Does a green network effect lower pollution emissions?*

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Abstract

Firms increasingly adopt sustainable practices and green strategies in order to attract consumers. We consider a duopolistic market in which a green firm competes with a brown rival, and both firms offer vertically differentiated products. Consumers are heterogeneous in both willingness to pay for intrinsic quality and environmental consciousness. The latter is positively related to the green firm's market share, giving rise to a green network effect. We characterize how consumers sort between the two firms and show that the green firm enjoys higher profits. When considering pollution from both consumption and production, we show that the pollution emissions of the green firm can be higher than those of the brown firm. We then compute total welfare and evaluate the impact of a subsidy for the consumption of the green good. We show that total welfare improves, but this may also increase total pollution emissions, even when producing the green good is only slightly more polluting relative to the brown variety. In this circumstance, we demonstrate that the green network effect exacerbates such negative environmental outcome. This introduces a trade-off for the social planner and reveals a possible dark side of policy interventions aimed at enhancing green consumerism.

JEL classification: D43, L13, Q51, Q58.

Keywords: bidimensional consumers' heterogeneity; environmental concern; green network effect; pollution emissions; price discrimination; subsidy.

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1 Introduction

Over the past years, the degree of consumers' environmental concern has substantially increased around the globe. According to the 2020 Eurobarometer survey, 94% of citizens in all EU Member States acknowledged the importance of protecting the environment.[1] In particular, citizens believe that big companies and national governments should be more involved in this important issue. A survey by the Pew Research Center in 2020 found that, compared with a decade ago, more US citizens claim protecting the environment is a top priority.[2] According to this survey, nearly two-thirds of U.S. adults believe that the government should do more to address climate change. Recent contributions also show that environmental responsibility and consciousness have significantly increased in China.[3]

Remarkably, the COVID-19 pandemic seemed to heighten consumers' environmental awareness, as the notable reduction in pollution during the periods of lock-down allowed many citizens to experience first-hand an increase in the quality of urban air and water.[4] A study conducted in China by Kahn *et al.* (2020) showed that citizens' concern about environmental issues increased during the first wave of coronavirus in winter 2020. A global survey by management consultancy firm Accenture found that 60% of consumers were reporting making more environmentally-friendly and ethical purchases since the start of the pandemic.[5] The pandemic also made clear to consumers the importance of coordinated actions in reducing pollution.

The growing concern for environmental issues had a significant impact for firms' strategies and governments' actions. Governments across the globe adopted different policies to promote the use of eco-friendly goods. Firms from diverse industries developed and launched products characterized by a significant reduction of their pollution emissions. Increasing attention has also been given to the environmental cost associated to the production process. As reported by the aforementioned Eurobarometer survey, the interviewed citizens considered that the most effective ways of tackling environmental problems are 'changing the way we consume' and 'changing the way we produce'.

Hence, *both consumption and production* are increasingly taken into account when it comes to evaluate the environmental performance of a product. Indeed, the production of green products might generate a higher level of pollution than brown products. Case in point, electric vehicles are certainly less polluting

[1] https://ec.europa.eu/commission/presscorner/detail/en/IP_20_331

[2] https://www.pewresearch.org/politics/2020/02/13/as-economic-concerns-recede-environmental-protection-rises-on-the-publics-policy-agenda/

[3] See, among others, the recent book by Zhong and Shi (2020, especially Chapters 6 and 7) and the 2018 report by the think tank Tsingyan Research, available at https://chinadevelopmentbrief.cn/reports/report-shows-beijing-publics-environmental-awareness-and-satisfaction-are-growing/.

[4] He *at al.* (2020) and Dang and Trinh (2021), *inter alios*, provide evidence of improved air quality following COVID-19 restrictions.

[5] https://www.accenture.com/_acnmedia/PDF-134/Accenture-COVID-19-Pulse-Survey-Wave7.pdf%20-%20zoom=40

than conventional vehicles when they are used by drivers, but not when they are produced by car manufacturers. Studies have shown that in the US, EU, and in China, producing an electric vehicle creates more greenhouse-gas emissions than an equivalent gas-powered vehicle.[6] The process of making batteries for electric vehicles is mainly responsible for this emissions gap as it is currently very energy-intensive, from mining raw materials such as cobalt and lithium to production in gigafactories and transportation. Automakers are however taking steps to reduce such gap, but using cleaner sources of energy for the production process is still very costly.

The aim of this paper is to show that there are instances in which consumer preferences towards green goods may lead to suboptimal outcomes in terms of pollution emissions. The preconditions for this to occur, which lay the foundations for our theoretical model, is that producing a green variant of a good is more costly (and potentially more polluting) than a brown variant, and that consumers' environmental concern depends on the overall fraction of consumers that patronize the green firm. Notwithstanding the cost disadvantage, we show that the green firm reaps the benefit of such *green network effect* to the extent that its profits are always higher than the brown rival.

One might therefore be tempted to conclude that the presence of a relevant green externality is beneficial for the environment, as green goods pollute less than brown ones when they are used by consumers. However, an excessive adoption of the green good, propelled by the network effect, may lead to the opposite result, with detrimental consequences for the environment. This is particularly evident when the green good, whose consumption (or use) generates lower emissions than the brown good, requires a production process which is dirtier. Interventions by the policy maker may exacerbate the problem rather than solving it, if not carefully thought out.

Formally, we consider a duopoly in which a firm offers a standard variety of a good whereas its rival makes an additional (and more costly) effort to offer a variety of the good which is more environmentally friendly when consumed and used. The latter is therefore considered as *green* and the former as *brown*. Consumers are heterogeneous in both their willingness to pay (WTP) for intrinsic quality and in their environmental concern, that are independently distributed. As in mainstream literature, we interpret environmental concern as a non-monetary benefit a consumer enjoys when buying the green variety of the good (see, among others, Ostrom, 2000; Carlsson *et al.*, and 2010; Deltas *et al.* 2013).

In our model, however, consumers' environmental concern is unrelated to the intrinsic quality of the good while it is directly related to the market share of the green firm. The way we formalize this concern differs therefore from conventional theories. On the one hand, unlike standard models of vertical

[6] A 2015 study from the Union of Concerned Scientists found that manufacturing a midsize electric vehicle entails about 15% more emissions than a similar gas-powered vehicle. For bigger electric vehicles, that gap could grow to 68% or more, due to the larger dimension of the battery. The interested reader can visit: https://www.businessinsider.fr/us/building-electric-cars-how-much-pollution-versus-gas-powered-vehicles-2019-11?r=US&IR=T.

differentiation applied to environmental issues (Moraga-Gonzales and Padron-Fumero, 2002; Lombardini-Riipinen, 2005; among others), we do not assume that environmental performance necessarily translates into superior quality. On the other hand, we depart from the "warm-glow" approach (Andreoni, 1989 and 1990, *inter alios*) in which consumers feel better just by the fact they are doing "the right thing". Rather, consumers believe that only a collective behaviour can have sizeable effects, and the additional satisfaction they enjoy from buying the green variety is higher, the bigger is the market of the green good. Hence, similarly to Brécard (2013), we consider a *green network effect* as the preference for buying green is crucially driven by the amount of other green adopters.[7]

We also depart from previous contributions in terms of the methodological approach. We embed the Mussa and Rosen (1978) model of quality differentiation into a richer setup in which there is strategic interaction between a green and a brown firm. Each firm designs a menu of contracts, contingent on consumer's WTP for hedonic quality, consisting in a hedonic quality target and a price. When consumers' valuations for quality are observable to firms, a crucial role is played by consumers' environmental consciousness, whose intensity determines which firm they decide to patronize. At equilibrium, each firm designs the menu of contracts that maximizes its expected profit, given the choice of the rival and consumers' purchasing decisions.

We first show that two different classes of Nash equilibria can emerge, interior or corner solutions. At a corner solution, namely when consumers' valuation for intrinsic quality is sufficiently low, a positive selection for the green firm is obtained, meaning that the higher the consumers' WTP for hedonic quality, the larger the fraction of consumers served by the green firm. The opposite occurs at the interior solution, namely for higher levels of consumers' valuation for intrinsic quality, where we find a positive selection for the brown firm. This preliminary result will help interpret some of the findings of our analysis. Considering firms' prices and profit differentials, the green firm always enjoys a higher profit than the brown firm, despite charging a lower price when consumers' WTP for hedonic quality is relatively high. This holds notwithstanding the fact that the green firm faces a higher cost of production.

Interestingly, *considering both pollution from consumption and from production*, and therefore computing the aggregate pollution emissions produced by each firm, we find situations in which the green firm pollutes more than the brown rival. This occurs when the consumption of the brown good does not emit an excessive level of pollution, and even when the pollution from producing each unit of the green good is lower than that associated to the production of the brown alternative. We also evaluate total pollution, given by the sum of all emissions coming from the green and the brown good, and show that it is strongly affected by the pollution from the production of the green good, whose consumption is spurred by the network effect.

[7] However, differently from Brécard (2013), a green good is not necessarily viewed as being of better quality than the brown good. We also depart from Brécard (2013) because there is no network externality regarding the brown firm.

We next compute social welfare in the presence of the green network effect, taking into account total pollution emissions, and compare it with the first-best optimum of a social planner. We first show that there is excessive quality differentiation at the market equilibrium, as firms want to relax price competition. Then, we introduce a subsidy on the consumption of the green good and show that this policy instrument may backfire in terms of fighting pollution emissions. Indeed, a subsidy that encourages green consumption increases the green firm's market share. This, in turn, not only widens the emissions gap between the green and the brown firm, but may also increase total pollution, especially when the production process of the green good generates more pollution than producing the brown one.

Finally, we carefully investigate the impact of the green network effect considered in our model. In doing so, we compare our results with what would have happened in the presence of an environmental concern unrelated to the market size of the green firm. Our analysis reveals that a massive adoption of the green good, induced by the network effect, may bring high aggregate levels of pollution that outweigh the beneficial effect of a per-unit reduction of pollution from consuming the green good.

The main take-away from our paper is that network externalities favoring green products may have undesired side effects in terms of total pollution emissions. Our results may then provide useful guidance in terms of indicating how to better direct the green transition that many important initiatives are supporting, such as the EU Green Deal. In fact, we show that such transition should not only focus on laying out the conditions for more green firms to thrive, but should also take into account the whole production process and its related pollution emission, including the supply chain of production inputs and the waste disposal.

The remainder of the paper is as follows. We next present the literature review and discusses how our paper differs from previous contributions. Section 2 introduces the model, while Section 3 characterizes the market equilibria, including consumers' self-selection, firms' price schedules and profits, and pollution emissions. Section 4 provides a social welfare analysis, including the first-best optimum. In Section 5, we introduce a subsidy on green consumption and consider its impact on welfare and pollution. In Section 6, we compare the market equilibria with and without the green network effect. Section 7 concludes.

1.1 Related Literature

Our paper contributes to the stream of research on behavioral economics that investigates the pro-environmental behavior of consumers embedded in a social context with other consumers (Croson and Treich, 2014; Dasgupta *et al.*, 2016). There are many important papers considering how moral motivation and personal/social norms explain the recent surge of green consumerism (see *e.g.*, Stern, 1999; Clark *et al.,* 2002; Brekke *et al.*, 2003; Kaufman, 2014; Czajkowski *et al.*, 2014) and analyze the impact of environmentally friendly behavior on market equilibrium (Conrad, 2005; Eriksson, 2004; García-Gallego and Georgantzís, 2009; Moraga-Gonzalez and Padron-Fumero, 2002; Nyborg *et al.*, 2006; Rodriguez-Ibeas 2007). These contributions share the idea that environmental concern is driven by a "warm glow" motivation (Andreoni, 1989, 1990) whereby consumers experience a sense of joy and satisfaction for "doing their part", regardless of the impact of their decisions.

We depart from this approach as we consider a scenario in which the consumer's environmental concern is *directly* related to the purchasing decisions of the other consumers. We are therefore close to Brécard (2013) in modeling a form of green network effect related to green consumption which is similar to the "bandwagon effect" introduced by Leibenstein (1950), and defined as "the extent to which the demand for a commodity is increased due to the fact that others are also consuming the same commodity".

In our context, consumers receive additional satisfaction from purchasing the less polluting good only if others do the same, and this increase in utility is proportional to the amount of other consumers who buy green.[8] Apart from Brécard (2013) and Grover and Bansal (2021), however, not much theoretical research has been carried out in this direction, even though recent studies acknowledge the importance of imitating the decisions of others.[9] Although inspired by Brécard (2013), our modeling strategy differs from hers as we consider firms offering menus of contracts contingent on consumers' WTP for quality. We also take into account different types of pollution emissions, both from consumption and from production.

Standard models of quality differentiation applied to environmental issues typically collapse two dimensions of vertical differentiations into a single one, assuming the green good is of high quality and the brown good is of low quality (Moraga-Gonzales and Padron-Fumero, 2002; Lombardini-Riipinen, 2005; Deltas *et al.*, 2013; among others).[10] In our paper, consumers value the intrinsic performance of a good but their utility is also affected by an environmental concern. They are heterogeneous in the valuations for these two product characteristics, which are independently distributed. Ultimately, their consumption choice depends on which driver is stronger. In this respect, we depart from Marini *et al.* (2022), where consumers are heterogeneous in their attitude towards the environment but homogeneous in their valuation for the quality of a good. Quality is determined by a combination of the intrinsic and the environmental attribute. Moreover, when the green variant is also superior in terms of the intrinsic attribute, they show that an excessive environmental concern may be detrimental for the environment as it enhances the green firm's marker power, resulting in higher prices. Our results are seemingly in line, nonetheless, in our analysis, it is the (potentially dirtier) production process of the green firm which causes green consumerism to worsen the environmental outcome by increasing pollution emissions.

[8] Empirical validation to the green bandwagon effect was provided by Carlsson *et al.* (2010), whose research indicated the bandwagon effect increases marginal willingness to pay for environmentally friendly products.

[9] A recent article by White *et al.* (2019) summarizes much of the studies and papers on this issue. Bansal *et al.* (2021) find evidence of peer effects influencing the corporate social responsibility expenditure of firms in India.

[10] A relevant exception is represented by Mantovani *et al.* (2016). Based on the observation that brown goods can have higher performance than green alternatives, they model the high-quality good as brown and the low-quality good as green.

Our paper also contributes to the discussion about which policy tools should be adopted to curb pollution emissions. Moraga-Gonzalez and Padron-Fumero (2002) and Lombardini-Riipinen (2005) compare different frequently used environmental policies: the former focus on unit emissions standards, *ad valorem* taxes and technology subsidization, the latter takes an approach similar to Amacher *et al.* (2004) and considers a combination of a uniform *ad valorem* tax with an emission tax (or a subsidy to green consumers).[11] Bansal and Gangopadhyay (2003) consider environmentally concerned consumers and compare uniform policies versus policies that discriminate firms depending on the environmental quality of their products. A similar issue is investigated by Bansal (2008), who uses a vertical differentiated model to examine the welfare implications of *ad valorem* taxes/subsidies and emissions taxes. These authors find that the optimal policy depends on various factors, including the magnitude of pollution emissions, consumers' WTP and their degree of environmental awareness.

Sartzetakis *et al.* (2012) consider information provision on environmental damages associated to consuming certain products as a policy instrument supplementing environmental taxation. Van der Made and Schoonbeek (2009) propose a campaign that increases consumers' environmental concern through persuasive advertising. They focus on the entry effect of a firm which is endowed with a cleaner technology than the incumbent. Deltas *et al.* (2013) evaluate the choice of greenness and the implications of various policy interventions, among which cost-sharing of development costs for improving the greenness of a good. Yu *et al.* (2016) examine manufacturers' decision problem in determining the green goods and production quantity of each green level, and consider green preferences and government subsidized manufacturers' optimization models. The aim of our paper is to examine the possible limits of one of these policy tools, namely a subsidy favoring green consumption, when a green network effect is present.

Brécard (2013) suggests a pollution tax to limit environmental damage together with a subsidy or tax on green products, depending on the intensity of the network effect. As already anticipated, we are close to this paper but obtain different results in terms of the desirability of some of these tools, at least in terms of curbing pollution emissions. Indeed, in our model, we jointly consider pollution from consumption and from production, and show that overall pollution emissions can increase when consumers' environmental concern generates a network effect.[12] For this reason, a stimulus to the consumption of the green product could be counterproductive. Rather, we recommend R&D subsidies for green producers to carry out innovation in order to reduce emissions from production, especially when the green good is expected to be adopted on a large scale.

[11] Montero (2002) models imperfect competition on the permit market and studies investment incentives of tradable permits together with two types of standards, based on emissions and performance, respectively.

[12] Tarola and Zanaj (2020), in a model of international trade with two countries, consider both pollution from production and pollution from transportation.They investigate how the interplay between trade and consumption home bias affects global pollution emissions.

2 The model

We consider a duopolistic environment in which two firms compete to sell their products to consumers. Each consumer (she) can buy at most one unit of the good exclusively from one firm. Firms and consumers are assumed to be risk neutral.

Firms

Firms differ in their environmental commitment: one firm is *green* because it produces a variety of the good which is environmentally friendly when finally used by consumers, while the other firm is *brown* because it produces a standard variety. Accordingly, firms are indexed by $i = G, B$. The products sold by the two firms also differ in another characteristic, which is a usual attribute of vertical differentiation, indicated with q for (intrinsic or hedonic) quality. Firms have similar technologies and their profit margins (per unit, conditional on the customer buying) are given by

$$\pi_i(q) = p_i(q) - C_i(q), \tag{1}$$

where $p_i(q)$ is the price set by firm i for quality q_i and $C_i(q_i)$ is the cost of providing one unit of the good with quality q_i. Following Mussa and Rosen (1978), for simplicity, we set $C_i(q_i) = \frac{1}{2}k_i q_i^2$ and assume that $k_B = 1 < k_G = k$, with k representing the cost disadvantage of producing a green good.[13] This corresponds, for example, to the higher input costs a green firm incurs when producing a variant of a good which is environmentally friendly when consumed, for each given quality level q_i. Think of a car manufacturer that incurs in higher unit costs when it produces hybrid or electric cars rather than traditional combustion engine cars, for each given model.[14] Let us reiterate that the extra marginal cost incurred by the green firm, represented by parameter k, allows firm G to offer an environmentally friendly variety of the good, but only from the point of view of its usage and consumption. This is an important point, as in Section 3.5 we will consider not only emissions from consumption but we will also analyze the ecological footprint of firms' technologies, which determine pollution emissions at the source of the production process.

Consumers

Consider a population of consumers with unit mass, with each consumer buying at most one unit of the good. Consumers differ in two characteristics, the willingness to pay for intrinsic quality and the environmental concern, that are independently distributed. Consumers' WTP for quality θ is assumed

[13] Conrad (2005) assumes that green products are costlier to produce than standard products as they are more labor intensive. Yu *et al.* (2016) consider emissions from consumption and assume, as we do, that a product with a higher green level generates fewer emissions but is produced at higher costs.

[14] Similar assumptions can be found in Moraga-Gonzáles and Padrón-Fumero (2002), where the unit marginal cost of producing a given variant is constant, but the cost of producing environmental-sustainable varieties is higher. Also in Mahenc (2008) it is assumed that the environmental performance raises marginal costs.

to be continuous and uniformly distributed on the support $\left[\overline{\theta}-1,\overline{\theta}\right]$, with $\overline{\theta}>1$. The support of unit length is chosen for simplicity, while a sufficiently high upper bound $\overline{\theta}$ ensures that all consumers buy the good, so that the market is covered, as in Brécard (2013). Thus, one can concentrate the attention on consumer self-selection between the two firms, as a result of their strategic interaction. Consumers' environmental consciousness γ is continuously and uniformly distributed in the interval $[0,1]$.[15]

We interpret environmental concern as a non-monetary benefit that a consumer enjoys when buying from the green firm, which is unrelated to the intrinsic quality of the good, but which depends on the overall fraction of consumers that patronize the green firm. This captures the idea that environmentally concerned consumers want to make the difference with their purchasing choice and realize that their individual choices might be irrelevant, whereas only their collective behavior can have sizeable effects. A similar network effect does not apply for the consumption of the brown good, neither do we consider the social stigma that consumers may face when they fail to comply with an environmentally responsible consumption behavior.

Therefore, when a consumer abstains from buying, her utility is zero. When a consumer of type (θ,γ) buys one unit of the good from firm G, her utility is given by

$$u_G\left(\theta,\gamma\right)=\theta q_G+\gamma M_G-p_G, \tag{2}$$

where $M_G\in[0,1]$ denotes the market share of firm G. Conversely, when a consumer of type (θ,γ) buys one unit of the good from firm B, her utility is simply

$$u_B\left(\theta\right)=\theta q_B-p_B, \tag{3}$$

and environmental concern γ does not play any role. As a consequence, from the brown firm's standpoint, consumer valuation θ for hedonic quality is the only relevant characteristic.

Given our assumptions about the distributions of consumers' attributes and about their utility, a key role will be played by the relative weight of intrinsic quality *vis-à-vis* environmental consciousness in consumers' preferences. In particular, low values of θ will be associated to consumers caring relatively more about the environmental friendliness rather than the intrinsic quality dimension of the good; conversely, high values of θ characterize customers whose environmental consciousness is outweighed by their concern for the intrinsic performance of the good they decide to purchase.

Firms' strategic interaction

We first take the consumers' decision to buy from one firm as given, and suppose that firms offer price schedules that are conditional on the hedonic quality. In other words, we derive non-linear price schedules $p_i\left(q_i\right)$ offered by each firm $i=B,G$. To do so, given that a consumer of type θ has preferences over

[15] This assumption is made for convenience. It is possible to show that the qualitative nature of the results is robust to the generalization $\gamma\sim U[0,\overline{\gamma}]$ with $\overline{\gamma}\in(0,\infty)$.

quality-price pairs which are independent of γ (conditional on buying from one firm), we consider each firm offering menus of θ-contingent contracts, one for each type θ, consisting in a hedonic quality target and a price, $\{q_i(\theta), p_i(\theta)\}_{i=B,G}$, and each customer selecting the preferred pair. We can thus treat the firms' problem as independent of the consumers' choice, which is determined by their degree of environmental consciousness γ. In order to simplify the exposition, it is more convenient to reason in terms of consumers' indirect utility and to focus on quality-utility schedules of the form $\{q_i(\theta), U_i(\theta)\}_{i=B,G}$.

Let $U_i(\theta)$ denote the *indirect utility* of a consumer of type θ who buys from firm $i = B, G$, *absent* the benefit accruing from environmental consciousness. Given the non-linear price schedule $p_i(q_i)$ offered by firm i, a consumer of type θ, conditional on buying from firm i, solves

$$\max_{q_i} \quad \theta q_i - p_i(q_i);$$

denoting by $q_i(\theta)$ the solution to the above program, one can thus write

$$U_i(\theta) = \theta q_i(\theta) - p_i(q_i(\theta)). \tag{4}$$

Given $U_i(\theta)$, it is possible to single out the consumer of type (θ, γ) who is indifferent between buying from firm G or firm B. Indeed, a consumer of type (θ, γ) receives indirect utility $U_B(\theta)$ if she buys from the brown firm, whereas if the same consumer buys from the green firm, her *total* indirect utility becomes

$$\mathcal{U}_G(\theta) = U_G(\theta) + \gamma M_G.$$

Definition 1 ***Indifferent consumer.*** *The consumer with willingness to pay for intrinsic quality θ, who is indifferent between buying from the green or the brown firm, is characterized by environmental concern*

$$\widehat{\gamma}(\theta) \equiv \frac{U_B(\theta) - U_G(\theta)}{M_G}. \tag{5}$$

A consumer of type (θ, γ) strictly prefers to buy from the brown firm if her environmental concern falls short of $\widehat{\gamma}(\theta)$, *i.e.* if $U_G(\theta) + \gamma M_G \leq U_B(\theta)$; conversely, she strictly prefers to buy from the green firm if her environmental concern exceeds $\widehat{\gamma}(\theta)$, and $U_G(\theta) + \gamma M_G > U_B(\theta)$ holds. Given that γ is uniformly distributed on the interval $[0, 1]$, condition (5) implicitly defines the share of consumers with valuation θ who prefer to buy from the green firm, which is

$$M_G(\theta) \equiv \Pr(\gamma > \widehat{\gamma}(\theta)) = 1 - \widehat{\gamma}(\theta) = 1 - \frac{U_B(\theta) - U_G(\theta)}{M_G(\theta)}. \tag{6}$$

Similarly, the market share of the brown firm is

$$M_B(\theta) \equiv \Pr(\gamma \leq \widehat{\gamma}(\theta)) = \widehat{\gamma}(\theta) = \frac{U_B(\theta) - U_G(\theta)}{M_G(\theta)} = 1 - M_G(\theta). \tag{7}$$

Solving the right-most equality in (7) for $M_G(\theta)$ yields

$$M_G(\theta) = \quad \frac{1}{2} + \frac{\sqrt{1 - 4(U_B(\theta) - U_G(\theta))}}{2} \quad , \tag{8}$$

and then

$$M_B(\theta) = 1 - M_G(\theta) = \frac{1}{2} - \frac{\sqrt{1 - 4\left(U_B(\theta) - U_G(\theta)\right)}}{2}\ . \tag{9}$$

In order for both firms to have a positive market share from type θ consumers, it must be that $M_i(\theta) \in (0,1)$ for each $i = B, G$ and each θ, a necessary condition being that $U_B(\theta) - U_G(\theta) > 0$. Moreover, the determinant in both (8) and (9) must be positive, which occurs for $U_B(\theta) - U_G(\theta) < \frac{1}{4}$.

In order to set up each firm's maximization problem, let us first rewrite (4), solving it in terms of the price as

$$p_i(\theta) = \theta q_i(\theta) - U_i(\theta). \tag{10}$$

One can use expression (10) to eliminate the price from (1). Then, profit margins relative to each θ-type consumer become

$$\pi_i(\theta) = \theta q_i(\theta) - C_i(q_i(\theta)) - U_i(\theta) = \theta q_i(\theta) - \frac{1}{2} k_i q_i^2(\theta) - U_i(\theta), \tag{11}$$

while

$$S_i(\theta) \equiv \pi_i(\theta) + U_i(\theta) = \theta q_i(\theta) - C_i(q_i(\theta)) = \theta q_i(\theta) - \frac{1}{2} k_i q_i^2(\theta) \tag{12}$$

denotes the total surplus realized when a consumer of type θ buys hedonic quality $q_i(\theta)$ from firm $i = B, G$ (again, absent the benefit accruing from environmental concerns).

The programme of each firm $i = B, G$ consists then in maximizing its total profits with respect to the quality level $q_i(\theta)$ and the indirect utility $U_i(\theta)$ associated with each θ-type consumer, taking as given the indirect utility that the rival firm leaves to the consumer, i.e. $U_{-i}(\theta)$. Once the firms' quality levels and consumers' utilities are obtained, the corresponding prices $p_i(\theta)$ are derived using equation (10).

We assume that consumers' valuation θ is fully observable by each firm, while environmental consciousness γ is private information. This is consistent with the fact that consumers' WTP for intrinsic quality can be viewed as the inverse of their marginal utility of income. Hence, when firms can observe consumers' income (which is usually the case when the good is paid in installments), they can also correctly infer their WTP for quality, because a high income translates into a low marginal utility of income and thus a high θ. Conversely, firms' knowledge about consumers' environmental consciousness is much less precise.

Then, for each θ, firm $i = B, G$ solves the following programme

$$\max_{q_i(\theta), U_i(\theta)} \left(S_i(\theta) - U_i(\theta)\right) M_i(\theta) = \left(\theta q_i(\theta) - \frac{1}{2} k_i q_i^2(\theta) - U_i(\theta)\right) M_i(\theta). \tag{P_i}$$

Notice that environmental consciousness γ does not appear in the above programme, because it is replaced by the fraction $M_i(\theta)$ of type θ consumers buying from firm $i = B, G$, which in turn depends on the difference between indirect utilities. Moreover, in firm i's programme, the utility offered by the other firm, *i.e.* $U_{-i}(\theta)$, is treated as given even though it is endogenous (and dependent on θ only). Thus, firms compete against each other in the utility space: when a firm increases the utility offered to a given type of consumer, it reduces its payoff when serving that consumer but it increases its own probability of serving the consumer herself.

Finally, the timing of the game is as follows. The two firms simultaneously design the schedules $\{q_i(\theta), U_i(\theta)\}_{i=B,G}$. Consumers observe the corresponding non-linear price schedule $p_i(q_i)$ for $i = B, G$ and select the preferred one, *i.e.* they choose which quality to purchase and which firm to patronize. An equilibrium of the game is such that each firm chooses a menu of contracts that maximizes its expected profit, given the contracts offered by the rival firm and given the equilibrium choices of consumers. Each consumer chooses the contract that maximizes her utility, including her environmental concern as well.

3 Market Equilibria

3.1 Firms' reaction functions

When consumers' valuations θ are perfectly observable to firms, the choice of hedonic quality $q_i(\theta)$ is straightforward: such quality is chosen in order to maximize total surplus and it is then set at the level

$$q_i^*(\theta) = \frac{\theta}{k_i}. \tag{13}$$

Notice that $q_B^*(\theta) > q_G^*(\theta)$ for every θ. As a consequence, fixing the type of consumer, the brown firm always produces the highest quality variant of the good. In particular, for every θ, the quality differential between the brown and the green firm is

$$q_B^*(\theta) - q_G^*(\theta) = \frac{\theta(k-1)}{k}$$

which is increasing in both θ and k. Also notice that the quality-differentiated spectrum of goods produced by each firm is infinite, because each consumer of type θ is offered a different intrinsic quality of the good by each firm.

Substituting (13) into firm i's objective function, there remains to maximize profits with respect to net utilities U_i. These computations deliver the reaction functions of the two firms, which describe the optimal utility left by firm $i = B, G$ to a θ-type consumer given the utility $U_{-i}(\theta)$ that the same consumer receives from the competing firm $-i$. As it will be shown, at an interior solution, reaction functions have positive slopes so that utilities can be interpreted as *strategic complements* in this game.

Before proceeding further with the characterization of firms' reaction functions, let us emphasize which are the constraints that indirect utilities have to satisfy.

Condition 1 *For every* θ, *indirect utilities* $U_i(\theta)$, *with* $i = B, G$, *must be such that: (i)* $U_B(\theta) - U_G(\theta) > 0$; *(ii)* $U_B(\theta) - U_G(\theta) < \frac{1}{4}$; *(iii)* $U_i(\theta) \leq S_i(\theta) \Leftrightarrow \pi_i(\theta) \geq 0$; *(iv)* $U_B(\theta) \geq 0$ *and* $U_G(\theta) + \gamma M_G(\theta) \geq 0$.

Requirements (i) and (ii) ensure that $M_i(\theta) \in (0,1)$, so that each firm is active on the market and cases in which a single firm supplies the entire market are excluded. Constraint (iv) follows from consumers' participation constraints; in particular, environmentally-concerned consumers, who patronize the green firm, enjoy not only utility $U_G(\theta)$ but also their pro-environmental premium, so their total indirect utility becomes $\mathcal{U}_G(\theta) = U_G(\theta) + \gamma M_G(\theta)$, which must be non-negative.

The green firm

For firm G, the programme is

$$\max_{U_G(\theta)} \left(S_G(\theta) - U_G(\theta)\right) M_G(\theta) = \left(\frac{\theta^2}{2k} - U_G(\theta)\right)\left(\frac{1}{2} + \frac{\sqrt{1-4\left(U_B(\theta)-U_G(\theta)\right)}}{2}\right). \qquad (PG)$$

Notice that this programme uncovers a trade-off. On the one hand, an increase in U_G decreases firm G's profits because it corresponds to a lower price per unit sold and it shifts the division of total surplus towards consumers. On the other hand, it increases firm G's profits because it enhances the probability of selling the good and hence the quantity sold by firm G, and ultimately its market share. The optimal level of U_G balances these two opposing forces.

Computing the first-order condition associated to such programme, solving it for U_G as a function of U_B, and omitting the dependence of indirect utilities on θ, allows us to provide firm G's reaction function

$$U_G(U_B) = \frac{3\theta^2 - 2k + 12kU_B - \sqrt{2k\left(2k+3\theta^2-6kU_B\right)}}{18k}. \qquad (RF_G)$$

Further details are given in Appendix A.1.

The brown firm

Similarly, the programme of firm B is

$$\max_{U_B(\theta)} \left(S_B(\theta) - U_B(\theta)\right) M_B(\theta) = \left(\frac{\theta^2}{2} - U_B(\theta)\right)\left(\frac{1}{2} - \frac{\sqrt{1-4\left(U_B(\theta)-U_G(\theta)\right)}}{2}\right). \qquad (PB)$$

From the first-order condition associated to this programme, one can obtain the reaction function of firm B, which is given by

$$U_B^-(U_G) = \frac{2+12U_G+3\theta^2-\sqrt{2\left(2+6U_G-3\theta^2\right)}}{18} \quad \text{and} \quad U_B^+(U_G) = \frac{2+12U_G+3\theta^2+\sqrt{2\left(2+6U_G-3\theta^2\right)}}{18}. \qquad (RF_B)$$

Notice the asymmetry with respect to firm G's reaction function: for each possible level of indirect utility U_G that firm G leaves to the consumer with valuation θ, there are two possible utilities that maximize firm B's payoffs. Both $U_B^-(U_G)$ and $U_B^+(U_G)$ are admissible, even though the second solution $U_B^+(U_G)$ can be discarded when U_G is sufficiently low.[16]

[16] Again, further details are provided in Appendix A.1.

3.2 Nash equilibria

In a Nash equilibrium, the utility levels left by both firms to each type θ consumer solve the two equations RF_G and RF_B simultaneously, satisfy constraints (i)-(iv) in Condition 1, and obey second-order conditions. There are two classes of solutions that can be singled out: interior vs corner solutions.

Interior solutions

There exists a unique interior solution satisfying all of the above-mentioned requirements which is

$$U_G^* = \frac{\theta^2(3+2k) - k - \sqrt{5k\left(k - 2\theta^2\left(k-1\right)\right)}}{10k} \quad \text{and} \quad U_B^* = \frac{\theta^2(2+3k) - k - \sqrt{5k\left(k - 2\theta^2\left(k-1\right)\right)}}{10k}. \tag{14}$$

This solution exists when the determinant is non-negative, which amounts to

$$\theta \leq \sqrt{\frac{k}{2\left(k-1\right)}} \equiv \theta_0.$$

Note that, when k is sufficiently close to 1, *i.e.* when the cost differential between the green and brown firm is low, the threshold θ_0 tends to infinity. Moreover, it can be checked that the solution is such that both $U_G^* < S_G$ and $U_B^* < S_G < S_B$ hold provided that $\theta < \theta_0$. Finally, $U_B^* > 0$ if and only if

$$\theta > \frac{\sqrt{k\left(3 - 8k + 5\sqrt{4k^2+1}\right)}}{3k+2} \equiv \theta_1,$$

where $\theta_1 < \theta_0$. Hence $U_B^* > U_G^*$ always holds. When $\theta < \theta_1$, we have $U_G^* < U_B^* < 0$, which is not admissible at an interior solution, whereas when $\theta_1 \leq \theta \leq \theta_0$ we have $\max\{U_G^*, 0\} < U_B^*$. It follows that the solution in (14) only holds for $\theta_1 \leq \theta \leq \theta_0$.

Corner solutions

When $\theta < \theta_1$ the interior solution is no longer valid, but there is a candidate corner solution which is

$$U_B^* = 0 \quad \text{and} \quad U_G^* = \frac{3\theta^2 - 2k - \sqrt{2k\left(2k+3\theta^2\right)}}{18k}, \tag{15}$$

with both $U_G^* < \dfrac{\theta^2}{2k} = S_G$ and $U_G^* < U_B^* = 0$ being satisfied in the relevant parameter range. At this equilibrium, despite competing against the green firm, the brown firm is able to perfectly price discriminate its consumers and extracts all the surplus from them.

Finally, consider the case in which $\theta > \theta_0$. The reaction functions considered up to now no longer intersect, not even at the corners, so a solution in pure strategies does not exist. The following assumption enables us to exclude this latter case and to focus our attention on pure strategy Nash Equilibria.

Assumption 1 *$\overline{\theta} \leq \theta_0$ and $k \in (1, 2)$.*

Notice that θ_0 rapidly decreases with k; indeed $\lim_{k\to 1}\theta_0 = \infty$ and $\lim_{k\to 2}\theta_0 = 1$. Hence, the constraint $\overline{\theta} \leq \theta_0$ holds when both k and $\overline{\theta}$ are sufficiently low.

For expositional clarity, we label Region 1 the parametric interval $\theta \in \left[\overline{\theta}-1, \theta_1\right]$ and Region 2 the interval $\theta \in \left[\theta_1, \overline{\theta}\right]$. Continuity is guaranteed at the threshold θ_1. We use superscripts to distinguish the two regions, so that $U_i^r(\theta)$ denotes the equilibrium level of utility for consumer of type θ served by firm $i = B, G$ in Region $r = 1, 2$. The following proposition summarizes our results so far.

Proposition 1 ***Nash equilibria*** *(i) In Region 1,* i.e. *when consumers' valuation for intrinsic quality lies in $\theta \in \left[\overline{\theta}-1, \theta_1\right]$, there is a corner solution such that firm G's reaction function is strictly positively sloped and it intersects firm B's reaction function, which is constant at $U_B^1 = 0$; (ii) In Region 2,* i.e. *when consumers' valuation for intrinsic quality lies in $\theta \in \left[\theta_1, \overline{\theta}\right]$, there is an interior solution such that reaction functions intersect when they are both strictly positively sloped.*

3.3 Consumers' self-selection

Given indirect utility $U_i^r(\theta)$ set by each firm $i = B, G$ in each region $r = 1, 2$ at equilibrium, prospective consumers decide which firm to patronize according to their degree of environmental concern. This determines how consumers characterized by different valuations for hedonic quality θ self-select between the two firms. Three different sorting patterns are possible. Neutrality captures the situation in which $M_i(\theta)$, *i.e.* the fraction of consumers who self-select into firm $i = B, G$, is constant and does not depend on consumers' valuation θ. Positive (respectively, negative) selection into the green firm, instead, describes a situation in which the higher the consumers' WTP for hedonic quality θ, the bigger (resp. smaller) is the fraction of consumers served by firm G and, accordingly, the smaller (resp. bigger) the fraction of consumers served by firm B.

In Region 1, given the equilibrium utilities U_B^1 and U_G^1, one can compute the equilibrium market shares of the two firms $M_i^1(\theta)$, and finally the level of environmental concern which makes each consumer with valuation $\theta \in \left[\overline{\theta}-1, \theta_1\right]$ indifferent between patronizing firm B or firm G. Such indifferent consumer is

$$\widehat{\gamma}^1(\theta) = \frac{1}{2}\left(1 - \frac{1}{3}\sqrt{\frac{5k + 6\theta^2 - 2\sqrt{2k\left(2k + 3\theta^2\right)}}{k}}\right). \qquad (16)$$

It is easy to check that $\widehat{\gamma}^1(\theta)$ is strictly decreasing in θ in the relevant range, so there is *positive selection* into the green firm. In other words, the higher is consumers' valuation θ, the bigger is the share of consumers served by the green firm.

Similarly, in Region 2, equilibrium utilities U_B^2 and U_G^2 can be used to compute the equilibrium market shares of the two firms $M_i^2(\theta)$, yielding as indifferent consumer

$$\widehat{\gamma}^2(\theta) = \frac{1}{2}\left(1 - \sqrt{\frac{k - 2\theta^2(k-1)}{5k}}\right). \tag{17}$$

The above function is strictly increasing in θ when $\theta \in [\theta_1, \overline{\theta}]$ and we obtain *negative selection* for the green firm, meaning that the higher is the consumers' valuation θ, the smaller is the share of consumers served by the green firm. Moreover, notice that $\widehat{\gamma}^2(\theta)$ coincides with $\widehat{\gamma}^1(\theta)$ for $\theta = \theta_1$, so that continuity is satisfied. In Figure 1, we set $k = 1.5$, $\overline{\theta} = 1.1$ and plot function $\widehat{\gamma}(\theta)$ in the two parametric regions.

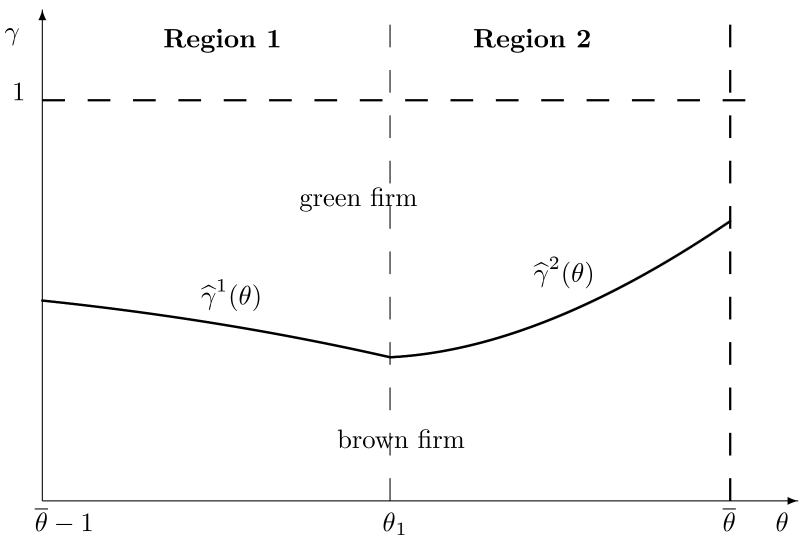

Figure 1: Consumer type space and consumer sorting

For the sake of comparison, notice that, had both firms the same costs of hedonic quality, irrespective of the environmental nature of the good (*i.e.* $k_i = 1$ for $i = B, G$), then they would produce the same quality levels $q_B(\theta) = q_G(\theta)$. Moreover, we would obtain $\widehat{\gamma} = \frac{1}{2}\left(1 - \frac{\sqrt{5}}{5}\right)$ independently of θ, meaning that sorting of consumers into firms would be neutral.

Consumer sorting patterns can be then summarized as follows.

Proposition 2 ***Consumer sorting patterns.*** (i) *In Region 1, when* $\theta \in [\overline{\theta} - 1, \theta_1]$*, there is positive selection for firm G;* (ii) *In Region 2, when* $\theta \in [\theta_1, \overline{\theta}]$*, there is negative selection for firm G.*

Hence, when consumers' WTP for hedonic quality θ is sufficiently low, *i.e.* when $\theta \in [\overline{\theta} - 1, \theta_1]$, it means that consumers care relatively more about the environmental than the intrinsic quality dimension of the good, and the share of consumers buying from the green firm increases with θ. The opposite holds for higher values of θ, *i.e.* when $\theta \in [\theta_1, \overline{\theta}]$.

3.4 Firms' price schedules and profits

Our previous analysis confirms that a consumer with a given valuation θ is always offered a higher intrinsic quality by the brown firm. We first analyze the difference in price schedules to see whether the consumer also ends up paying more for the brown good. Then we evaluate the profit difference between the two firms. The analytical expressions of equilibrium prices and profits are confined to Appendix A.2, in which we also provide a graphical representation of the relevant threshold values of θ.

Regarding the price difference, we find that $p_G(\theta) > p_B(\theta)$ always holds when $\theta \in \left[\overline{\theta} - 1, \theta_1\right]$ and it also holds when $\theta \in \left[\theta_1, \overline{\theta}\right]$, provided that

$$\theta < \sqrt{\frac{2k}{9(k-1)}} = \theta_2,$$

with $\theta_1 < \theta_2 < \overline{\theta}$. The green good is always priced higher in Region 1, where we have positive selection for the green firm. In Region 2, a price premium for this firm still emerges, but only when consumers' WTP θ is not very high, *i.e.* when $\theta < \theta_2$. Notice that θ_2 is decreasing in k, meaning such price premium is more likely to emerge when producing the green good is not too costly relative to the brown variety.

Turning to equilibrium profits, for a given θ and for each firm $i = B, G$, we compute per-unit profit margins and multiply them by the market share of that firm, namely $\Pi_i(\theta) = \pi_i(\theta) M_i(\theta)$. We find that $\Pi_G(\theta) > \Pi_B(\theta)$ holds in both regions, provided that Assumption 1 is satisfied.[17] Considering price and profit differentials together, one can conclude the following.

Proposition 3 *The green firm always enjoys higher profits than the brown rival and it also charges a higher price provided that consumers' WTP for hedonic quality is not too high.*

Although in our model the firm's decision to carry out green production is not strategic (it is rather taken as given), Proposition 3 provides a rationale for the choice to "go green".[18] This result is in line with increasing evidence that financial profits are not necessarily at odds with responsible behavior. In 2020, companies with higher Environmental, Social, and Governance (ESG) ratings performed better than the overall indices. An S&P 500 sub-index, which groups companies meeting a minimum set of ESG criteria, had a 1.4% higher profitability than the S&P 500 index as a whole last year.[19] El Ouadghiri *et al.* (2021), using US data on stock indices from 2004 to 2018, found that public attention to environmental issues had a significantly positive effect on the returns of US sustainability stock indices (DJSI and FTSE4Good), whereas the opposite occurred for conventional stock indices (S&P 500 and FTSE).

[17] More specifically, $\Pi_G(\theta) > \Pi_B(\theta)$ always holds in Region 1, whereas in Region 2, the above inequality holds if and only if $\theta < \theta_0$, which is always the case under Assumption 1.

[18] Incidentally, notice that considering firms that are differentiated along the environmental dimension allows us to overcome the Bertrand paradox.

[19] See https://www.spglobal.com/_media/documents/the-sp-500-esg-index-integrating-esg-values-into-the-core.pdf

3.5 Pollution Emissions

The previous analysis revealed that producing costlier green varieties of a good always pays off in terms of profitability in the presence of a green network effect. In order to evaluate the consequences for the environment, we have to take into account the negative externalities related to both the consumption and the production of the good, which neither the two firms nor consumers internalize.

In particular, let e_i denote the per-unit emissions related to the consumption of the good. Such emissions are assumed to be increasing in the hedonic quality of the good, in such a way that $e_i(\theta) = \phi_i q_i(\theta)$, with $\phi_i \geq 0$ for $i = G, B$. Without lack of generality, we assume that $\phi_G = 0$, meaning that there are no emissions generated by the use or the *consumption* of the green good, no matter what its hedonic quality is, whereas $\phi_B = \phi > 0$. Furthermore, let μ_i denote the per-unit emissions related to the *production* of the good by firm $i = B, G$. Differently from consumption emissions, we assume that emissions from production are independent of the quality of the good, but are only determined by the overall amount of the good produced and sold. Moreover, we do not *a priori* rank μ_B and μ_G.

It follows that aggregate pollution emissions generated by each firm are given by the sum of emissions from consumption and emissions from production, multiplied by its market share as

$$E_i(\theta) = (e_i(\theta) + \mu_i)M_i(\theta) = (\phi q_i(\theta) + \mu_i)M_i(\theta), \tag{18}$$

with $i = B, G$. In order to compute the above emissions levels, we have to integrate with respect to consumers' valuation for intrinsic quality θ, taking into account that $M_B(\theta) = \widehat{\gamma}(\theta)$, that $M_G(\theta) = 1 - \widehat{\gamma}(\theta)$, and that market shares differ across the two regions, thus

$$E_B = \int_{\overline{\theta}-1}^{\theta_1} (\phi q_B(\theta) + \mu_B)\widehat{\gamma}^1(\theta)\, d\theta + \int_{\theta_1}^{\overline{\theta}} (\phi q_B(\theta) + \mu_B)\widehat{\gamma}^2(\theta)\, d\theta \tag{19}$$

and

$$E_G = \int_{\overline{\theta}-1}^{\theta_1} \mu_G\left(1 - \widehat{\gamma}^1(\theta)\right) d\theta + \int_{\theta_1}^{\overline{\theta}} \mu_G\left(1 - \widehat{\gamma}^2(\theta)\right) d\theta. \tag{20}$$

Given their complexity, it is not possible to evaluate the above integrals. Alternatively, we linearize the expressions for $\widehat{\gamma}^r(\theta)$, computing their first-order Taylor approximation around θ_1 as[20]

$$\widehat{\gamma}^r_T(\theta) = \left.\frac{\partial \widehat{\gamma}^r(\theta)}{\partial \theta}\right|_{\theta=\theta_1} (\theta - \theta_1) + \widehat{\gamma}_r(\theta_1), \tag{21}$$

Replacing $\widehat{\gamma}^r(\theta)$ with $\widehat{\gamma}^r_T(\theta)$ in both (19) and (20), we can approximate the actual amount of aggregate emissions associated to each firm and evaluate which one pollutes more.

Proposition 4 ***Emissions gap.*** *There exist situations in which the green firm emits a higher level of pollution than the brown firm. This is more likely to occur when:* (*i*) *the cost disadvantage of the green*

[20] Additional details are provided in Appendix A.3. Moreover, the complex algebraic calculations in this section have been done using Mathematica and are available upon request.

firm k is sufficiently low; (ii) the pollution from consumption of the brown firm ϕ is sufficiently low; (iii) the pollution from producing the green good μ_G is higher than the pollution from producing the brown good μ_B; (iv) consumers' maximal WTP for quality $\overline{\theta}$ is not too high.

In Figure 2, we represent $E_G - E_B$ as a function of $k \in (1, 2)$, fixing $\mu_G = \mu_B = 0.1$, $\phi = 0.25$, and $\overline{\theta} = 1.3$. Notice that $E_G > E_B$ for relatively low values of k, meaning that the green firm emits a higher level of aggregate pollution when its cost disadvantage is moderate. This might seem counterintuitive, as a low k means that the green firm is able to offer a good which is emission-free when consumed, at a unit cost which is just slightly higher than that of the brown firm. Nonetheless, a low k also implies that both the differential in hedonic qualities $q_B(\theta) - q_G(\theta)$ and the utility gap $U_B(\theta) - U_G(\theta)$ are very low. This in turn strengthens the market power of the green firm, whose aggregate pollution may then be higher than that of the brown rival.

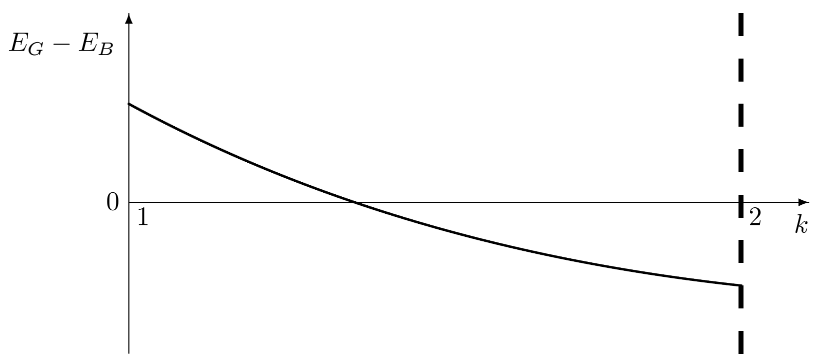

Figure 2: Emissions gap

Obviously, the curve $E_G - E_B$ shifts up when $\mu_G > \mu_B$, as well as when ϕ diminishes, *i.e.* when pollution emissions associated to the brown firm are not that intense. Also notice that $E_G - E_B$ shifts up when $\overline{\theta}$ decreases, that is when consumers care less about the intrinsic quality of the good relative to its environmental characteristic. This enlarges the parametric region in which there is positive selection into the green firm (see Proposition 2), thus contributing to increase the market share of the green firm, which in turn induces more consumers to patronize the green good through the network effect.

Turning to total pollution, *i.e.* $E = E_G + E_B$, it is obviously increasing in the pollution parameters μ_i and ϕ. Interestingly, we find that

$$\frac{\partial E}{\partial \mu_G} > \frac{\partial E}{\partial \mu_B} + \frac{\partial E}{\partial \phi},$$

which shows that total pollution is affected by μ_G more than by the combined effect of μ_B and ϕ. This again follows from the fact that the market power of the green firm, spurred by the network effect, is substantially higher than the market share of the brown firm. Hence, according to (18), the emissions of the green firm have therefore a higher impact on total pollution than those of the brown firm.

This does not represent a problem when $\mu_G \leq \mu_B$, as our model does not allow for market expansion. Indeed, given that the total mass of consumers is fixed and that each consumer buys exactly one unit of the good, a shift in demand from the brown to the green good diminishes total pollution because the green firm emits less pollution both from consumption and from production, for each unit of the good. This holds even if the emissions gap $E_G - E_B$ is positive, as it occurs in Figure 2 for low values of k and for $\mu_G = \mu_B$.

The situation may drastically change if $\mu_G > \mu_B$. In such a case, in fact, it might well occur that a switch from brown to green consumption increases total pollution, especially when aggregate emissions generated by the production of the green good are higher than the combined effect of the emissions coming from the production and the consumption of the brown good. We will come back to this point in Section 6, in which we explicitly examine the impact on total pollution of the green network effect.

4 Social Welfare

Let us now consider social welfare. On the one hand, we have to account for negative externalities related to the consumption as well as to the production of both goods, that neither firms nor consumers internalize. On the other hand, there are also positive externalities, represented by the green network effect, that increase the surplus of green consumers. It follows that the expression for social welfare is given by

$$\begin{aligned} W = \quad & W_B + W_G = \int_\theta \left(S_B(\theta) - \phi q_B(\theta) - \mu_B\right) M_B(\theta)\, d\theta \\ & + \int_{\widehat{\gamma}(\theta)}^{1} \int_\theta \left(S_G(\theta) + \gamma M_G(\theta) - \mu_G\right) M_G(\theta)\, d\theta d\gamma. \end{aligned} \tag{22}$$

Recall that $S_i(\theta)$ is the total surplus, *i.e.* the sum of consumer utility and producer profit, obtained when one unit of good $i = G, B$ is sold to a buyer of type θ (see expression 12). Since, for each θ, the market share of firm $i = G, B$ is given by $M_i(\theta)$, surplus $S_i(\theta)$ has to be weighted by the total amount of transactions $M_i(\theta)$. Also notice that, similarly to Brécard (2013), we include the network effect in the surplus of green consumers.

As there are two different regions for θ, characterized by different levels of $\widehat{\gamma}^r(\theta) = M_B^r(\theta)$, when integrating over θ one has to compute the above integrals twice, first for $\overline{\theta} - 1 \leq \theta \leq \theta_1$ and then for $\theta_1 \leq \theta \leq \overline{\theta}$. Finally, given that the expressions for $\widehat{\gamma}^r(\theta)$, $r = 1, 2$, are non-linear in θ, we resort to the first-order Taylor approximation (21) introduced in Section 3.5. Therefore, (22) can be written as the sum of

$$W_B = \int_{\overline{\theta}-1}^{\theta_1} \left(S_B(\theta) - \phi q_B(\theta) - \mu_B\right) \widehat{\gamma}_T^1(\theta)\, d\theta + \int_{\theta_1}^{\overline{\theta}} \left(S_B(\theta) - \phi q_B(\theta) - \mu_B\right) \widehat{\gamma}_T^2(\theta)\, d\theta$$

and

$$W_G = \int_{\widehat{\gamma}_T^1(\theta)}^{1} \int_{\overline{\theta}-1}^{\theta_1} \left(S_G(\theta) + \gamma \left(1 - \widehat{\gamma}_T^1(\theta) \right) - \mu_G \right) \left(1 - \widehat{\gamma}_T^1(\theta) \right) d\theta d\gamma$$
$$+ \int_{\widehat{\gamma}_T^2(\theta)}^{1} \int_{\theta_1}^{\overline{\theta}} \left(S_G(\theta) + \gamma \left(1 - \widehat{\gamma}_T^2(\theta) \right) - \mu_G \right) \left(1 - \widehat{\gamma}_T^2(\theta) \right) d\theta d\gamma.$$

It is possible to show that W is always decreasing in k and increasing in $\overline{\theta}$, as expected. Total welfare also obviously decreases in the parameters capturing pollution emissions; however, we find that

$$\left| \frac{\partial W}{\partial \mu_G} \right| > \left| \frac{\partial W}{\partial \phi} \right| > \left| \frac{\partial W}{\partial \mu_B} \right|,$$

meaning that the negative effect on welfare brought by pollution from production of the green good μ_G is higher than that respectively brought by pollution from consumption ϕ and from production μ_B of the brown good. This confirms that, in the presence of green network effect, pollution emissions associated to the production of the green good may not only generate a high level of total pollution, but also represent a concern in terms of total welfare. Let us now turn to examine what a benevolent social planner would do in our setup.

4.1 Social Planner

A social planner maximizes the sum of consumer and producer surplus, as represented by expression (22). In order to so, it chooses optimal qualities $q_i(\theta)$ and market shares $M_i(\theta)$ taking into account the externalities generated by the production and the consumption of the different varieties of the brown and green good.

Recall that market shares $M_i(\theta)$, given by expressions (6) and (7), depend on utilities $U_i(\theta)$, which are affected by how total surplus is shared between consumers and producers. This, in turn, is determined by prices $p_i(\theta)$. We then follow Brécard (2013) and consider "fair prices" that drive each firm's profits to zero. In this way, total surplus can be entirely identified with consumer surplus and thus with consumers' indirect utilities. For each firm, the unit fair price equals the marginal production cost plus the marginal environmental damages from consumption and production, in such a way that

$$p_B(\theta) = \frac{1}{2} q_B^2(\theta) + \phi q_B(\theta) + \mu_B \tag{23}$$

and

$$p_G(\theta) = \frac{1}{2} k q_G^2(\theta) + \mu_G. \tag{24}$$

Substituting (23) or (24) into (4) and the latter again into (9) yields

$$M_B(q_B, q_G) = \widehat{\gamma}(q_B, q_G) = \frac{1}{2} \left(1 - \sqrt{1 - 4 \left(\theta (q_B - q_G) - \frac{1}{2} (q_B^2 - k q_G^2) - \phi q_B + \mu_G - \mu_B \right)} \right). \tag{25}$$

Total welfare can then be written as

$$\begin{aligned} W &= \int_{\overline{\theta}-1}^{\overline{\theta}} \left(S_B(\theta) - \phi q_B(\theta) - \mu_B\right) \widehat{\gamma}(q_B, q_G)\, d\theta \\ &\quad + \int_{\widehat{\gamma}(q_B,q_G)}^{1} \int_{\overline{\theta}-1}^{\overline{\theta}} \left[S_G(\theta) + \gamma\left(1 - \widehat{\gamma}(q_B, q_G)\right) - \mu_G\right] \left(1 - \widehat{\gamma}(q_B, q_G)\right) d\theta d\gamma. \end{aligned} \tag{26}$$

The social planner maximizes W by choosing optimal qualities (see Appendix A.4 for the detailed analysis of this programme). Thus, differentiating the above expression with respect to q_B and q_G, solving the first-order conditions and taking into account the second-order conditions, we find that

$$q_G^o(\theta) = \frac{\theta}{k} \text{ and } q_B^o(\theta) = \theta - \phi,$$

where superscript o indicates the first-best optimum. Notice that $q_G(\theta)$ is unchanged relative to the market equilibrium, as $q_G^o(\theta) = q_G^*(\theta)$, whereas $q_B^o(\theta) < q_B^*(\theta)$, which means that the quality differential at the social planner's solution is lower relative to the Nash equilibrium.[21] Indeed, the planner internalizes the negative externality represented by the unit emissions from consumption of the brown variety ϕ.

Observation 1 *There is excessive quality differentiation at the market equilibrium, i.e.* $q_B^o(\theta) - q_G^o(\theta) < q_B^*(\theta) - q_G^*(\theta)$.

The surplus or consumer's utility (per unit of consumed good) for the brown variety is then given by

$$U_B^o(\theta) = (\theta - \phi)\, q_B^o(\theta) - \frac{1}{2} q_B^o(\theta)^2 - \mu_B = \frac{(\theta - \phi)^2}{2} - \mu_B,$$

and, similarly, the unit surplus for the green variety is

$$U_G^o(\theta) = \theta q_G^o(\theta) - \frac{1}{2} k q_G^o(\theta)^2 - \mu_G = \frac{\theta^2}{2k} - \mu_G.$$

Given that utility $U_B^o(\theta)$ must be strictly positive, we impose that that $\theta > \phi + \sqrt{2\mu_B}$, which is always the case when $\overline{\theta}$ is sufficiently high, in particular $\overline{\theta} > 1 + \phi + \sqrt{2\mu_B}$. Conversely, $U_G^o(\theta)$ need not to be strictly positive, as it suffices that $U_G^o(\theta) + \gamma M_G^o(\theta) > 0$.

Then, inserting $q_i^o(\theta)$ into (25), we can compute the expression for the indifferent consumer, or else the market share of the brown firm, which is

$$M_B^o(\theta) = \widehat{\gamma}^o(\theta) = \frac{1}{2}\left(1 - \sqrt{1 - 4\left(\frac{(\theta - \phi)^2}{2} - \frac{\theta^2}{2k} + \mu_G - \mu_B\right)}\right). \tag{27}$$

Recall that, according to Condition 1, in order for the above market share to be meaningful, it must be that: (*i*) $M_B^o(\theta)$ is a real number, which corresponds to $U_B^o(\theta) - U_G^o(\theta) < \frac{1}{4}$; (*ii*) $M_B^o(\theta) > 0$, which

[21] Observe that the quality differential $q_B^o(\theta) - q_G^o(\theta)$ is still positive provided that ϕ is sufficiently low, that is for $\phi < \frac{(k-1)\theta}{k}$.

corresponds to $U_B^o(\theta) > U_G^o(\theta)$. These requirements are satisfied when the difference in emissions from production between the green and the brown firm satisfies the following chain of inequalities

$$\frac{\phi^2}{2(k-1)} < \mu_G - \mu_B < \frac{1}{4} + \frac{\phi^2}{2(k-1)}. \tag{28}$$

The right-most inequality relates to condition (i), and it also ensures that $M_B^o(\theta)$ is strictly concave, whereas the left-most inequality relates to condition (ii). Notice that $\mu_G < \mu_B$ would drive the market share of firm B to zero, so we focus on the case in which $\mu_G > \mu_B$.

Indeed, there is some empirical evidence confirming that the green firm pollutes more than the brown firm during the production process. For instance, think of electric cars that do not generate CO_2 emission while driving, but whose battery production (and waste disposal) can be very polluting.[22] Recall that, as we mentioned at page 20, the green network effect may have a detrimental consequences on total emissions precisely when $\mu_G > \mu_B$.

Finally, going back to expression (26), it is again necessary to use a linear approximation of $\widehat{\gamma}^o(\theta)$ to integrate total welfare with respect to both consumers' characteristics γ and θ.[23] We denote the social planner solution as W^o, and compare it with total welfare W. As expected, $W^o > W$ as illustrated in Figure 3, which has been plotted as a function of k for the same values of ϕ, μ_B and $\overline{\theta}$ as in Figure 2, but setting $\mu_G = 0.15 > \mu_B$.

A natural question is then which policy mix should be adopted by the regulator in order to converge to the first-best optimum represented by W^o. The analytical model that we are considering is very complex but it delivers results that are qualitatively similar to those already available in the literature (see Brécard, 2013, and Lombardini-Ripiinen, 2005). In particular, an emission tax on the brown good would limit environmental pollution from consumption, and an *ad valorem* tax on the brown good would reduce product differentiation, thus reducing the distance between W^o and W. Since the objective of our paper is to analyze the green network effect, in what follows we focus on a policy tool that directly affects the network externality, abstracting from the optimal mix of policy interventions. The right candidate is a subsidy for the consumption of the green good.

[22] Electric cars store energy in large batteries that may have high environmental costs as these batteries are made of rare earth elements like lithium, nickel,cobalt or graphite, whose extraction may require very polluting processes.

[23] Instead of resorting to a first-order Taylor approximation, we simply decompose (27) in two lines, which intersect at the minimum of $\widehat{\gamma}^o(\theta)$ and whose precise expressions can be found in Appendix A.4.

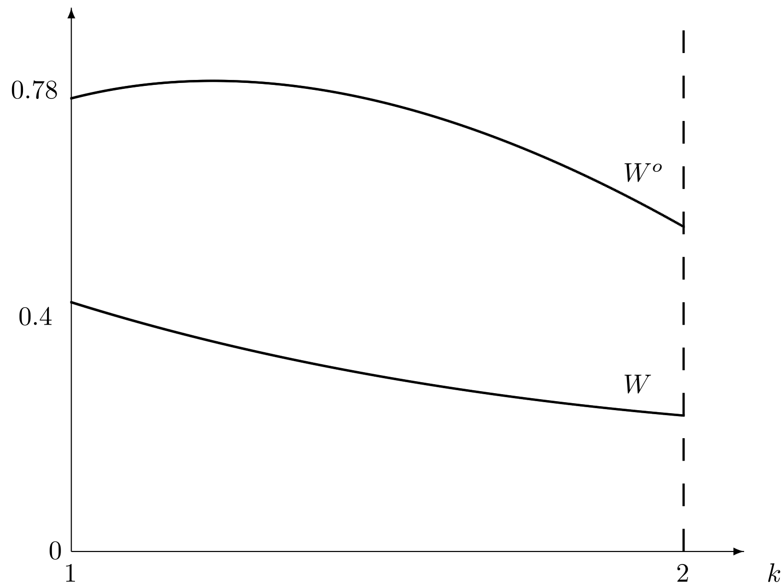

Figure 3: Unregulated social welfare vs. social planner solution

5 Subsidy for the green good

Let us now consider the effect of a subsidy for the consumption of green good, that enhances the green network effect. When consumers buy from the green firm, they benefit from a subsidy, and the price they pay equals $p_G(\theta) - s$. The price is instead unchanged for consumers patronizing firm B. Optimal qualities are the same as before, but the subsidy has an effect on the programme of firm G, which (omitting the dependence of market shares and thus indirect utilities on θ) becomes

$$\max_{U_G} \quad (S_G(\theta) + s - U_G) M_G = (S_G(\theta) + s - U_G)\left(\frac{1}{2} + \frac{\sqrt{1 - 4(U_B - U_G)}}{2}\right). \tag{29}$$

Computing the first-order condition and solving for U_G as a function of U_B, we obtain firm G's reaction function

$$U_G^s(U_B) = \frac{3\theta^2 - 2k(1 - 3s) + 12kU_B - \sqrt{2k\left(2k(1 + 3s) + 3\theta^2 - 6kU_B\right)}}{18k}. \tag{30}$$

The reaction function for firm B is the same as before and therefore there are two candidate solutions. In Appendix A.5, we replicate the analysis carried out in Section 3 and obtain corresponding results in terms of prices and profits at the regulated equilibrium. We also show that, when the subsidy is in place, the market share of the brown firm unambiguously decreases whereas the market power of the green firm increases, as expected.

We then compute pollution emissions, and find that $E_G - E_B$ is higher in the presence of a subsidy.[24] Figure 4 represents the difference in emissions between the two firms, with and without the subsidy. As in Figure 2, we represent the emissions gap as a function of k, keeping $\mu_G = \mu_B = 0.1$, $\phi = 0.25$, and $\overline{\theta} = 1.3$. It is immediate to see that the gap is always greater when the consumption of the green good is incentivized by the governmental subsidy s, which increases the market power of the green firm. The presence of a subsidy equal to $s = 0.2$, for example, shifts the curve upwards, as indicated by $E_G^s - E_B^s$ in the figure.

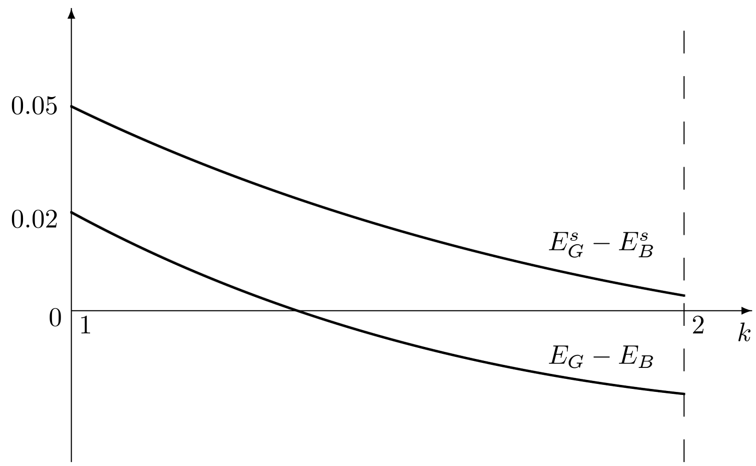

Figure 4: Comparison of emission gaps with and without a subsidy for the green good

Turning to total pollution, $E^s = E_G^s + E_B^s$, we confirm our previous results in terms of the effects of emissions parameters μ_i and ϕ, with total pollution being more negatively affected by μ_G than by μ_B and ϕ. Remarkably, we also obtain the following result.

Proposition 5 *Total pollution is increasing in the subsidy s provided that $\mu_G - \mu_B$ is sufficiently high and that both ϕ and $\overline{\theta}$ are sufficiently low.*

It follows that, in a scenario in which a network effect is positively associated to the green good only, a policy tool meant to favor its consumption may have detrimental consequences in terms of increasing total pollution emissions. This is more likely to occur when the aggregate emissions generated by the green firm are sizably higher than those generated by the brown firm, and when consumers' WTP for hedonic quality is not too high. This latter point is related to the fact that, when $\overline{\theta}$ is relatively low, the region in which there is positive selection for the green firm expands, thus reinforcing the network effect, as we also indicated in Section 3.5.

[24] In this case too, calculations are available upon request. The procedure is however outlined in Appendix A.5.

As for social welfare, it is possible to show that welfare is always higher in the presence of a subsidy.[25] So, when a subsidy is in place, the negative effect of higher emissions on welfare is more than compensated by the positive effect that the increased market power to the green firm has on both profits of the green firm and on the utility of consumers who buy the green good. Social welfare with a subsidy set equal to $s = 0.2$ is indicated as W^s and is plotted in Figure 5 as a function of k, together with W^o and W, keeping constant the values of μ_i, ϕ, and $\overline{\theta}$ as in Figure 3. The figure clearly shows that $W < W^s < W^o$.

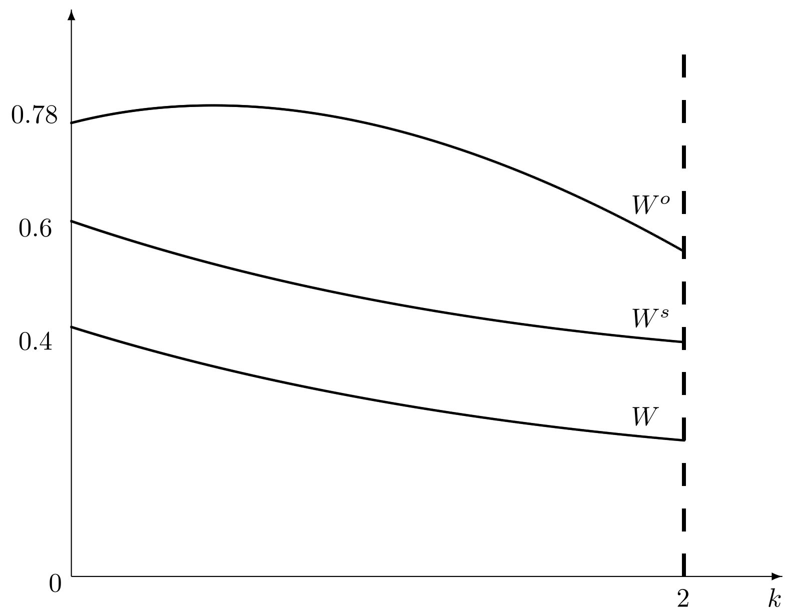

Figure 5: Comparison of social welfare

Proposition 6 *The introduction of a subsidy s for the green good improves social welfare but it may increase total pollution emissions.*

Our analysis then reveals that a policy tool that enhances the green network effect benefits society at large but may have detrimental effects for the environment. This type of intervention should therefore be carefully gauged in the presence of green consumerism amplified by a bandwagon effect, especially when the production of the green good generates relevant pollution emissions. An intervention to favor the adoption of cleaner production techniques by both firms would certainly lower pollution emissions, but its social desirability would crucially depend on its costs.

[25] Expression (22) does not change as the subsidy s cancels out: on the one hand the subsidy is added to consumer surplus in the market for the green good, on the other hand it is subtracted from governement revenue. However, the presence of the subsidy alters the market shares, thereby affecting total welfare.

6 The dark side of the green network effect

Our theoretical model hinges upon the assumption that consumers' environmental concern γ is directly related to the market share of the green firm, as specified in (2). Formalizing such green network effect captures the idea that environmentally concerned consumers are somewhat pragmatic and believe that only a collective behaviour can have sizeable effects. We wonder whether this assumption *drives* our main results, especially in terms of the possible trade-off between social welfare and pollution emissions identified before, or if it simply *amplifies* them.

In order to answer this question, we compare our main results with those of an alternative scenario in which the green network effect is absent, and the environmental concern is simply represented by a non-monetary benefit a consumer enjoys when buying the green good. Consider the case in which (2) no longer holds because a consumer of type (θ, γ) who buys one unit of green good rather enjoys utility

$$u_G(\theta, \gamma) = \theta q_G + \gamma - p_G.$$

All other modelling specifications remain unchanged with respect to the framework considered in Section 2. We then replicate the analysis carried out in Sections 3-6 for this simplified version of the environmental concern.[26]

Focusing first on pollution emissions, we find that the green network effect is responsible for an increase in the emissions generated by the green firm, whereas it reduces those of the brown firm. This is somewhat expected, hence what is relevant is the impact on total pollution emissions.

Proposition 7 *Total pollution increases in the presence of a green network effect, provided that $\mu_G - \mu_B$ is sufficiently high and that both ϕ and $\overline{\theta}$ are sufficiently low.*

Proposition 7 completes the discussion we introduced at the end of Subsection 3.5, revealing that the green network effect may have undesired consequences for the environment when the production of the green good generates higher pollution emissions relative to the brown good. We can also show that the introduction of a subsidy reinforces such negative effect because it pushes more consumers to patronize the green good. Thus, results similar to those emphasized in Section 5, indicating that pollution emissions increase in the parametric region under consideration.

Turning to social welfare, we find that the presence of a green network effect is always welfare-improving, even though it may increase total pollution, as highlighted above. This final proposition summarizes the main finding of our analysis.

[26] In fact, in this scenario we obtain much simpler expressions and we can compute emissions and welfare exactly, withuot having to resort to Taylor approximations of market shares. The full development of the analytical model in the absence of the network effect can be found in Appendix A.6.

Proposition 8 *The presence of a green network effect improves social welfare but it may also increase total pollution emissions. This trade-off is amplified by the introduction of a subsidy for the consumption of the green good.*

To sum up, the presence of a green network effect is crucial to determine the intensity of the main trade-off highlighted in this paper, but it is not the only driver of our main results. Interestingly, in situations in which the network effect increases total emissions, the presence of a subsidy exacerbates such negative outcome. This reinforces the message that policies designed to spur green consumption may be detrimental for the environment if they neglect to take into account the whole production process of a good and its related pollution emission.[27]

7 Concluding remarks

In this paper, we have analyzed competition between a green and a brown firm along two different quality dimensions, namely hedonic and environmental quality. We have assumed consumers are heterogeneous in their willingness to pay for intrinsic quality and in their environmental consciousness. A crucial element of our model is the presence of a green network effect such that the market share of the green firm positively affects consumers' utility when buying green. This is meant to capture the idea that environmentally concerned consumers really want to make the difference with their purchasing behavior, and enjoy an additional satisfaction in proportion to how many other consumers patronize the green good. We instead have taken a neutral approach towards the consumption of the brown good, which does not enjoy any external effect.

We have characterized how consumers with different valuations for hedonic quality sort between the two firms and have shown that the green firm always enjoys a higher profit, notwithstanding a production cost disadvantage, which captures its effort to eliminate emissions from consumption. The green network effect that we have included in our analysis seems therefore to provide the right compensation for the green producer. However, when considering pollution not only from consumption but also from production, we have demonstrated that the aggregate pollution emissions of the green firm can be higher than those of the brown firm. The main driver for this result is the increased market power of the green firm which is spurred by the network effect.

Our analysis has then highlighted a possible dark side of green consumerism, thus revealing a trade-off for the social planner. Indeed, policy interventions favoring green consumption may backfire, at least in terms of fighting pollution. In fact, we have considered a subsidy to green consumers and demonstrated

[27] Holtsmark and Skonhoft (2014) critized the generous policies that increased the use of electric vehicles in Norway. An important point they raise is that most of electricity supply feeding the batteries was generated from fossil sources.

it may trigger an even higher level of total pollution, thus increasing the emissions gap between the green and the brown firm.

The analysis carried out in this paper relies on modeling assumptions that are meant to describe the real-world scenario we have in mind, and on simplifying assumptions that are useful to reduce the complexity of the calculations. While the latter are innocuous and do not reduce the generality of our results, the former may seem somehow exaggerating the reward accruing to the green firm through the network effect. However, as we have shown in the last section, such green network effort is not the main driver of our results, rather a reinforcer. As there is increasing evidence of the effect of peer pressure and imitation that favor green and social responsible firms, our paper warns about the possible negative consequences that the proliferation of green goods may generate, when the production process of these goods is still associated with non-negligible pollution emissions.

A Appendix

A.1 Firms' reaction functions

Let us first derive the reaction function of firm G, namely $U_G(U_B)$. The programme of firm G is given by (PG) in the main text and its associated first-order condition, simplifying and omitting the dependence of indirect utilities on θ, is

$$\theta^2 - k + 4kU_B - 6kU_G - k\sqrt{1-4(U_B - U_G)} = 0, \tag{31}$$

which defines implicitly the reaction function of firm G. Notice that the quantity under square root is strictly positive: this comes from constraint (ii) in Condition 1 in the main text, requiring that $U_B(\theta) - U_G(\theta) < \frac{1}{4}$. It follows that a necessary condition for equation (31) to hold is that

$$\theta^2 - k + 4kU_B - 6kU_G > 0,$$

or else that

$$U_G < \frac{\left(\theta^2 - k + 4kU_B\right)}{6k} \equiv U_G^0(U_B). \tag{32}$$

Moreover, the second-order condition is satisfied when

$$-\left(\theta^2 + 2k - 8kU_B + 6kU_G\right) \leq 0,$$

or else if and only if

$$U_G \geq \frac{8kU_B - \theta^2 - 2k}{6k} \equiv U_G^1(U_B), \tag{33}$$

with $U_G^1(U_B) < U_G^0(U_B)$ for $U_B < \frac{2\theta^2 + k}{4k} = U_B^a$. Finally, solving (31) for U_G as a function of U_B yields

$$U_G^-(U_B) = \frac{3\theta^2 - 2k + 12kU_B - \sqrt{2k\left(2k + 3\theta^2 - 6kU_B\right)}}{18k}$$

and

$$U_G^+(U_B) = \frac{3\theta^2 - 2k + 12kU_B + \sqrt{2k\left(2k + 3\theta^2 - 6kU_B\right)}}{18k},$$

whose determinants are positive for $U_B < \dfrac{2k + 3\theta^2}{6k} = U_B^b$. Nonetheless, observe that the second solution, $U_G^+(U_B)$, can be discarded because it does not satisfy the necessary condition, being $U_G^+(U_B) > U_G^0(U_B)$. Conversely, the first solution is such that both $U_G^-(U_B) < U_G^0(U_B)$ and $U_G^-(U_B) > U_G^1(U_B)$ hold if and only if $U_B < \dfrac{2\theta^2 + k}{4k} = U_B^a$, which must be satisfied.

The above expression is useful when one wants to take into account possible corner solutions. For instance, when $U_B = 0$, $U_G^-(U_B)$ simplifies as

$$U_G^0 = \frac{3\theta^2 - 2k - \sqrt{2k\left(2k + 3\theta^2\right)}}{18k},$$

with $U_G^0 < \dfrac{\theta^2}{2k} = S_G$ being always satisfied and $U_G^0 < U_B = 0$ if and only if $\theta < \sqrt{2k}$.

Secondly, let us consider firm B. From the first-order condition associated to programme (PB), one can obtain the reaction function of firm B which is defined implicitly, omitting again the dependence of indirect utilities on θ, by

$$1 + \theta^2 - 6U_B + 4U_G - \sqrt{1 - 4\left(U_B - U_G\right)} = 0. \tag{34}$$

Since the quantity under square root is positive under constraint (ii) of Condition 1, a necessary condition for the above equation to be satisfied is that

$$1 + \theta^2 - 6U_B + 4U_G > 0$$

or else that

$$U_B < \frac{1 + \theta^2 + 4U_G}{6} \equiv U_B^0(U_G). \tag{35}$$

Moreover, the second-order condition associated to programme (PB) is satisfied when

$$2 - \theta^2 - 6U_B + 8U_G \geq 0$$

or else if and only if

$$U_B \leq \frac{2 - \theta^2 + 8U_G}{6} \equiv U_B^1(U_G), \tag{36}$$

with $U_B^0(U_G) < U_B^1(U_G)$ if and only if $U_G > \dfrac{2\theta^2 - 1}{4} = U_G^a$.

Solving (34) to obtain U_B as a function of U_G yields expressions (RF_B) in the main text, whose determinant is positive for $U_G > \dfrac{3\theta^2 - 2}{6} = U_G^b$, with $U_G^a > U_G^b$. Moreover, the second solution $U_B^+(U_G)$ is such that both $U_B^+(U_G) < U_B^0(U_G)$ and $U_B^+(U_G) < U_B^1(U_G)$ hold for $U_G > U_G^a$. So, when $U_G > U_G^a$, solution $U_B^+(U_G)$ is perfectly admissible because it satisfies both conditions (35) and (36). Conversely, when $U_G < U_G^a$, the second solution $U_B^+ (U_G)$ can be discarded because both conditions (35) and (36) are violated.

The above expressions are useful when one wants to take into account possible corner solutions. In particular, when $U_G = S_G = \frac{\theta^2}{2k}$ we have $U_G = S_G > U_G^a$ if and only if $\theta < \theta_0$. In order to demonstrate it, consider expressions (RF_B), when $U_G = S_G = \frac{\theta^2}{2k}$, we obtain

$$U_B^- (S_G) = \frac{3\theta^2 (k+2) + 2k - \sqrt{2k \left(2k - 3\theta^2 (k-1)\right)}}{18k}$$

and

$$U_B^+ (S_G) = \frac{3\theta^2 (k+2) + 2k + \sqrt{2k \left(2k - 3\theta^2 (k-1)\right)}}{18k}$$

whose determinant is positive for $\theta < \sqrt{\frac{2k}{3(k-1)}} = \theta_3$. Moreover, $S_G < U_B^- (S_G) < S_B$ holds provided that $\theta < \theta_3$; inequality $U_B^+ (S_G) > S_G$ always holds, whereas inequality $U_B^+ (S_G) < S_B$ is satisfied if and only if $\theta > \sqrt{\frac{k}{2(k-1)}} = \theta_0$. Hence, when $\theta < \theta_0$, the second solution $U_B^+ (S_G)$ can be discarded.

A.2 Price schedules and profits

Equilibrium prices can easily be recovered from (2) and (3), substituting for optimal qualities, that are given by $q_i (\theta) = \frac{\theta}{k_i}$, and for optimal indirect utilities, that correspond to the intersection of firms' reaction functions and vary according to whether a corner or an interior solution realizes. Recall that we use superscript $r = 1, 2$ to distinguish between the two regions, and subscript $i = B, G$ to indicate the two different firms.

Let us start from Region 1, *i.e.* from $\theta \in \left[\overline{\theta} - 1, \theta_1\right]$, where the corner solution (15) applies. We obtain

$$p_B^1 = \theta^2 \text{ and } p_G^1 = \frac{2k + 15\theta^2 + \sqrt{2k(2k + 3\theta^2)}}{18k},$$

with $p_G^1 > p_B^1$ being always satisfied in this region, meaning that a price premium for the green firm is always in place in Region 1. In Region 2, *i.e.* when $\theta \in (\left[\theta_1, \overline{\theta}\right]$, equilibrium prices are given by

$$p_B^2 = \frac{\theta^2(7k-2) - k + \sqrt{5k\left[k - 2\theta^2(k-1)\right]}}{10k} \text{ and } p_G^2 = \frac{\theta^2(7-2k) + k + \sqrt{5k\left[k - 2\theta^2(k-1)\right]}}{10k}.$$

It is immediate to check that $p_G^2 > p_B^2$ if and only if $\theta < \sqrt{\frac{2k}{9(k-1)}} = \theta_2$, with $\theta_1 < \theta_2 < \theta_0$, thus confirming the results of Proposition 3 in terms of the price difference.

Let us then move to consider firms' profits at equilibrium. For a given θ and for each firm $i = B, G$, per-unit profit margins given by (1) have to be multiplied by the firm's market share, namely $\Pi_i (\theta) =$

$\pi_i(\theta) M_i(\theta)$. The expressions for $\Pi_i(\theta)$ correspond to

$$\Pi_B^1 = \frac{1}{12}\theta^2\left(3 - \sqrt{\frac{5k + 6\theta^2 - 2\sqrt{2k(2k+3\theta^2)}}{k}}\right)$$

and

$$\Pi_G^1 = \frac{1}{108k}\left(2k + 6\theta^2 + \sqrt{2k(2k+3\theta^2)}\right)\left(3 + \sqrt{\frac{5k + 6\theta^2 - 2\sqrt{2k(2k+3\theta^2)}}{k}}\right)$$

in Region 1, where $\Pi_G^1 > \Pi_B^1$ always holds, and to

$$\Pi_B^2 = \frac{\left(k - 2\theta^2(k-1) - \sqrt{5k\left(k - 2\theta^2(k-1)\right)}\right)}{100k}\left(5 - \sqrt{\frac{5k - 10\theta^2(k-1)}{k}}\right)$$

and

$$\Pi_G^2 = \frac{\left(k - 2\theta^2(k-1) + \sqrt{5k\left(k - 2\theta^2(k-1)\right)}\right)}{100k}$$

in Region 2, where $\Pi_G^2 > \Pi_B^2$ also holds. The only remarkable difference between the two regions is that the profit gain for the green firm increases in θ in the first region, whereas it decreases in θ in the second one, reflecting positive (resp. negative) self-selection of consumers into the green firm.

A.3 Linearization of market shares

In order to be able to compute pollution emissions and total welfare associated to the different regimes, it is necessary to linearize firms' market shares, otherwise the integrand is too complex to be calculated. At the market equilibrium, the indifferent consumer $\widehat{\gamma}(\theta)$ is defined piecewise, according to whether $\overline{\theta} - 1 \leq \theta \leq \theta_1$, in which case Region 1 is relevant and reaction functions intersect at the corner, or $\theta_1 \leq \theta \leq \overline{\theta}$, in which case Region 2 is relevant and an interior solution attains. Given that $\widehat{\gamma}(\theta)$ is continuous at θ_1, we linearize its expression around this value. When $\overline{\theta} - 1 \leq \theta \leq \theta_1$, the relevant indifferent consumer is $\widehat{\gamma}^1(\theta)$ whose expression is given by (16). Its first-order Taylor approximation can be computed as

$$\widehat{\gamma}_T^1(\theta) = \frac{1}{2}\left(1 - \frac{(6\theta_1\theta + 5k)\sqrt{2\left(3\theta_1^2 + 2k\right)} - 6\theta_1(\theta + \theta_1) + 8k^2}{3\sqrt{2\left(3\theta_1^2 + 2k\right)\left(5k + 6\theta_1^2 - 2\sqrt{2k\left(3\theta_1^2 + 2k\right)}\right)}}\right).$$

Likewise, when $\theta_1 \leq \theta \leq \overline{\theta}$, the relevant indifferent consumer is $\widehat{\gamma}^2(\theta)$, as given by (17), whose first-order Taylor approximation around θ_1 is denoted as $\widehat{\gamma}_T^2(\theta)$ and whose actual expression

$$\widehat{\gamma}_T^2(\theta) = \frac{1}{2}\left(1 - \frac{k - 2\theta_1(k-1)\theta}{\sqrt{5k\left(k - 2(k-1)\theta_1^2\right)}}\right).$$

A.4 The social planner solution

The social planner maximizes (26) with respect to q_B and q_G. Performing the integration of the second term relative to γ yields

$$\begin{aligned}\max_{q_B,q_G} W &= \int_{\overline{\theta}-1}^{\overline{\theta}} \left\{ \left(\theta q_B - \frac{1}{2}q_B^2 - \phi q_B - \mu_B\right) \widehat{\gamma}\left(q_B, q_G\right) \right. \\ &\quad \left. + \left(1-\widehat{\gamma}\left(q_B,q_G\right)\right)^2 \left[\theta q_G - \frac{1}{2}kq_G^2 - \mu_G + \frac{1}{2}\left(1-\widehat{\gamma}\left(q_B,q_G\right)\right)^2\right]\right\} d\theta. \qquad (37)\end{aligned}$$

where $\widehat{\gamma}\left(q_B, q_G\right)$ is given by (25).

Differentiating (37) with respect to q_B and q_G yields the following pair of first-order conditions

$$\frac{\partial W}{\partial q_B} = \frac{\left(\phi-\theta+q_B\right)\left(4-12\varphi+\left[1+4q_G\left(\theta-\frac{1}{2}kq_G\right)-4\mu_G\right]\sqrt{1-4\varphi}-\left(1-4\varphi\right)\sqrt{1-4\varphi}\right)}{4\sqrt{1-4\varphi}} = 0,$$

and

$$\frac{\partial W}{\partial q_G} = \frac{\left(\theta-kq_G\right)\left(1-3\varphi+\left[1+q_G\left(\theta-\frac{1}{2}kq_G\right)-\mu_G\right]\sqrt{1-4\varphi}\right)}{\sqrt{1-4\varphi}} = 0,$$

with

$$\varphi = \theta\left(q_B-q_G\right) - \frac{1}{2}\left(q_B^2-kq_G^2\right) - \phi q_B + \left(\mu_G-\mu_B\right).$$

It is immediate to check that one pair of solutions is $q_B^o = \theta - \phi$ and $q_G^o = \dfrac{\theta}{k}$, which also satisfies the second-order conditions (we do not list them here for the sake of brevity).

Inserting q_i^o into (25) we obtain the indifferent consumer at the social planner solution, namely $\widehat{\gamma}^o\left(\theta\right)$, which is also equal to the market share of firm B, and whose expression is given by (27). This function is continuous and smooth in θ, it is also strictly convex if $\dfrac{\phi^2}{2\left(k-1\right)} < \mu_G - \mu_B < \dfrac{\left(k-1\right)+2\phi^2}{4\left(k-1\right)}$. Finally, it reaches a minimum at $\theta^o = \dfrac{k\phi}{\left(k-1\right)}$, with $\widehat{\gamma}^o\left(\theta^o\right) > 0$.

Again, the expression for $\widehat{\gamma}^o\left(\theta\right)$ is too complex to be used in the integrand of welfare W^o. A first-order Taylor approximation of $\widehat{\gamma}^o\left(\theta\right)$ does not seem particularly suited to this case either, because there is no obvious value of θ around which to compute it. For this reason, we have decided to approximate $\widehat{\gamma}^o\left(\theta\right)$ by decomposing it into two lines. The first line is downward sloping and connects points $P_0 = \left(\overline{\theta}-1, \widehat{\gamma}^o\left(\overline{\theta}-1\right)\right)$ and $P_1 = \left(\dfrac{k\phi}{k-1}, \widehat{\gamma}^o\left(\dfrac{k\phi}{k-1}\right)\right)$, the second line is upward sloping and it connects points P_1 and $P_2 = \left(\overline{\theta}, \widehat{\gamma}^o\left(\overline{\theta}\right)\right)$. Therefore, we have

$$\widehat{\gamma}_1^o\left(\theta\right) = \frac{1}{2}\left(1-\sqrt{1+\frac{2\phi^2}{k-1}-4\left(\mu_G-\mu_B\right)}\right) + \frac{\Theta\left(\theta\left(k-1\right)-k\phi\right)}{2\left(k\phi-\left(k-1\right)\left(\overline{\theta}-1\right)\right)},$$

with

$$\Theta = \sqrt{1-4\left(\mu_G-\mu_B\right)-\frac{2\left(k\left(\overline{\theta}-1-\phi\right)^2-\left(\overline{\theta}-1\right)^2\right)}{k}} - \sqrt{1+\frac{2\phi^2}{k-1}-4\left(\mu_G-\mu_B\right)}$$

and

$$\widehat{\gamma}_2^o(\theta) = \frac{1}{2}\left(1 - \sqrt{1 + \frac{2\phi^2}{k-1} - 4(\mu_G - \mu_B)}\right) - \frac{\Upsilon(\theta k - 1 - k\phi)}{2\left(\overline{\theta}(k-1) - k\phi\right)},$$

with

$$\Upsilon = \sqrt{1 - 4(\mu_G - \mu_B) - \frac{2\left(k\left(\overline{\theta} - \phi\right)^2 - \overline{\theta}^2\right)}{k}} - \sqrt{1 + \frac{2\phi^2}{k-1} - 4(\mu_G - \mu_B)}.$$

A.5 Subsidy for the green product

When the government introduces a subsidy that benefits the consumers of the green good, the programme of firm G becomes (29), which enables us to provide firm G's reaction function (30). The reaction function for firm B does not change and there are two candidate solutions. The corner solution (which would hold in Region 1) is such that $U_B^s = 0$, so that

$$U_G^s = \frac{3\theta^2 - 2k(1-3s) - \sqrt{2k\left(2k(1+3s) + 3\theta^2\right)}}{18k},$$

in which case the indifferent consumer is

$$\widehat{\gamma}^{1s}(\theta) = \frac{1}{2}\left(1 - \frac{1}{3}\sqrt{\frac{5k + 6\theta^2 + 12ks - 2\sqrt{2k\left(2k(1+3s) + 3\theta^2\right)}}{k}}\right).$$

The interior solution (which would hold in Region 2) is such that

$$U_G^s = \frac{3\theta^2 + k\left(6s + 2\theta^2 - 1\right) - \sqrt{5k\left(k(1+4s) - 2(k-1)\theta^2\right)}}{10k}$$

and

$$U_B^s = \frac{k(1+4s) + \theta^2(2+3k) - \sqrt{5k\left(k(1+4s) - 2(k-1)\theta^2\right)}}{10k},$$

where the quantity under square root is positive if and only if $\theta \leq \sqrt{\frac{k(1+4s)}{2(k-1)}} = \theta_0^s$, whereas $U_B^s > 0$ if and only if

$$\theta < \frac{\sqrt{k\left(3 - 8k - 8s - 12ks + 5\sqrt{1 + 4k(k + 2s + 3ks)}\right)}}{(3k+2)} = \theta_1^s.$$

This allows us to compute the indifferent consumer

$$\widehat{\gamma}_2^{2s}(\theta) = \frac{1}{2}\left(1 - \sqrt{\frac{k(1+4s) - 2(k-1)\theta^2}{5k}}\right).$$

Paralleling what we have done in Section 3, when the subsidy is in place, we can still define two different parametric regions in order to distinguish whether a corner or an interior solution occurs, although the bounds change. Region 1 is such that $\theta \in \left[\overline{\theta} - 1, \theta_1^s\right]$, whereas Region 2 is such that $\theta \in \left[\theta_1^s, \overline{\theta}\right]$, with

$\overline{\theta} \leq \theta_0^s$ for $k \in (1,2)$. It is possible to check that $\theta_1^s < \theta_1$ when s is not too small, whereas $\theta_0^s > \theta_0$ always holds. It is also easy to verify that $\widehat{\gamma}^s(\theta) < \widehat{\gamma}(\theta)$ is true in both regions, meaning that the effect of a the subsidy is to increase the market share of the green firm, while decreasing that of the brown firm.

We omit expressions for equilibrium prices and profits in the two relevant regions, when the subsidy is in place, and focus instead on pollution emissions and social welfare. Aggregate emissions are computed as in Subsection 3.5, and require complex integration operations. We resort to Taylor approximations of market shares, computed around θ_1^s, given by

$$\widehat{\gamma}_T^{1s}(\theta) = \frac{1}{2}\left(1 - \frac{6\theta_1^s(\theta - \theta_1^s)(\Omega - k) + \left[\left(5k + 6(\theta_1^s)^2 + 12ks\right) - 2\Omega\right]\Omega}{3\Omega\sqrt{5k + 6(\theta_1^s)^2 + 12ks - 2\Omega}}\right)$$

with

$$\Omega = \sqrt{2k\left(2k + 3(\theta_1^s)^2 + 6ks\right)},$$

which is decreasing in θ, and

$$\widehat{\gamma}_T^{2s}(\theta) = \frac{1}{2}\left(1 - \frac{k(1+4s) - 2\theta_1^s(k-1)\theta}{\sqrt{5k\left(k(1+4s) - 2(k-1)(\theta_1^s)^2\right)}}\right),$$

which is increasing in θ, instead. Precise expressions for aggregate pollution emissions E_i^s, $i = B, G$, are extremely long and are omitted for brevity. They are however available upon request, together with the expression for social welfare, which is obtained by replicating the steps carried out in Section 4.

A.6 Environmental consciousness without network effect

Consider the same scenario as in Section 2, with the only difference that a consumer of type (θ, γ) enjoys utility

$$u_G(\theta, \gamma) = \theta q_G + \gamma - p_G$$

when buying the green good. Contrary to the model set up in the main text, there is *no green network effect* at work. We will therefore use the superscript n to distinguish the results we obtain in this case to those presented in the main text.

We follow the analysis carried out in Sections 2 and 3, with the notable exception that the indifferent consumer is now defined as

$$\widehat{\gamma}^n(\theta) \equiv U_B(\theta) - U_G(\theta). \tag{38}$$

Optimal quality levels are still contingent on consumer's WTP for hedonic quality and given by $q_i^n(\theta) = \dfrac{\theta}{k_i}$. The reaction functions of the two firms are linear and given by

$$U_B(\theta) = \frac{1}{2}\left(\frac{\theta^2}{2} + U_G(\theta)\right) \quad \text{and} \quad U_G(\theta) = \frac{1}{2}\left(\frac{\theta^2}{2k} - (1 - U_B(\theta))\right). \tag{39}$$

In a Nash equilibrium, the utility levels offered by each firms to each type θ consumer solve the two equations in (39) simultaneously, and must be such that: (i) $U_i(\theta) \leq S_i(\theta)$, or else $\pi_i(\theta) \geq 0$ for all $i = B, G$ and all θ; (ii) $U_B(\theta) \geq 0$ and $U_G(\theta) + \gamma \geq 0$.

In this case too, two different classes of Nash equilibria emerge, depending on whether an interior or a corner solution realizes. In Region 1, firm G's reaction function is strictly positively sloped and it intersects firm B's reaction function which is constant at $U_B(\theta) = 0$. In this region, a Nash equilibrium is such that

$$U_B^n(\theta) = 0 \quad \text{and} \quad U_G^n(\theta) = -\frac{1}{2}\left(1 - \frac{\theta^2}{2k}\right) < 0$$

and it exists for $\theta \leq \theta_1^n = \sqrt{\dfrac{2k}{2k+1}}$. Using (38), the marginal consumer of type θ, who is indifferent between the two firms, is

$$\widehat{\gamma}^{1n}(\theta) = \frac{1}{2}\left(1 - \frac{\theta^2}{2k}\right),$$

which is decreasing in θ, thus confirming the presence of positive selection for relatively low values of θ.

In Region 2, reaction functions intersect when they are both strictly positively sloped and a Nash equilibrium delivers indirect utilities

$$U_B^n(\theta) = \frac{1}{3}\left(\frac{\theta^2(1+2k)}{2k} - 1\right) \quad \text{and} \quad U_G^n(\theta) = \frac{1}{3}\left(\frac{\theta^2(2+k)}{2k} - 2\right)$$

This equilibrium exists when $\theta_1^n \leq \theta \leq \theta_0^n = \sqrt{\dfrac{4k}{k-1}}$, with $\theta_0^n > \theta_0$. The indifferent consumer is therefore given by

$$\widehat{\gamma}^{2n}(\theta) = \frac{1}{3}\left(1 + \frac{\theta^2(k-1)}{2k}\right),$$

which is increasing in θ, confirming Proposition 2 about negative selection for firm G when θ is sufficiently high.[28]

It is possible to compare equilibrium prices and profits in the two regions. In Region 1, we find that $p_G^{1n}(\theta) > p_B^{1n}(\theta)$ and $\Pi_G^{1n} > \Pi_B^{1n}$ are always true, whereas in Region 2 we obtain that $p_G^{2n}(\theta) > p_B^{2n}(\theta)$ when $\theta < \sqrt{\dfrac{2k}{5(k-1)}} = \theta_2^n$, and $\Pi_G^{2n} > \Pi_B^{2n}$ provided that we consider the restrictions outlined in Assumption 1. To sum up, the results obtained in Propositions 1 and 3 continue to hold without the green network effect, even though we consider slightly different parametric regions.

Let us then move to consider aggregate pollution emissions. The relevant expression is still given by (18), and in order to compute their levels we have to integrate with respect to θ, taking into account that $\widehat{\gamma}^n(\theta)$ differs across the two regions. Pollution emissions associated to firm B and firm G are given,

[28] There is yet another corner solution when $\theta > \theta_0^n$, such that firm B's reaction function is striclty positively sloped and it intersects firm G's reaction function at $U_G(\theta) = S_G(\theta) = \theta^2/2$. In this region, firm G would have a zero market share and thus we do not consider it here.

respectively by

$$E_B^n = \int_{\overline{\theta}-1}^{\theta_1^n} \left(\phi q_B(\theta) + \mu_B\right) \widehat{\gamma}^{1n}(\theta)\, d\theta + \int_{\theta_1^n}^{\overline{\theta}} \left(\phi q_B(\theta) + \mu_B\right) \widehat{\gamma}^{2n}(\theta)\, d\theta,$$

and

$$E_G^n = \int_{\overline{\theta}-1}^{\theta_1^n} \mu_G \left(1 - \widehat{\gamma}^{1n}(\theta)\right) d\theta + \int_{\theta_1^n}^{\overline{\theta}} \mu_G \left(1 - \widehat{\gamma}^{2n}(\theta)\right) d\theta,$$

where $\widehat{\gamma}^{rn}(\theta) = M_B^n(\theta)$, and $(1 - \widehat{\gamma}^{rn}(\theta)) = M_G^n(\theta)$, for $r = 1, 2$. Their analytical expressions can be computed directly, without resorting to the first-order Taylor approximation; they are not reported as they are extremely long, but we confirm the results of Proposition 4. Moreover, comparing the emissions gaps and the total pollution between the two scenarios (*i.e.* with and without the green network effect) we obtain the results reported in Proposition 7.

Turning to social welfare, we consider expression (22) and replicate the analysis of Section 4. The expressions for W_B and W_G are given by

$$W_B^n = \int_{\overline{\theta}-1}^{\theta_1^n} \left(S_B(\theta) - \phi q_B(\theta) - \mu_B\right) \widehat{\gamma}^{1n}(\theta)\, d\theta + \int_{\theta_1^n}^{\overline{\theta}} \left(S_B(\theta) - \phi q_B(\theta) - \mu_B\right) \widehat{\gamma}^{2n}(\theta)\, d\theta$$

and

$$W_G^n = \int_{\widehat{\gamma}^{1n}(\theta)}^{1} \int_{\overline{\theta}-1}^{\theta_1^n} \left(S_G(\theta) + \gamma - \mu_G\right) \left(1 - \widehat{\gamma}^{1n}(\theta)\right) d\theta d\gamma + \int_{\widehat{\gamma}^{2n}(\theta)}^{1} \int_{\theta_1^n}^{\overline{\theta}} \left(S_G(\theta) + \gamma - \mu_G\right) \left(1 - \widehat{\gamma}^{2}(\theta)\right) d\theta d\gamma$$

respectively. In this case too, the analytical expressions are extremely long and omitted for brevity. We compare welfare with and without the network effect, and repeat the analysis of Section 5 with the introduction of a subsidy, obtaining the results of Proposition 8.

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