A.7) is

$$p_\kappa^* = A_1 b_1^\kappa + A_2 b_2^\kappa \tag{A.8}$$

where A_1 and A_2 are two unknown constants.

To find A_1 and A_2, we proceed as follows. Note, first, that the equilibrium condition for firm 1 is

$$p_2 = q + 2p_1.$$

Applying (A.7) to firm 1 yields:

$$4p_1 - p_0 - p_2 = 0,$$

where p_0 is the price set by a hypothetical firm selling a variant of quality 0. It then follows from the above two equations that

$$4p_1 - p_0 - q - 2p_1 = 0$$

whose solution in p_0 is given by

$$p_0 = 2p_1 - q.$$

Using (A.8), we obtain

$$p_0 = A_1 b_1^0 + A_2 b_2^0 = A_1 + A_2 = 2p_1 - q = 2A_1 b_1 + 2A_2 b_2 - q,$$

which implies

$$A_2 = \frac{q + A_1 (1 - 2b_1)}{2b_2 - 1}. \tag{A.9}$$

Equation (A.4) may be rewritten as follows:

$$A_1 b_1^{n-1} + A_2 b_2^{n-1} = 2A_1 b_1^n + 2A_2 b_2^n = q + \beta.$$

Plugging (A.9), this expression becomes:

$$A_1 b_1^{n-1} + \frac{(q + A_1 (1 - 2b_1)) b_2^{n-1}}{2b_2 - 1} - 2A_1 b_1^n - 2\frac{(q + A_1 (1 - 2b_1)) b_2^n}{2b_2 - 1} + q + \beta = 0$$

whose solution in A_1 is equal to

$$A_1 = \frac{\beta + q}{(2b_1 - 1)\left(b_1^{n-1} - b_2^{n-1}\right)} > 0$$

because $2b_1 - 1 > 0$. By implication of (A.9),

$$A_2 = \frac{\beta + q(1 - b_1^{n-1})}{(2b_2 - 1)\left(b_1^{n-1} - b_2^{n-1}\right)},$$

the sign of which depends on β.

If the equilibrium is interior, the equilibrium prices are then given by

$$p_\kappa^*(\beta; n) = \frac{1}{b_1^{n-1} - b_2^{n-1}} \left[\frac{\beta + q\left(1 - b_2^{n-1}\right)}{2b_1 - 1} b_1^\kappa + \frac{\beta + q(b_1^{n-1} - 1)}{1 - 2b_2} b_2^\kappa \right] \qquad \text{for } \kappa = 1, ..., n. \tag{A.10}$$

Note that (A.10) is equal to (A.5) (resp., (A.6)) when $n = 3$ and $\kappa = 1$ (resp., $n = 2$ and $\kappa = 1, 2$).

The equilibrium prices increase with β or q because a higher supply of environmentalism or a wider quality gap endows firms more market power. Since $b_1 > b_2$, we have $p_{\kappa+1}^* > p_\kappa^*$ for $\kappa = 1, ..., n-1$. Furthermore, p_κ^* increases faster than $p_{\kappa-1}^*$ with β, so that $\theta_1(p_1^*, p_2^*)$ and $\theta_{n-1}(p_{n-1}^*, p_n^*)$ increases with β. As a result, when β rises, more consumers buy the bottom environmental quality while fewer consumers buy the top quality.

The equilibrium with n firms is interior if $p_1^*(\beta) > 0$. For this to hold, β must be larger that the solution to the equation $p_1^*(\beta) = 0$, which is given by

$$\beta_1 \equiv q \frac{b_1 \frac{b_2^{n-1} - 1}{2b_1 - 1} + b_2 \frac{b_1^{n-1} - 1}{1 - 2b_2}}{\frac{b_1}{2b_1 - 1} + \frac{b_2}{1 - 2b_2}}.$$

By contrast, when $\beta < \beta_1$, $p_1^*(\beta) = 0$ and firm 1 is out of business.

Assume now that $\kappa - 1 > 0$ firms are out of business. Since $p_\kappa > p_{\kappa-1} > ... > p_1$, these firms are $1, ..., \kappa - 1$, which means the first active firm is firm κ. Let $\beta_\kappa \equiv \beta_1(n - \kappa)$ be the solution to

$$p_1^*(\beta; n - \kappa) = \frac{1}{b_1^{n-\kappa-1} - b_2^{n-\kappa-1}} \left[\frac{\beta + q\left(1 - b_2^{n-\kappa-1}\right)}{2b_1 - 1} b_1 + \frac{\beta + q(b_1^{n-\kappa-1} - 1)}{1 - 2b_2} b_2 \right] = 0,$$

that is,

$$\beta_\kappa = \beta_1(n - \kappa) = q \frac{b_1 \frac{b_2^{n-\kappa-1} - 1}{2b_1 - 1} + b_2 \frac{b_1^{n-\kappa-1} - 1}{1 - 2b_2}}{\frac{b_1}{2b_1 - 1} + \frac{b_2}{1 - 2b_2}}.$$

Differentiating this expression with respect to n yields

$$\frac{d\beta_\kappa}{dn} = q \frac{(2b_1 - 1) b_1^{n-\kappa-1} b_2 \ln b_1 + (1 - 2b_2) b_1 b_2^{n-\kappa-1} \ln b_2}{b_1 - b_2} > 0$$

because $b_1 > b_2$. Thus, the value of β that solves $p_1^*(\beta; n - \kappa) = 0$ decreases as the number of active firms decreases. Therefore, we may rank the thresholds associated with the exit of firms $n - 1, n - 2, ..., 2$ as follows: $\beta_1 > \beta_2 \equiv \beta_1(n - 1) > ... > \beta_{n-1} \equiv \beta_1(2)$. Firm $n - \kappa$ remains active provided that $\beta > \beta_\kappa$.

When β crosses β_κ, firm $n-\kappa$ is out of business at price $p^*_{n-\kappa+1}=0$. To put the other way round, *as β steadily increases from 0 firms $i=n-1,n-2,...,1$ enter the market sequentially* each time that β crosses β_{n-i+1} from below.

For the proof to be complete, it remains to show that $\beta_\kappa>0$ for $\kappa=1,...,n-1$. First, β_κ decreases with κ. Indeed, we have

$$\frac{d\beta_\kappa}{d\kappa}=q\frac{(1-2b_1)b_1^{-\kappa+n-1}b_2\ln b_1+(2b_2-1)b_1b_2^{-\kappa+n-1}\ln b_2}{b_1-b_2}<0 \qquad \text{for } \kappa<n-1$$

because $b_2<1$. Therefore, β_κ takes on its minimum value at $\kappa=1$. Since $\beta_1(2)=q>0$, it must be that $\beta_\kappa=\beta_1(n-\kappa)$ is positive.

We may summarize our main results as follows. When β is small enough ($\beta<\beta_1$), only the best environmental quality firm is active. When β becomes larger than β_1, then firm 2 enters the market with a lower environmental quality, which leads to a worse ecological footprint. As β keeps rising above $\beta_2,\beta_{3,}...$, more and more firms that produce lower and lower environmental qualities get into business. This gradually downgrades the environmental performance of the market outcome because a growing number of consumers buy the worst environmental qualities. Note also that a wider quality gap ($q\uparrow$) raise the value of the thresholds β_κ and thus slows down the entry of lower environmental qualities.

This completes the proof of Proposition 1a, that is, a loftier environmental ideology leads to a worse ecological footprint through the gradual entry of firms selling more polluting products.

Appendix B

1. $(k^{1/2},0)$ **is a Nash equilibrium over** $(k/3,\ \bar\beta)$ The argument involves two steps.

Step 1. What is firm G's best reply against $q_B=0$ when $\beta>k/3$? By construction, $k^{1/2}$ is the best reply when $\bar\theta=0$. When $0<\bar\theta<1$, it follows from (9) that firm G's profits are given by

$$\pi^*_G(q_G,0)=\frac{(4\beta+k^{1/2}q_G)^2}{18\beta}-\frac{1}{2}q_G^2.$$

Differentiating with respect to q_G yields the solution

$$\bar q_G=\frac{4k^{1/2}\beta}{9\beta-k}=q^*_G(0).$$

Since the second derivative of $\pi^*_G(q_G,0)$ is always negative, $\pi^*_G(q_G,0)$ is concave and maximized at $\bar q_G$. Hence, $\bar q_G$ is the best reply against $q_B=0$ for $0<\bar\theta<1$ because

$$\bar\theta(\bar q_G,0)=-\frac{k}{6\beta}\frac{4\beta}{9\beta-k}+\frac{1}{3}=\frac{3\beta-k}{9\beta-k}$$

is positive for $\beta > k/3$. Evaluating $\pi_G^*(q_G, 0)$ at $\bar{q}_G$ yields

$$\pi_G^*(\bar{q}_G, 0) = \frac{8\beta^2}{9\beta - k} > 0.$$

Since the other candidate best reply is $q_G = k^{1/2}$ with $\bar{\theta}(k^{1/2}, 0)$, it remains to compare $\pi_G^*(\bar{q}_G, 0)$ and $\pi_G(k^{1/2}, 0)$. Observe that

$$\frac{k}{2} - \frac{8\beta^2}{9\beta - k} = \frac{1}{2}\frac{-16\beta^2 + 9k\beta - k^2}{2(9\beta - k)}$$

is a concave parabola in β, which is negative at $\beta = 0$. Therefore, the numerator $-16\beta^2 + 9k\beta - k^2 = 0$ of the above expression has two positive roots given by

$$\frac{k}{9} < \frac{9 - \sqrt{17}}{32}k \simeq 0.152k < \frac{k}{3} \quad \text{and} \quad \frac{k}{3} < \frac{\sqrt{17} + 9}{32}k \simeq 0.410k < \frac{4k}{9}$$

Only the larger root is relevant because the smaller one is smaller than $k/3$. Setting

$$\bar{\beta} \equiv k\frac{\sqrt{17} + 9}{32} \simeq 0.410k < 4k/9,$$

we have

$$\frac{k}{2} - \frac{8\beta^2}{9\beta - k} > 0 \Leftrightarrow k/3 < \beta < \bar{\beta}.$$

In other words, when $\beta > \bar{\beta}$, we have $k/2 > \pi_G^*(\bar{q}_G, 0)$ over $(k/3, \bar{\beta})$, which means that $q_G = k^{1/2}$ *is firm G's best reply against* q_B*=0 over* $(k/3, \bar{\beta})$.

Step 2. What is firm B's best reply against $q_G = k^{1/2}$ when $\beta > k/3$? It follows from (11a) that firm B's best reply is

$$q_B^*(k^{1/2}) = k^{1/2}\frac{2\beta - k}{9\beta - k} > 0.$$

At the strategy pair $(k^{1/2}, q_B^*(k^{1/2}))$, we have

$$\bar{\theta}(k^{1/2}, q_B^*(k^{1/2})) = \frac{3}{2}\frac{2\beta - k}{9\beta - k} > 0$$

if and only if $\beta > k/2$. Otherwise, $q_B = 0$ is B's best reply against $k^{1/2}$. Therefore, $q_B = 0$ *is B's best reply against* $k^{1/2}$ *over* $(k/9, k/5)$.

Putting Steps 1 and 2 together implies that $(k^{1/2}, 0)$ is a Nash equilibrium over $(k/3, \bar{\beta})$.

2. Proof of Lemma 1. Set $b \equiv \beta/k$ and assume $b > 1/3$. It is readily verified that $\bar{\theta}(k^{1/2}, q_B^*) > 0$ iff $b > 4/9$ while $\bar{\theta}(q_G^*, 0) > 0$ always holds. Furthermore, we also have $\bar{\theta}(q_G^*, 0) < 1$ and $\bar{\theta}(k^{1/2}, q_B^*) < 1$ because $b > 1/3$. Since $\bar{\beta} < 4k/9$, the only relevant case is $\bar{\theta}(k^{1/2}, q_B^*) = 0$.

The corner equilibrium risk-dominates the interior equilibrium if and if:

$$\begin{aligned} & \left[\pi_G(k^{1/2},0)-\pi_G\left(q_G^*,0\right)\right]\cdot\left[\pi_B(k^{1/2},0)-\pi_B\left(k^{1/2},q_B^*\right)\right] \\ > & \left[\pi_G(q_G^*,q_B^*)-\pi_G\left(k^{1/2},q_B^*\right)\right]\cdot\left[\pi_B(q_G^*,q_B^*)-\pi_B\left(q_G^*,0\right)\right]. \end{aligned}$$

The payoff matrix is as follows:

$\pi_G(k^{1/2},0)=\dfrac{k}{2}$	$\pi_G\left(q_G^*,0\right)=\frac{2k}{81}\frac{2916b^4-972b^3+36b^2+3b+k^4}{b(9\beta-2k)^2}$
$\pi_B(k^{1/2},0)=0$	$\pi_B\left(k^{1/2},q_B^*\right)=-\frac{2k}{9}\frac{(3b-1)^2}{(9b-2)^2}$
$\pi_G(q_G^*,q_B^*)=\frac{2k}{9}\frac{(6b-1)^2(9b-1)}{(9b-2)^2}$	$\pi_G\left(k^{1/2},q_B^*\right)=\frac{k}{2}$
$\pi_B(q_G^*,q_B^*)=\frac{2k}{9}\frac{(3b-1)^2(9b-1)}{(9b-2)^2}$	$\pi_B\left(q_G^*,0\right)=\frac{2k}{81}\frac{(3b-1)^2(9b-1)^2}{b(9b-2)^2}$

The corner equilibrium risk-dominates the interior equilibrium if and if:

$$\begin{aligned} & \left[\pi_G(k^{1/2},0)-\pi_G\left(q_G^*,0\right)\right]\cdot\left[\pi_B(k^{1/2},0)-\pi_B\left(k^{1/2},q_B^*\right)\right] \\ > & \left[\pi_G(q_G^*,q_B^*)-\pi_G\left(k^{1/2},q_B^*\right)\right]\cdot\left[\pi_B(q_G^*,q_B^*)-\pi_B\left(q_G^*,0\right)\right]. \end{aligned} \tag{B.1}$$

Using the above payoffs yields:

$$\begin{aligned} & \left[\pi_G(k^{1/2},0)-\pi_G\left(q_G^*,0\right)\right]\cdot\left[\pi_B(k^{1/2},0)-\pi_B\left(k^{1/2},q_B^*\right)\right] \\ = & \left(\frac{k}{2}-\frac{2}{81}\frac{2916b^4-972b^3+36b^2+3b+1}{b\left(9b-2\right)^2}\right)\cdot\left(0+\frac{2}{9}k\frac{\left(3b-1\right)^2}{\left(9b-2\right)^2}\right) \\ = & \frac{k^2}{729}\frac{\left(-11\,664b^4+10\,449b^3-3060b^2+312b-4\right)\left(3b-1\right)^2}{b\left(9b-2\right)^4}. \end{aligned}$$

Similarly,

$$\begin{aligned} & \left[\pi_G(q_G^*,q_B^*)-\pi_G\left(k^{1/2},q_B^*\right)\right]\cdot\left[\pi_B(q_G^*,q_B^*)-\pi_B\left(q_G^*,0\right)\right] \\ = & k^2\left(\frac{2}{9}\frac{\left(6b-1\right)^2\left(9b-1\right)}{\left(9b-2\right)^2}-\frac{1}{2}\right)\cdot\left(\frac{2}{9}\frac{\left(3b-1\right)^2\left(9b-1\right)}{\left(9b-2\right)^2}-\frac{2}{81}\frac{\left(3-1\right)^2\left(9b-1\right)^2}{b\left(9b-2\right)^2}\right) \\ = & \frac{k}{729}\frac{\left(3b-1\right)^2\left(9b-1\right)\left(1296b^3-1305b^2+408b-40\right)}{b\left(9b-2\right)^4}. \end{aligned}$$

The inequality (B.1) holds if and only if

$$\begin{aligned} & \frac{k}{729}\frac{\left(-11\,664b^4+10\,449b^3-3060b^2+312b-4\right)\left(3b-1\right)^2}{b\left(9b-2\right)^4} \\ > & \frac{k}{729}\frac{\left(3b-1\right)^2\left(9b-1\right)\left(1296b^3-1305b^2+408b-40\right)}{b\left(9b-2\right)^4}, \end{aligned}$$

which is equivalent to

$$\frac{1}{729}\frac{(3b-1)^2\left(-2592b^3+2034b^2-441b+22\right)}{b\left(9b-2\right)^3}>0.$$

The above expression is positive because its numerator

$$-2592b^3+2034b^2-441b+22,$$

is positive over the interval $(1/3,\bar{\beta})$. This completes the proof of Lemma 1.

Appendix C

In this appendix, we provide the main expressions used to prove the results of Section 5.

1. (Net) Environmental surplus. Consider an interior equilibrium so that $\beta > 6k/9$. The value of the environmental surplus at the equilibrium outcome is given by the following expression:

$$ES(q_G^*,q_B^*)=\frac{2k^{1/2}}{3}\frac{45\beta^2-37k\beta+8k^2}{\left(9\beta-4k\right)^2}.$$

Differentiating w.r.t. β yields:

$$\frac{\mathrm{d}ES}{\mathrm{d}\beta}=-\frac{2k^{3/2}}{3}\frac{27\beta-4k}{\left(9\beta-4k\right)^3}<0.$$

As for the net surplus, it is given by

$$NES(q_G^*,q_B^*)=\frac{2k}{9}\frac{90\beta^2-75\beta k+16k^2}{\left(9\beta-4k\right)^2}.$$

Differentiating NES w.r.t. β yields:

$$\frac{\mathrm{d}NES}{\mathrm{d}\beta}=-\frac{2k^2}{3}\frac{\left(15\beta-4k\right)k^2}{\left(9\beta-4k\right)^3}<0.$$

Likewise, differentiating NES w.r.t. k yields:

$$\frac{\mathrm{d}NES}{\mathrm{d}k}=\frac{4}{9}\left(3\beta-k\right)\frac{-120k\beta+135\beta^2+32k^2}{\left(9\beta-4k\right)^3},$$

which is positive for all $\beta > 0$.

2. Net psychic benefits. (i) Interior equilibrium: $\beta > k/3$.

$$\Psi(\beta) = \frac{\beta}{2} - \frac{\beta}{2}\left(\frac{3\beta - k}{9\beta - 2k}\right)^2,$$

so that

$$\frac{\mathrm{d}^2\Psi}{\mathrm{d}\beta^2} = \frac{3\,(9\beta - 4k)\,k^2}{(9\beta - 2k)^4} > 0.$$

Hence, Ψ is strictly convex.

Since the derivative

$$\frac{\mathrm{d}\Psi}{\mathrm{d}\beta} = \frac{3}{2}\frac{216\beta^3 - 2k^3 - 144k\beta^2 + 31k^2\beta}{(9\beta - 2k)^3}$$

evaluated at $\beta = 0$ is positive, Ψ is increasing in β for $\beta > 0$.

(ii) Corner solution: $2k/9 < \beta \leq k/3$. Since $\bar{\theta}(q_G^*(0), 0) = 0$, we have

$$\Psi(\beta) = \frac{\beta}{2},$$

which also increases with β.

3. Social welfare at the market outcome. Assume $\beta > \bar{\beta}$. Social benefit across greens is equal to

$$SG(q_G, q_B) \equiv \int_{\bar{\theta}}^{1} (q_G + \beta\theta)\mathrm{d}\theta = (1 - \bar{\theta})q_G + \frac{\beta}{2}(1 - \bar{\theta}^2),$$

while social benefit across browns is similarly defined by

$$SB(q_G, q_B) \equiv \int_{0}^{\bar{\theta}} (q_B - \beta\theta)\mathrm{d}\theta = \bar{\theta}q_B - \frac{\beta}{2}\bar{\theta}^2.$$

Evaluating the total social welfare at the market equilibrium yields:

$$\begin{aligned} SW(q_G^*, q_B^*) &\equiv (1 - \bar{\theta})q_G^* k^{1/2} + \frac{\beta}{2}(1 - \bar{\theta}^2) + \bar{\theta}q_B^* k^{1/2} - \frac{\beta}{2}\bar{\theta}^2 - \frac{1}{2}(q_G^*)^2 - \frac{1}{2}(q_B^*)^2 \\ &= \frac{1}{18}\frac{567\beta^3 + 144\beta^2 k - 126\beta k^2 + 16k^3}{(9\beta - 2k)^2}, \end{aligned}$$

so that

$$\frac{\mathrm{d}SW(q_G^*, q_B^*)}{\mathrm{d}\beta} = \frac{1}{2}\frac{567\beta^3 - 378\beta^2 k + 62\beta k^2 - 4k^3}{(9\beta - 2k)^3} > 0,$$

and

$$\frac{\mathrm{d}^2 SW(q_G^*, q_B^*)}{\mathrm{d}\beta^2} = \frac{2\,(99\beta - 4k)\,k^2}{(9\beta - 2k)^4} > 0.$$

Appendix D

We know from (17) and (30) that

$$\pi_G(q_G^*, q_B^*) = \frac{2}{9}\frac{(9\beta - k)(6\beta - k)^2}{(9\beta - 2k)^2}, \qquad \pi_B(q_G^*, q_B^*) = \frac{2}{9}\frac{(9\beta - k)(3\beta - k)^2}{(9\beta - 2k)^2}$$

$$\pi_G^\gamma(q_G^\gamma, q_B^\gamma) = \frac{2}{9}\frac{(9\beta - k\gamma^2)(6\beta - k\gamma)^2}{(9\beta - 2k\gamma)^2}, \qquad \pi_B^\gamma(q_G^\gamma, q_B^\gamma) = \frac{2}{9}\frac{(9\beta - k\gamma^2)(3\beta - k\gamma)^2}{(9\beta - 2k\gamma)^2}$$

Assume that firm G adopts the new technology whereas firm B does not. Then, profits are defined by

$$\pi_G^\gamma(q_G, q_B) = \frac{\left(4\beta + k^{1/2}(q_G - q_B)\right)^2}{18\beta} - \frac{1}{2\gamma}q_G^2, \qquad \pi_B^*(q_G, q_B) = \frac{\left(2\beta - k^{1/2}(q_G - q_B)\right)^2}{18\beta} - \frac{1}{2}q_B^2. \quad \text{(D.1)}$$

Applying the FOCs yields the following equilibrium qualities:

$$q_G^\gamma = \frac{2\gamma k^{1/2}}{3}\frac{6\beta - k}{9\beta - k(\gamma + 1)}, \qquad q_B^* = \frac{2k^{1/2}}{3}\frac{3\beta - k\gamma}{9\beta - k(\gamma + 1)}.$$

Plugging q_G^γ and q_B^* into (D.1), we obtain

$$\pi_G^\gamma(q_G^\gamma, q_B^*) = \frac{2}{9}\frac{(6\beta - k)^2(9\beta - k\gamma)}{(9\beta - k(\gamma + 1))^2}, \qquad \pi_B^*(q_G^\gamma, q_B^*) = \frac{2}{9}\frac{(9\beta - k)(3\beta - k\gamma)^2}{(9\beta - k(\gamma + 1))^2}. \quad \text{(D.2)}$$

Firm B prefers to select the new technology ($\gamma > 1$) rather than sticking to the old technology ($\gamma = 1$) as

$$\pi_B^\gamma(q_G^\gamma, q_B^\gamma) - \pi_B^*(q_G^\gamma, q_B^*) = \frac{(9\beta - k\gamma)(9\beta - k(\gamma + 1))^2 - (9\beta - k)(9\beta - 2k\gamma)^2}{(9\beta - 2k\gamma)^2(9\beta - k(\gamma + 1))^2} > 0. \quad \text{(D.3)}$$

Indeed, the denominator of this expression is always positive and strictly decreasing in γ, while the numerator is equal to 0 for $\gamma = 1$ and increasing in γ for $\gamma > 1$. This implies that $\pi_B^\gamma(q_G, q_B) - \pi_B^*(q_G, q_B) = 0$ at $\gamma = 0$ and increases in γ. Consequently, (D.3) is positive and increasing for all $\gamma > 1$. In other words, when firm G adopts the new technology, firm B finds it profitable to do the same.

Similarly, the equilibrium profits when firm B adopts the new technology and firm G does not are given by

$$\pi_G^*(q_G^*, q_B^\gamma) = \frac{2}{9}\frac{(9\beta - k)(6\beta - k\gamma)^2}{(9\beta - k(\gamma + 1))^2}, \qquad \pi_B^\gamma(q_G^*, q_B^\gamma) = \frac{2}{9}\frac{(3\beta - k)^2(9\beta - k\gamma)}{(9\beta - k(\gamma + 1))^2}. \quad \text{(D.4)}$$

Firm G's profit difference between adopting and not adopting the new technology when firm B adopts the new technology is given by

$$\pi_G^\gamma(q_G^\gamma, q_B^\gamma) - \pi_G^*(q_G^*, q_B^\gamma) = \frac{(9\beta - k\gamma)(9\beta - k(\gamma + 1))^2 - (9\beta - k)(9\beta - 2k\gamma)^2}{(9\beta - 2k\gamma)^2(9\beta - k(\gamma + 1))^2} > 0. \quad \text{(D.5)}$$

Repeating the above argument shows that $\pi_G^\gamma(q_G^\gamma, q_B^\gamma) - \pi_G^*(q_G^*, q_B^\gamma) > 0$ for all $\gamma > 1$. In other words, it is not optimal for firm G to stick to the old technology when firm B adopts this technology.

Consider now the 2×2 game where the two firms possess two strategies, either *to adopt* (A) or *not to adopt* (NA).

$G \setminus B$	A	NA
A	$\pi_G^\gamma(q_G^\gamma, q_B^\gamma), \pi_B^\gamma(q_G^\gamma, q_B^\gamma)$	$\pi_G^\gamma(q_G^\gamma, q_B^*), \pi_B^*(q_G^\gamma, q_B^*)$
NA	$\pi_G^*(q_G^*, q_B^\gamma), \pi_B^\gamma(q_G^*, q_B^\gamma)$	$\pi_G^*(q_G^*, q_B^*), \pi_B^*(q_G^*, q_B^*)$

Using (D.2) and (17) imply

$$\begin{aligned} \pi_B^\gamma(q_G^*, q_B^\gamma) &> \pi_B^*(q_G^*, q_B^*) \\ &\Leftrightarrow \frac{2}{9}\frac{(3\beta - k)^2 (9\beta - k\gamma)}{(9\beta - k(\gamma+1))^2} > \frac{2}{9}\frac{(9\beta - k)(3\beta - k)^2}{(9\beta - 2k)^2} \\ &\Leftrightarrow k(\gamma - 1)\frac{9\beta(9\beta - k(\gamma+1)) + k^2(\gamma-1)}{(2k - 9\beta)^2 (k - 9\beta + k\gamma)^2} > 0. \end{aligned} \tag{D.6}$$

Similarly, (D.4) and (17) imply

$$\begin{aligned} \pi_G^\gamma(q_G^\gamma, q_B^*) &> \pi_G^*(q_G^*, q_B^*) \\ &\Leftrightarrow \frac{2}{9}\frac{(6\beta - k)^2 (9\beta - k\gamma)}{(9\beta - k(\gamma+1))^2} > \frac{2}{9}\frac{(9\beta - k)(6\beta - k)^2}{(9\beta - 2k)^2} \\ &\Leftrightarrow \frac{2}{9}k(k - 6\beta)^2(\gamma - 1)\frac{9\beta(9\beta - k(\gamma+1)) + k^2(\gamma-1)}{(9\beta - 2k)^2 (9\beta - k(\gamma+1))^2} > 0. \end{aligned} \tag{D.7}$$

It then follows from (D.3), (D.5), (D.6), and (D.7) that A is a dominant strategy for each player. This completes the proof of Lemma 2.