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“Environmental policies with green network effect
and price discrimination”

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Abstract

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 both in their willingness to pay for intrinsic quality and in their environmental concern. The latter is positively related to the green firm's market share, giving rise to a green network effect. We characterize how price and quality schedules are set and how consumers sort between the two firms at the market equilibrium. When considering pollution from both consumption and production, we compute total welfare and evaluate the impact of an emission tax, and of a subsidy for the consumption of the green good. Our analysis demonstrates that efficiency can be achieved through an emission tax, which restores the optimal differential between firms' intrinsic qualities, combined with a discriminatory subsidy, which re-establishes the optimal sorting of consumers.

JEL classification: D21, H21, H23, L13, L15.

Keywords: bidimensional product differentiation; environmental concern; green network effect; pollution emissions; price discrimination; green subsidy.

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1 Introduction

According to Eurobarometer 535 “The EU Ecolabel” Report (2023),¹ quality and price are the two most important aspects in consumers’ purchasing decisions, with 97% of respondents replying that the quality of the product is ‘very’ or ‘rather important’ to them, and 94% responding similarly about the price. Consumer environmental concern also plays a crucial role, as 73% of respondents consider the product’s impact on the environment to be ‘very’ or ‘rather important’ when making purchasing decisions. Additionally, a majority of respondents agree that they have bought products specifically because of their lower environmental impact.

This suggests that consumers increasingly consider a product as a bundle of attributes related to both its hedonic characteristics, such as performance and functionality, and its environmental characteristics, which account for the ecological footprint of the product throughout its whole life cycle, from production to usage and disposal. It is not always clear whether hedonic and environmental quality dimensions are aligned or in contrast with each other. For instance, electric vehicles (EVs) have lower polluting emissions than internal combustion engine vehicles, but their limited range and the scarcity of charging stations can be problematic. Similarly, ecological cleansers and detergents, produced without chemical additives that might harm the environment, are often less effective than their chemical-based counterparts. Analogous considerations apply to organic food, which is healthier and less harmful to the ecosystem but has a shorter shelf life and less curb appeal than conventionally grown food.

Adding to this, as reported by the Eurobarometer 538 “Climate Change” Report (2023),² 77% of all respondents view climate change as a very serious problem, with 58% thinking the transition to a green economy should be sped up. More than three quarters (77%) of respondents feel a personal responsibility to act to limit climate change. Accordingly, 37% say that when buying a new household appliance, lower energy consumption is an important factor in their choice. Other actions individually taken include buying and eating less meat (31%), regularly using environmentally-friendly alternatives to their private car (28%), or buying and eating more organic food (28%). However, when it comes to the fairness perceptions of the green transition, the Eurobarometer 527 Report (2022) highlights that almost a third of respondents (27%) think they do not need to take action personally to fight climate change if other people take no action either.³

These figures underscore that people recognize climate change as the result of collective rather than individual human behavior. Even if individuals modify their consumption habits because they consider their personal contribution to combating global warming important, the anticipated inaction of others

¹ See <https://europa.eu/eurobarometer/surveys/detail/3072>

² See <https://europa.eu/eurobarometer/surveys/detail/2954>

³ See <https://europa.eu/eurobarometer/surveys/detail/2672>

could demotivate people from taking individual action. In other words, there is indeed a network externality involved, which determines the prevailing social norm and shapes consumer preferences towards environmentally-friendly products. An illustrative example often cited by psychologists is meat consumption. As Bolderdijk and Jans (2021) point out, ‘If most people believe that most people eat meat, most people will keep eating meat, without questioning the validity of that practice’ (see page 26). Thus, the social norm of eating meat might become self-fulfilling and create a vicious cycle, as a network of individuals becomes locked in a collective behavior harmful to society as a whole.⁴ However, vegetarian and vegans, deviating from the *status quo*, can signal that high levels of meat consumption are not sustainable. If they reach a critical mass, they have the potential to impose a new, pro-environmental social norm, that spreads throughout the entire social network, to which people will conform.

This growing environmental concern on the part of consumers is going hand in hand with significant changes in government actions and firm strategies worldwide. Governments across the globe are adopting various policies to promote the use of eco-friendly and energy-efficient products. Firms from diverse industries are developing products with significantly reduced pollution emissions, and investing in cleaner production processes. As reported by the aforementioned Eurobarometer 538 and 527 Reports, respondents believe that the most effective ways of mitigating climate change are not only by ‘changing the way we consume’ but also ‘changing the way we produce’. Moreover, 57% of respondents say that private companies and businesses are not doing enough, while more than half believe that the European Union and national governments should be held responsible for tackling climate change. Respondents think that it is important for their national government (86%) and the European Union (85%) to take action to improve energy efficiency, such as encouraging people to insulate their homes, install solar panels, or buy electric cars. Additionally, almost eight in ten agree that more public financial support should be allocated to the green transition to ensure no one is left behind. Specifically, 89% of Europeans favor subsidizing people, especially those with lower disposable income, to help them buy environmentally friendly products, and 71% support taxing products and services that contribute most to climate change.

Inspired by these observations, we study the impact of consumer environmental concern on firms’ quality choices and pricing strategies, and examine the role of governments in promoting the consumption of green goods. For this purpose, we consider a duopoly where one firm offers a standard good while its rival offers an environmentally friendly variety of the same good, produced at a higher cost. This distinction categorizes firms (and their products) into *brown* and *green*, respectively. Moreover, each firm offers a range of vertically differentiated versions of the good to attract consumers characterized by heterogeneous willingness to pay (henceforth WTP) for the pure performance of the good, *i.e.*, for its intrinsic or hedonic quality (see Mussa and Rosen, 1978). We incorporate environmental concerns in

⁴This phenomenon may be driven by the fear of social sanctions, such as social exclusion or stigma, which are particularly effective in ‘tight’ societies where conformity pressure is strong.

the preferences of consumers, who value not only the pure performance of a good, but also its environmental footprint. A distinctive feature of our analysis is that the decision of a single consumer to buy green depends on the so-called *green network effect*. Indeed, each consumer knows that their individual consumption decision has a negligible impact on the environment, being the collective rather than the individual behavior what matters. Therefore, when buying an environmentally-friendly product, the consumer receives a non-monetary benefit which is proportional to the share of consumers buying the same green commodity (see also Brécard, 2013, Hauck *et al.*, 2014, and Grover and Bansal, 2021).

We assume that firms are able to collect detailed information about consumer WTP for the intrinsic quality of the good, although they lack insight into consumer environmental consciousness. Indeed, firms are increasingly gaining access to consumer data through purchase histories, used for personalized pricing, which involves charging different prices to consumers based on their WTP.⁵ Furthermore, as data analytics and pricing algorithms have become common business practices in the digital era, there is increasing evidence of firms engaging in personalized pricing. According to the OECD Report (2018), dominant retailers such as Staples and Home Depot set personalized prices based on various consumer characteristics, including location, presumed income, and browsing history.⁶

Within this framework, firms' strategies consist in designing menus of contracts, each featuring a hedonic quality target and a price, both contingent on consumer WTP for hedonic quality. Consumer environmental concern also plays a crucial role, because it determines how consumers sort between the brown and the green firm. Therefore, our modelling strategy differs from the mainstream literature in environmental economics (see, *e.g.*, Cremer and Thisse, 1999; Moraga-Gonzalez and Padron-Fumero, 2002; and Bansal and Gangopadhyay, 2003; among others) in that we do not consider environmental friendliness as a vertical attribute of the good, for which consumers have higher WTP. Rather, we envision a product as a bundle of attributes which are hedonic as well as environmental, and assume that firms compete along the hedonic (rather than the environmental) quality dimension, with firms and their products being differentiated at the outset according to the environmental attribute. Accordingly, in our model the ranking of hedonic qualities offered by the two firms is endogenous, and whether hedonic and environmental qualities are aligned or not is not *a priori* determined (differently from Mantovani *et al.*, 2016, Grover and Bansal, 2021 and Marini *et al.*, 2022).

At the market equilibrium, each firm offers quality and price schedules that maximize its expected profit, given the rival's choice and consumer purchasing decisions. We find two different classes of equi-

⁵In the seminal work by Fudenberg and Tirole (2000), consumer past behavior is used in the second period of a dynamic Hotelling model to design a discriminatory pricing scheme by firms. The research on behavior-based pricing has been extended to various settings and applications (a comprehensive literature review can be found in Fudenberg and Villas-Boas, 2007).

⁶See the OECD Report (2018) "Personalised Pricing in the Digital Era", retrieved at [https://one.oecd.org/document/DAF/COMP\(2018\)13/en/pdf](https://one.oecd.org/document/DAF/COMP(2018)13/en/pdf)

libria: interior or corner solutions. Corner solutions arise when consumer valuation for intrinsic quality is either sufficiently low or sufficiently high. In both cases, we find a positive selection for the green firm, meaning that, the higher the consumer WTP for hedonic quality, the larger the fraction of consumers served by the green firm. Conversely, an interior solution occurs when consumer valuation for intrinsic quality is intermediate, resulting in a negative selection for the green firm. We also find that the green firm always earns higher profits than the brown firm, despite facing higher production costs.

We then examine the extent to which governments should promote the consumption of green goods, and eventually how to do so. Notably, our notion of social welfare accounts for negative externalities from pollution that are generated during the whole life cycle of the goods, *e.g.* by both consumption and production of the goods, that neither firms nor consumers internalize. We first show that there is excessive quality differentiation at the market equilibrium due to firms' attempt to relax price competition. However, the policy maker can induce firms to produce the socially optimal qualities by levying an appropriate emission tax. This tax has a Pigouvian interpretation, as it reflects the social marginal cost associated with the negative externality. The Norwegian car tax system represents an example of such "polluter pays principle", as it is based on high taxes for high emission cars and lower taxes for low and zero-emission cars.⁷

We then identify the optimal subsidy for green purchases that might restore the optimal sorting of consumers between the two firms. Our analysis reveals that, when the market equilibrium features interior solutions, such a subsidy is strictly decreasing in consumer WTP for hedonic quality. Given that consumer WTP for hedonic quality can be viewed as a proxy for consumer wealth, our findings suggest that the policy maker should offer higher incentives to lower-income consumers, thereby promoting fairness in the adoption of environmentally friendly practices. Both the picture resulting from the Eurobarometer 527 and the increasing adoption of income-based subsidies for green consumption in real-world contexts align with our findings, confirming their relevance for guiding effective policy implementation. Conversely, our results reveal that the widespread implementation of subsidies which are inversely proportional to the price of the green products might not be optimal.

The remainder of the paper is as follows. We next present the literature review and discuss how our paper differs from previous contributions. Section 2 introduces the model, while Section 3 characterizes market equilibria, including consumer self-selection, firms' price schedules and profits, and pollution emissions. Section 4 provides a social welfare analysis, including the first-best optimum, and considers optimal fiscal policies. Section 5 concludes.

⁷See <https://elbil.no/english/norwegian-ev-policy/>

1.1 Related Literature

Our paper contributes to the stream of research on behavioral economics that investigates pro-environmental behavior of consumers embedded in a social context with other consumers (Croson and Treich, 2014; Dasgupta *et al.*, 2016). There are many relevant papers that consider 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; Czaikowski *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 and 1990) whereby consumers experience a sense of joy and satisfaction for “doing their part”, regardless of the impact of their decisions.

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.*, 2010; and Deltas *et al.*, 2013). However, we depart from the “warm-glow” approach and consider instead the “bandwagon effect” introduced by Leibenstein (1950) 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’ (see also Farrell and Klemperer, 2007; and Lambertini and Orsini, 2005). As in Brécard (2013) and Grover and Bansal (2021), we then use the term *green network effect* to describe the situation in which consumer satisfaction from buying the green good is proportional to the market share of the green good.⁸ This approach allows us to capture the importance of conforming to the prevalent pro-environmental social norm or imitating the eco-friendly decisions of others in determining a collective shift towards environmentally friendly consumption. Apart from Hauck *et al.* (2014), Brécard (2013) and Grover and Bansal (2021), not much theoretical research has been carried out in this direction.⁹ Differently from the aforementioned papers, in our model the strength of the green network effect is not exogenous but is consumer specific.

A large body of theoretical literature followed Cremer and Thisse (1999) using models of vertical differentiation to study the provision of environmental quality (see Moraga-Gonzales and Padron-Fumero, 2002; Lombardini-Riipinen, 2005; Deltas *et al.*, 2013; among others). In these models, quality is unidimensional in that product differentiation only concerns the environmental attribute, whereas the hedonic

⁸However, we depart from Brécard (2013) because there is no network externality regarding the brown firm.

⁹From a psychological perspective, see the special issue on the “Psychology of Climate Change” (2021). From an economic perspective, we refer the reader to the excellent overview contained in Grover and Bansal (2021). In particular, an 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. Bansal *et al.* (2021) find evidence of peer effects influencing the corporate social responsibility expenditure of firms in India.

attribute is homogeneous across firms. As a consequence, the green good always has higher quality relative to the brown good. There are other theoretical papers that introduce two quality dimensions, with products having both hedonic and environmental attributes, but how the two attributes interact to affect the overall quality of the product is *a priori* determined. Specifically, Mantovani *et al.* (2016, 2017), and Grover and Bansal (2021), based on the observation that brown goods often perform better than green alternatives, assume that the two dimensions are in conflict with each other; Marini *et al.* (2022) also consider the case in which the two dimensions are aligned. In our paper, whether the green good is of superior intrinsic quality or not is endogenous and depends on the interplay between the relative production costs, the degree of consumer environmental concern and the willingness to pay for intrinsic quality. This modelling framework is common to Burani and Mantovani (2020), that disregards the bandwagon effect and concentrates on the consequences of asymmetric information about consumer WTP for intrinsic quality on the market equilibrium.

consumers value both the intrinsic performance of a good and its environmental footprint. They are heterogeneous in the valuation for intrinsic quality and in their environmental concern, and these two consumer characteristics are independently distributed. As a consequence,

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).¹⁰ Bansal and Gangopadhyay (2003) consider environmentally aware 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 differentiation 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 and consumer 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 consumer 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 firms' choice of greenness and the implications of various policy interventions, among which cost-sharing of development costs for improving the environmental friendliness of a good. Brécard (2013) suggests a pollution tax to limit environmental damage

¹⁰Montero (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.

together with a subsidy or tax on green products, depending on the intensity of the network effect. Mantovani and Vergari (2017) compare the effectiveness of a pollution tax versus a campaign raising consumer awareness about the relative impact of their consumption choices in curbing carbon emissions. Finally, Ambec and De Donder (2022) analyze environmental standard *vs* emission taxes in a model where some consumers derive satisfaction from buying a good of a higher environmental quality. They show that, when environmental policies can be chosen by consumers via majority voting, green consumerism reduces environmental protection with standards but not with taxes.

Due to the distinctive features of our theoretical framework, it becomes difficult to compare our results concerning environmental policies with those of the aforementioned literature. In particular, the environmental quality of the good is given in our model, so that we can not ascertain the effect of different policy interventions on this variable. Conversely, we can say a lot about the effects of introducing *ad valorem* and emission taxes on the hedonic quality schedules offered by both firms, which other papers consider as homogeneous across firms. We can not perform comparative statics analyses about the intensity of the network effect either, because, in our model, the latter is consumer specific rather than being subject to exogenous variations. Finally, we envisage a subsidy for green consumption that, rather than being uniform, discriminates among consumers with different valuations for intrinsic quality.

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, 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_i for intrinsic or hedonic quality. Firms have similar technologies and their profit margins (per unit, conditional on the customer buying) are given by

$$\pi_i = p_i - C_i(q_i), \quad (1)$$

where p_i is the price set by firm i for one unit of the good with quality q_i and $C_i(q_i)$ is the cost to firm i of providing one unit of the good with quality q_i . Following Mussa and Rosen (1978), we consider marginal costs that are constant in quantity but are increasing and convex in quality; hence 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

of a given quality.¹¹ 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.¹² Let us highlight that the extra marginal cost incurred by the green firm, represented by parameter k , allows this firm to offer a variety of the good which is more environmentally friendly, relative to the brown good, when used by consumers. 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. Consumer WTP for hedonic quality θ is assumed to be continuous and uniformly distributed on the support $[\bar{\theta} - 1, \bar{\theta}]$, with $\bar{\theta} > 1$. The support of unit length is chosen for simplicity, and a sufficiently high upper bound $\bar{\theta}$ ensures that all consumers buy the good, so that the market is fully covered. Thus, we can concentrate our attention on consumer self-selection between the two firms, as a result of their strategic interaction. Consumer environmental consciousness γ is continuously and uniformly distributed in the interval $[0, 1]$.¹³

We interpret environmental concern as a non-monetary benefit that a consumer enjoys when patronizing the green firm, which is unrelated to the intrinsic quality of the good, but depends on the overall fraction of consumers that buy from the green firm. This captures the idea that environmentally concerned consumers want to make the difference with their purchasing choice and realize that, while their individual choices might be irrelevant, only their collective behavior can have sizeable effects. We exclude that a similar network effect applies 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 of type (θ, γ) buys one unit of the good of quality q_i from firm $i = B, G$, her utility is given by

$$u_i(\theta, \gamma) = \theta q_i + I_i \gamma M_i - p_i, \quad (2)$$

¹¹Conrad (2005) assumes that green products are costlier to produce than standard products as they are more labor intensive. Yu *et al.* (2016) assume, as we do, that a product with a higher green level generates fewer emissions from consumption, but is produced at higher costs.

¹²Similar assumptions can be found in Moraga-González 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 higher environmental performance of the good raises marginal costs.

¹³This assumption is made for convenience. It is possible to show that the qualitative nature of the results is robust to the generalization $\gamma \sim U[0, \bar{\gamma}]$ with $\bar{\gamma} \in (0, \infty)$.

where $M_i \in [0, 1]$ denotes the market share of firm i and I_i is an indicator function taking value 1 when $i = G$ and value 0 when $i = B$. It follows that, when the consumer buys from firm B , environmental concern γ does not play any role and valuation θ for hedonic quality is the only relevant characteristic.

Given our assumptions about the distribution of consumer characteristics, consumer preferences will depend on the relative weight of the valuation for intrinsic quality θ *vis-à-vis* environmental concern γ . 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 intrinsic performance (see Figure 1).

Finally, when a consumer abstains from buying, her utility is zero.

Notice that the theoretical literature following Cremer and Thisse (1999) interpreted environmental-friendliness as a quality attribute of a good; therefore, models of vertical product differentiation have since been used to analyze consumer and firm behaviour in the presence of green goods. Moreover, consumer WTP for environmentally-friendly goods has been associated with consumer income, as wealthier households tend to have higher valuation for quality (see Bansal and Gangopadhyay, 2003). We depart from this approach because we hold the view that high income does not necessarily translate into high environmental concern, which is rather affected by culture and social norms (see Schumacher 2015). In addition, we believe that individual consumers are willing to buy environmentally-friendly products as long as the impact of their decisions on the environment is non-negligible. This motivates us to introduce the green network effect in consumer preferences and to abide by the original models of vertical product differentiation *à la* Mussa and Rosen (1978), whereby consumer valuation θ is associated to the hedonic rather than the environmental quality dimension.

We further assume that consumer valuation θ is 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, if 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 into a high θ (see the discussion in Tirole, 1988, on pages 96 and 97). In addition, big data analytics allow firms to adopt sophisticated consumer profiling techniques, including information about consumer valuation for hedonic quality. Conversely, firms' knowledge about consumer environmental consciousness remains much less precise.

An alternative framework, in which consumer valuation θ is privately known and assumes only two values, has been analyzed by Burani and Mantovani (2020).

Firms' strategic interaction

A consumer of type θ , who buys one unit of the good, has preferences over quality-price pairs which are independent of her degree of environmental consciousness γ . Therefore, one can treat the firms' problem as independent of the consumer choice about which firm to patronize (which is determined solely by γ). One can then consider that firms offer menus of θ -contingent contracts consisting in a hedonic quality target and a price, *i.e.*, $\{q_i(\theta), p_i(\theta)\}_{i=B,G}$. In order to simplify the exposition, it will be more convenient to reason in terms of consumers' indirect utility and to focus on quality-utility schedules of the form $\{q_i(\theta), U_i(\theta)\}_{i=B,G}$. Indeed, 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, namely

$$U_i(\theta) = \theta q_i(\theta) - p_i(\theta). \quad (3)$$

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, this consumer receives indirect utility $U_B(\theta)$ if she buys from the brown firm, whereas her *total* indirect utility becomes

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

if she buys from the green firm.

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*

$$\hat{\gamma}(\theta) \equiv \frac{U_B(\theta) - U_G(\theta)}{M_G}. \quad (4)$$

A consumer of type (θ, γ) strictly prefers to buy from the brown firm if her environmental concern falls short of $\hat{\gamma}(\theta)$, *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 $\hat{\gamma}(\theta)$, and $U_G(\theta) + \gamma M_G > U_B(\theta)$ holds. Given that γ is uniformly distributed on the interval $[0, 1]$, condition (4) implicitly defines the share of consumers with valuation θ who prefer to buy from the green firm, which is

$$M_G(\theta) \equiv \Pr(\gamma > \hat{\gamma}(\theta)) = 1 - \hat{\gamma}(\theta) = 1 - \frac{U_B(\theta) - U_G(\theta)}{M_G(\theta)}. \quad (5)$$

Similarly, the market share of the brown firm is

$$M_B(\theta) \equiv \Pr(\gamma \leq \hat{\gamma}(\theta)) = \hat{\gamma}(\theta) = \frac{U_B(\theta) - U_G(\theta)}{M_G(\theta)} = 1 - M_G(\theta). \quad (6)$$

Solving the right-most equality in (6) for $M_G(\theta)$ yields

$$M_G(\theta) = \frac{1}{2} + \frac{\sqrt{1 - 4(U_B(\theta) - U_G(\theta))}}{2}, \quad (7)$$

and then

$$M_B(\theta) = 1 - M_G(\theta) = \frac{1}{2} - \frac{\sqrt{1 - 4(U_B(\theta) - U_G(\theta))}}{2}. \quad (8)$$

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, $M_i(\theta)$ must be real-valued and the determinant in both (7) and (8) must be non-negative, which occurs for $U_B(\theta) - U_G(\theta) \leq \frac{1}{4}$.¹⁴

In order to set up each firm's maximization problem, let us first solve (3) in terms of the price, as

$$p_i(\theta) = \theta q_i(\theta) - U_i(\theta), \quad (9)$$

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

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

Letting

$$S_i(\theta) \equiv \theta q_i(\theta) - C_i(q_i(\theta)) = \theta q_i(\theta) - \frac{1}{2} k_i q_i^2(\theta) \quad (10)$$

denote the surplus realized when a consumer of type θ buys one unit of the good with hedonic quality $q_i(\theta)$ from firm $i = B, G$ (again, absent the benefit accruing from environmental concerns), we can write $\pi_i(\theta) = S_i(\theta) - U_i(\theta)$.

The program of each firm $i = B, G$ consists, then, in maximizing total profits with respect to quality level $q_i(\theta)$ and indirect utility $U_i(\theta)$ for each θ -type consumer, taking as given the indirect utility that the rival firm leaves to the same consumer, i.e. $U_{-i}(\theta)$. Once firms' quality levels and consumers' utilities are obtained, the corresponding prices $p_i(\theta)$ are derived using equation (9).

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

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

Notice that environmental concern γ does not appear in the above program, 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 program, the utility offered to consumers by the other firm, i.e. $U_{-i}(\theta)$, is taken as given. Thus, firms compete against each other in the utility space. Notice that program P_i uncovers a trade-off. Suppose that a firm increases the utility offered to a given type of consumer. On the one hand, its payoff is reduced because it is as if the firm lowers the price of the unit sold, thereby shifting the division of total surplus towards the consumer. On the other hand, the firm enhances the probability of selling the good to the given consumer and hence it increases its market share.

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 these schedules and select the preferred one, i.e. they choose

¹⁴See Condition 1 at page 14.

which firm to patronize. An equilibrium of the game is such that each firm chooses a menu of quality-utility schedules that maximizes its expected profit, given the schedules offered by the rival firm and given the equilibrium choices of consumers. Each consumer chooses the schedule that maximizes her utility, including her environmental concern if relevant.

3 Market Equilibria

3.1 Firms' reaction functions

When consumer valuations θ are perfectly observable to firms, the choice of hedonic quality $q_i(\theta)$ is straightforward: such quality is chosen independently by each firm in order to maximize P_i and it is then set at the level

$$q_i^*(\theta) = \frac{\theta}{k_i}. \quad (11)$$

Notice that $q_B^*(\theta) > q_G^*(\theta)$ for every θ : given 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 (11) into (10) yields maximal surplus

$$S_i^*(\theta) = \frac{\theta^2}{2k_i}. \quad (12)$$

There remains to maximize program P_i with respect to net utilities U_i . This delivers the reaction functions of the two firms, which describe the profit maximizing utility left by firm $i = B, G$ to a θ -type consumer given optimal surplus $S_i^*(\theta)$ and given the utility $U_{-i}(\theta)$ that the same consumer receives from the competing firm $-i$. Omitting the WTP for hedonic quality θ , we have

$$U_G(U_B) = \frac{6U_B + 3S_G^* - 1 - \sqrt{3S_G^* - 3U_B + 1}}{9} \quad (RF_G)$$

for firm G , whereas for firm B we obtain

$$U_B^-(U_G) = \frac{6U_G + 3S_B^* + 1 - \sqrt{1 + 3U_G - 3S_B^*}}{9} \quad \text{and} \quad U_B^+(U_G) = \frac{6U_G + 3S_B^* + 1 + \sqrt{1 + 3U_G - 3S_B^*}}{9}. \quad (RF_B)$$

Notice the asymmetry between the two firms' reaction functions: for each possible level of indirect utility U_G that firm G leaves to the consumer of type 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 can be discarded

when U_G is sufficiently high.¹⁵ In any case, reaction functions are not linear and have positive slopes in their relevant intervals so that utilities can be interpreted as *strategic complements* in this game.

3.2 Nash equilibria

In a Nash equilibrium, the utility levels left by each firms to the consumer of type θ , *i.e.*, $U_B(\theta)$ and $U_G(\theta)$, simultaneously solve the two equations RF_G and RF_B , while satisfying the following requirements.

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

Requirement (i) ensures that $M_i(\theta) \in (0, 1)$, so that each firm is active and no single firm supplies the entire market. Constraint (ii) ensures that market shares $M_i(\theta)$ are real-valued, whereas (iii) guarantees that firms' profits are non-negative. Finally, requirement (iv) follows from consumer 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 $\mathcal{U}_G(\theta) = U_G(\theta) + \gamma M_G(\theta)$.

There are two classes of solutions that can be singled out, interior *vs* corner solutions. The interior solution attains for intermediate values of θ , whereas two corner solutions emerge when θ is either low or high. For expositional clarity, we label Region *I* the interval in which θ takes low values and a corner solution realizes, Region *II* the interval of intermediate values of θ that delivers an interior solution, and Region *III* the interval of high values of θ in which the other corner solution attains. We use superscripts to distinguish the three regions which are denoted by $R = I, II, III$. We also characterize the solutions in terms of surpluses S_B^* and S_G^* which in turn depend on θ (see equation 12).

Interior solution

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

$$U_B^{II} = \frac{1+6S_B^*+4S_G^*-\sqrt{5(1-4(S_B^*-S_G^*))}}{10} \quad \text{and} \quad U_G^{II} = \frac{4S_B^*+6S_G^*-1-\sqrt{5(1-4(S_B^*-S_G^*))}}{10}. \quad (13)$$

This solution realizes when the determinant in the above expressions is non-negative, which amounts to $(S_B^* - S_G^*) \leq \frac{1}{4}$ or else

$$\theta \leq \sqrt{\frac{k}{2(k-1)}} \equiv \theta^{II}.$$

It can be checked that the solution is such that $U_G^{II} < U_B^{II}$ and $U_G^{II} < S_G^*$ always hold, and that $U_B^{II} \leq S_B^*$ is true provided that $\theta \leq \theta^{II}$. Finally, $U_B^{II} > 0$ if and only if

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

¹⁵Further details are provided in Appendix A.1.

where $\theta^I < \theta^{II}$. It then follows that the solution given by (13) only holds for $\theta^I < \theta \leq \theta^{II}$, in which case we have $\max\{U_G^{II}, 0\} < U_B^{II}$. In other words, the interior solution realizes in the interval $\theta \in (\theta^I, \theta^{II}]$ which characterizes Region *II*.

Corner solutions

When $\theta \leq \theta^I$ the interior solution is no longer valid, but there is a corner solution which is such that

$$U_B^I = 0 \quad \text{and} \quad U_G^I = \frac{3S_G^* - 1 - \sqrt{1 + 3S_G^*}}{9}, \quad (14)$$

with $U_G^I < U_B^I = 0$ being satisfied in the relevant parametric range. At this equilibrium, despite competing against the green firm, the brown firm is able to perfectly price discriminate its consumers, thus extracting all their surplus. Region *I* is characterized by $\theta \in (\bar{\theta} - 1, \theta^I]$, provided that $\bar{\theta} - 1 < \theta^I$. When $\bar{\theta} \geq \theta^I + 1$, Region *I* is empty.

Finally, consider the case in which $\theta > \theta^{II}$. In this interval, the green firm leaves all the surplus to its customers, and the solution is given by

$$U_B^{III} = \frac{6S_G^* + 3S_B^* + 1 + \sqrt{1 - 3(S_B^* - S_G^*)}}{9} \quad \text{and} \quad U_G^{III} = S_G^*. \quad (15)$$

Notice that this solution is relevant when the determinant in the expression of U_B^{III} is non-negative, namely when $(S_B^* - S_G^*) \leq \frac{1}{3}$ or else when

$$\theta \leq \sqrt{\frac{2k}{3(k-1)}} \equiv \theta^{III},$$

with $\theta^{III} > \theta^{II}$. Therefore, Region *III* is characterized by $\theta \in (\theta^{II}, \min\{\theta^{III}, \bar{\theta}\}]$. When $\bar{\theta} > \theta^{III}$ and $\theta \in (\theta^{III}, \bar{\theta}]$, a solution in pure strategies does not exist.

Notice that all threshold values of θ are strictly decreasing in k . In particular, while θ^I is always close to but slightly smaller than $1/2$, θ^{II} and θ^{III} are such that $\lim_{k \rightarrow 1} \theta^{II} = \lim_{k \rightarrow 1} \theta^{III} = \infty$ whereas $\lim_{k \rightarrow 2} \theta^{II} = \lim_{k \rightarrow 3} \theta^{III} = 1$. Hence, when k is not too far from 1 (namely when the cost disadvantage of the green firm is not too high), the distance between θ^I and either θ^{II} or θ^{III} becomes arbitrarily large and exceeds unity. In this case, Region *I* disappears when consumer WTP for intrinsic quality is sufficiently high that $\bar{\theta} \geq \theta^I + 1$. Conversely, all three solutions are relevant when k is sufficiently high and $\bar{\theta}$ is small enough. The following assumption ensures that a Nash equilibrium in pure strategies always exists.

Assumption 1 $k \in (1, 3)$ and $\bar{\theta} < \theta^{III}$.

Under the above assumption, Region *III* is characterized by $\theta \in (\theta^{II}, \bar{\theta}]$. The following proposition summarizes the results obtained so far.

Proposition 1 *Pure-strategy Nash equilibria* (i) In Region I, i.e., when $\theta \in [\bar{\theta} - 1, \theta^I]$, there is a corner solution such that $U_B^I = 0$; (ii) In Region II, i.e., $\theta \in (\theta^I, \theta^{II}]$, there is an interior solution given by (13); (iii) In Region III, i.e., when $\theta \in (\theta^{II}, \bar{\theta}]$, there is a corner solution such that $U_G^{III} = S_G^*$.

Observe that, in Region I, consumers care relatively more for the environmental than the intrinsic quality dimension of the goods. Those consumers with high environmental consciousness always buy from the green firm, because the benefits from their environmentally responsible consumption behavior more than compensate for the low net utility that they are left with. Conversely, consumers with lower environmental concern have no other option than to patronize the brown firm, which behaves as a monopolist that can perfectly price discriminate its customers and extract all their surplus. Another corner solution is obtained in Region III, where consumers have a high valuation for the intrinsic quality relative to the environmentally-friendly dimension. As a consequence, the green firm is forced to behave *à la* Bertrand in order to attract a positive share of consumers, who are left with all the surplus.

3.3 Consumer self-selection

Given qualities $q_i^*(\theta)$ and indirect utilities $U_i^R(\theta)$ set by each firm $i = B, G$ in each region $R = I, II, III$ at equilibrium, consumers decide which firm to patronize according to their degree of environmental concern. This determines how consumers characterized by different valuations for hedonic quality 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 consumer valuation θ . Positive (respectively, negative) selection into the green firm, instead, describes a situation in which the higher the consumer 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 I, given equilibrium indirect utilities U_B^I and U_G^I , one can compute the equilibrium market shares of the two firms $M_i^I(\theta)$, and then obtain the level of environmental concern which makes each consumer with valuation $\theta \in [\bar{\theta} - 1, \theta^I]$ indifferent between firm B and G . Such indifferent consumer is

$$\hat{\gamma}^I(\theta) \equiv \frac{1}{3} (2 - \sqrt{1 + 3S_G^*}) = \frac{1}{3} \left(2 - \sqrt{\frac{2k+3\theta^2}{2k}} \right). \quad (16)$$

It is easy to check that $\hat{\gamma}^I(\theta)$ is strictly decreasing in θ in the relevant range, so there is *positive selection* into the green firm.

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

$$\hat{\gamma}^{II}(\theta) \equiv \frac{1}{2} \left(1 - \frac{\sqrt{5}}{5} \sqrt{1 - 4(S_B^* - S_G^*)} \right) = \frac{1}{2} \left(1 - \sqrt{\frac{k-2\theta^2(k-1)}{5k}} \right). \quad (17)$$

The above function is strictly increasing in θ when $\theta \in (\theta^I, \theta^{II}]$ and we obtain *negative selection* for the green firm. Moreover, $\hat{\gamma}^{II}(\theta)$ coincides with $\hat{\gamma}^I(\theta)$ for $\theta = \theta^I$, so that continuity is satisfied.

Finally, in Region III, *i.e.*, when $\theta \in (\theta^{II}, \bar{\theta}]$, equilibrium utilities U_B^{III} and U_G^{III} deliver the following expression for the indifferent consumer

$$\hat{\gamma}^{III}(\theta) \equiv \frac{1}{3} (1 + \sqrt{1 - 3(S_B^* - S_G^*)}) = \frac{1}{3} \left(1 + \sqrt{\frac{2k - 3(k-1)\theta^2}{2k}} \right) \quad (18)$$

which is always decreasing in θ in the relevant range, resulting again in a *positive selection* into the green firm. Finally, continuity is satisfied because $\hat{\gamma}^{II}(\theta)$ coincides with $\hat{\gamma}^{III}(\theta)$ when θ equals θ^{II} ; in particular, when $\theta = \theta^{II}$, we have $\hat{\gamma}^{II}(\theta) = \hat{\gamma}^{III}(\theta) = \frac{1}{2}$, which is a global maximum reached by $\hat{\gamma}(\theta)$.

In Figure 1, we set $k = 1.5$, $\bar{\theta} = 1.3$ and plot function $\hat{\gamma}(\theta)$ in the three regions.

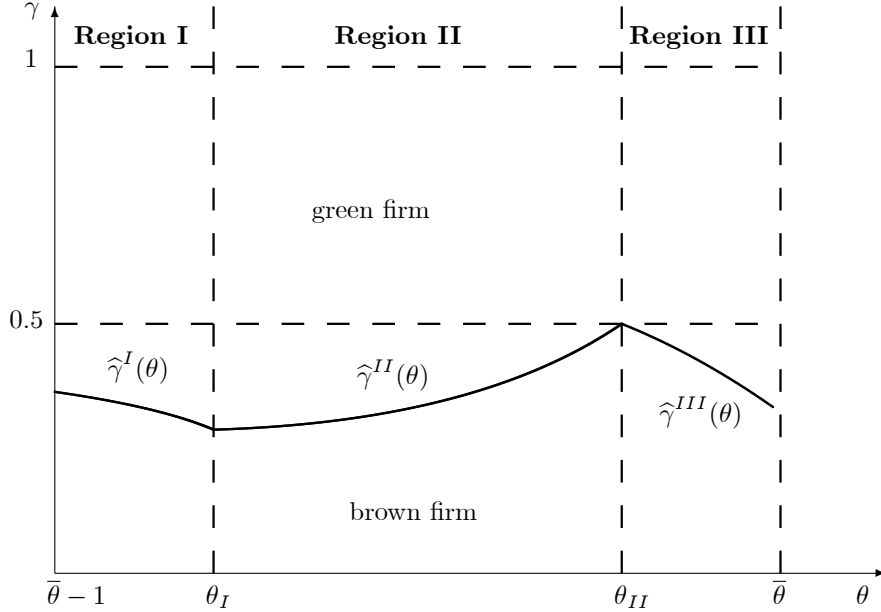


Figure 1: Consumer type space and consumer sorting

For the sake of comparison, notice that, had both firms the same costs of hedonic quality, *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 $\hat{\gamma} = \frac{1}{2} \left(1 - \frac{\sqrt{5}}{5} \right)$ which is independent of θ , meaning that sorting of consumers into firms would be neutral.

Consumer sorting patterns can then be summarized as follows.

Proposition 2 Consumer sorting patterns. (i) In Region I there is positive selection for firm G; (ii) In Region II, there is negative selection for firm G; (iii) in Region III, there is positive selection for firm G.

Hence, when consumer WTP for hedonic quality θ is sufficiently low, *i.e.*, when $\theta \in [\bar{\theta} - 1, \theta^I]$, it means that consumers care relatively more about the environmental than the intrinsic quality dimension of the good. The share of consumers buying from the green firm increases with θ because consumer indirect utility U_G increases with θ while U_B stays constant at 0. When consumer WTP for hedonic quality θ is sufficiently high, *i.e.*, when $\theta \in (\theta^{II}, \bar{\theta}]$, it means that consumers care relatively more about the intrinsic than the environmental quality dimension of the good. Then, the share of consumers buying from the green firm increases with θ because consumer indirect utility $U_G = S_G^*$ increases with θ faster than U_B does. The opposite holds for intermediate values of θ , *i.e.* when $\theta \in (\theta^I, \theta^{II}]$.

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. Does this consumer also end up paying more for the brown good? In order to answer this question, we analyze the difference in price schedules. We then consider which firm enjoys the highest profits. The analytical expressions of equilibrium prices and profits are confined to Appendix A.2, in which we also provide graphical representations.

Regarding the price difference, we find that $p_G(\theta) > p_B(\theta)$ always holds in Region *I*, where we have positive selection for the green firm. In Region *II*, a price premium for the green firm still emerges, provided that consumer WTP for hedonic quality is not very high, *i.e.* provided that

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

with $\theta^I < \tilde{\theta} < \theta^{II}$. Notice that $\tilde{\theta}$ is decreasing in k , meaning that such price premium is more likely to emerge when the cost disadvantage of the green firm is not too high. Finally, for every θ in Region *III*, the brown variety always has a higher price than the green one.

Turning to firms' total profits, notice that they are equal to per-unit profit margins multiplied by the corresponding market share, namely

$$\Pi_i^R(\theta) = \pi_i(\theta) M_i^R(\theta),$$

for any given θ , for each firm $i = B, G$ and for each region R . We find that $\Pi_G(\theta) > \Pi_B(\theta)$ holds in Region *I* and Region *II* but $\Pi_B(\theta) > \Pi_G(\theta)$ in Region *III*. Considering price and profit differentials together, one can conclude the following.

Proposition 3 (i) When consumer WTP for hedonic quality is such that $\theta \in [\bar{\theta} - 1, \tilde{\theta})$, the green firm charges higher prices and enjoys higher profits than the brown rival; (ii) when $\theta \in [\tilde{\theta}, \theta^{II}]$, the green firm charges lower prices but still enjoys higher profits than the brown rival; (iii) when $\theta \in (\theta^{II}, \bar{\theta}]$, *i.e.*, in Region *III*, the green firm charges lower prices and earns lower profits than the brown rival.

In our model, the firm’s decision to carry out green production is not strategic; it is rather taken as given. Nonetheless, Proposition 3 provides a rationale for the choice to “go green”.¹⁶ 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. A 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.¹⁷ A recent study by Kroll shows that companies with better ESG ratings outperform companies with lower ranking.¹⁸ 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).

3.5 Pollution Emissions

What is the environmental impact of the market outcome that we have described? In order to answer this question, we have to take into account the negative externalities related to the consumption and the production of the goods, which neither firms nor consumers internalize.

In particular, let e_i^C denote the per-unit emissions related to the *consumption* of the goods. Such emissions are assumed to be increasing in the hedonic quality of the good, in such a way that $e_i^C(\theta) = \phi_i q_i(\theta)$, 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 of the green good, no matter what its hedonic quality is, whereas $\phi_B = \phi > 0$. In the automotive sector, for instance, emissions from consumption of electric vehicles are strictly lower than emissions from standard combustion-engine vehicles, not only if one considers that electric cars do not generate CO₂ emissions while being driven, but also if one takes into account pollution from electricity generation.

Furthermore, let e_i^P denote the per-unit emissions related to the *production* of the goods, which are still assumed to be proportional to the quality of the good, whereby $e_i^P(\theta) = \rho_i q_i(\theta)$ for $i = G, B$. We do not *a priori* rank ρ_B and ρ_G , although there is some empirical evidence confirming that green firms pollute more than brown rivals during the production process. Think, for instance, of the production of batteries for electric vehicles. Those batteries may have a high environmental footprint, as they are

¹⁶Incidentally, notice that considering firms that are differentiated along the environmental dimension allows us to overcome the Bertrand paradox.

¹⁷See https://www.spglobal.com/_media/documents/the-sp-500-esg-index-integrating-esg-values-into-the-core.pdf

¹⁸Kroll is a leading independent provider of global risk and financial advisory solutions, that examines the relationship between historical returns of publicly traded companies and their ESG ratings globally. See <https://www.kroll.com/en/insights/publications/cost-of-capital/esg-global-investor-returns-study>

made of rare earth elements like lithium, nickel, cobalt or graphite, whose extraction may require very polluting processes; moreover their disposal can be very costly and polluting. Observe that the size of batteries is increasing in the intrinsic quality of the electric vehicle, therefore, in our model, pollution from production is increasing in the intrinsic quality of the good.¹⁹

Unit emissions are given by the sum of unit emissions from consumption and production:

$$e_i(\theta) = e_i^C(\theta) + e_i^P(\theta) = (\phi_i + \rho_i)q_i(\theta).$$

Consistently with our definition of green goods, we assume that, for each θ , the overall level of pollution generated by one unit of the good is higher for the brown than for the green variety, namely, $\phi + \rho_B > \rho_G$. Moreover, in order to make notation more compact, we rewrite $(\phi_i + \rho_i) = \mu_i$.

Assumption 2 $\mu_B \equiv \phi + \rho_B > \rho_G \equiv \mu_G$.

The unit *emission differential* is:

$$e_B(\theta) - e_G(\theta) = \frac{\theta(k\mu_B - \mu_G)}{k}, \quad (19)$$

which is always positive, provided that Assumption 2 holds.

Fixing θ , aggregate pollution emissions generated by each firm $i = B, G$ are given by unit emissions multiplied by the relevant market share. Integrating over all possible θ , and taking into account that market shares $M_i(\theta)$ differ across the three regions $R = I, II, III$, we obtain

$$E_i(\theta) = \int_{\theta} [e_i^C(\theta) + e_i^P(\theta)] M_i^R(\theta) d\theta = \int_{\theta} \mu_i q_i(\theta) M_i^R(\theta) d\theta, \quad (20)$$

for $i = B, G$. Despite the fact that, at the unit level, $e_B - e_G > 0$ always holds, we find that, at the aggregate level, the emission differential might be negative, *i.e.*, $E_B - E_G < 0$. This happens because, due to the green network effect, the market share enjoyed by the green firm can be significantly higher than that of the brown firm, and this causes the green firm to pollute more than the brown one. However, notice that 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 always diminishes total pollution because the green firm emits less overall pollution from consumption and production.

Finally, it can be shown that an aggregate negative emission differential is associated with low values of the cost differential k . A reduction in k means higher quality for the green firm and, being pollution proportional to quality, aggregate pollution emitted by the green firm tends to be higher when k decreases.

¹⁹Tarola and Zana (2023), 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.

4 Social Welfare

Let us now consider social welfare, which includes the negative externalities related to overall pollution emissions, that neither firms nor consumers internalize. The positive externalities, represented by the green network effect, are instead excluded from social welfare, following the approach of Ambec and De Donder (2022) and Heyes and Martin (2017), who draw on Andreoni (2006) and Diamond (2006).²⁰ We also assume that the marginal social damage of environmental pollution is equal to one. The expression for social welfare is therefore given by:

$$\begin{aligned} W = & W_B + W_G = \int_{\theta} [S_B(\theta) - \mu_B q_B(\theta)] M_B(\theta) d\theta \\ & + \int_{\theta} [S_G(\theta) - \mu_G q_G(\theta)] M_G(\theta) d\theta. \end{aligned} \quad (21)$$

Recall that $S_i(\theta)$ represents 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 10). Since the market share of firm $i = G, B$ is given by $M_i(\theta)$ for each θ , the surplus net of the pollution emissions has to be weighted by the total amount of transactions $M_i(\theta)$. As before, given that there are three different regions for θ characterized by different levels of $\hat{\gamma}^R(\theta) = M_B^R(\theta)$, $R = I, II, III$, it becomes necessary to compute the above integrals separately for each region.

4.1 Social Planner

Given that each consumer WTP θ is perfectly observable, the social planner maximizes welfare relative to q_i and U_i for each firm $i = G, B$ and for each θ , so that the program becomes

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

For each θ and each firm $i = B, G$, socially optimal qualities are such that

$$q_i^o(\theta) = \frac{\theta - \mu_i}{k_i}, \quad (22)$$

²⁰The alternative would have been to formalize welfare associated with the green firm including both negative and positive externalities, as:

$$W_G = \int_{\hat{\gamma}(\theta)}^1 \left[\int_{\theta} (S_G(\theta) - \mu_G q_G(\theta) + \gamma M_G(\theta)) M_G(\theta) d\theta \right] d\gamma,$$

This, however, would have required computing the above integral for the three different regions characterized by different levels of $\hat{\gamma}^R(\theta)$, $R = I, II, III$. Moreover, given that the expressions for $\hat{\gamma}^R(\theta)$ are non-linear in θ , resorting to first-order Taylor approximations would have been necessary. We opted to exclude the network effect from social welfare not only for tractability reasons but also to maintain a conservative approach towards the brown firm, whose market share would have dropped substantially with the inclusion of the network effect.

where superscript o indicates the social optimum. We require that θ be sufficiently high to ensure that all qualities are strictly positive.²¹ Notice that $q_i^o(\theta) < q_i^*(\theta)$ always holds for $i = G, B$. Additionally:

$$q_B^o(\theta) - q_G^o(\theta) = \underbrace{\frac{(k-1)\theta}{k}}_{q_B^* - q_G^*} - \frac{k\mu_B - \mu_G}{k}, \quad (23)$$

which clearly shows that the quality differential at the social planner solution is always lower than at the market equilibrium, provided Assumption 2 holds. Indeed, the planner internalizes the negative externalities from the unit emissions generated by the consumption and production of both varieties of the good.

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

We still need to consider how the social planner chooses the indirect utilities $U_i(\theta)$ and, consequently, the market shares $M_i(\theta)$ for each θ and each firm $i = B, G$. Recall that market shares are given by expressions (5) and (6) and 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 $p_i(\theta)$. As in Cremer and Thisse (1999), we assume that the social planner sets prices at marginal costs, so that each firm's profit margin is equal to zero and total unit surplus can be entirely identified with consumer indirect utilities. In particular, for each firm $i = B, G$, the unit price equals the marginal production cost plus the marginal environmental damages from consumption and production:

$$p_i^o(\theta) = \frac{1}{2}k_i q_i^o(\theta)^2 + \mu_i q_i^o(\theta). \quad (24)$$

Given (24), the utility from one unit of the good of quality $q_i^o(\theta)$ sold by firm $i = G, B$ is given by

$$U_i^o(\theta) = \theta q_i^o(\theta) - p_i^o(\theta) = \frac{(\theta - \mu_i)^2}{2k_i} = S_i^o(\theta), \quad (25)$$

where utilities $U_i^o(\theta)$ are always strictly positive. Then, we can compute the expression for the socially optimal market share of the brown firm, or else the indifferent consumer, which is

$$M_B^o(\theta) = \hat{\gamma}^o(\theta) = \frac{1}{2} \left(1 - \sqrt{1 - 4(S_B^o - S_G^o)} \right) = \frac{1}{2} \left(1 - \sqrt{1 - \frac{2(k(\theta - \mu_B)^2 - (\theta - \mu_G)^2)}{k}} \right). \quad (26)$$

Similarly to the market equilibrium, we require that: (i) $\hat{\gamma}^o(\theta)$ is real-valued; and (ii) $\hat{\gamma}^o(\theta) \in (0, 1)$. As for requirement (ii), $\hat{\gamma}^o(\theta) < 1$ is always satisfied, whereas $\hat{\gamma}^o(\theta) > 0$ corresponds to $S_B^o - S_G^o > 0$, which holds if and only if

$$\theta > \frac{\sqrt{k}\mu_B - \mu_G}{\sqrt{k} - 1} \equiv \theta_1^o.$$

²¹ Observe that the qualities at the social optimum remain the same regardless of the inclusion of the green network effect in the social welfare.

It is worth noting that a necessary condition for $S_B^o > S_G^o$ is that $q_B^o(\theta) - q_G^o(\theta) > 0$. Requirement (i) corresponds to $S_B^o - S_G^o \leq \frac{1}{4}$, and it is satisfied if and only if

$$\theta \leq \frac{2(k\mu_B - \mu_G) + \sqrt{2k(k-1+2(\mu_B - \mu_G)^2)}}{2(k-1)} \equiv \theta_2^o, \quad$$

with $\theta_2^o > \theta_1^o$. Finally, notice that program P_B^o is not well defined when the brown firm has no costumers and $M_B^o(\theta) = 0$. However, assuming that socially optimal qualities and prices are still given by (22) and (24), respectively, one can extend the social planner solution to market shares $M_B^o(\theta) = 0$ and $M_G^o(\theta) = 1$ whenever $\theta \leq \theta_1^o$.

In sum, we can identify two distinct regions. In Region 1, which holds when $\theta \in [\bar{\theta} - 1, \theta_1^o]$, we have that $\hat{\gamma}^o(\theta) = 0$. Conversely, in Region 2, which holds when $\theta \in (\theta_1^o, \min\{\theta_2^o, \bar{\theta}\}]$, $\hat{\gamma}^o(\theta)$ is given by expression (26), with $\hat{\gamma}^o(\theta_2^o) = \frac{1}{2}$.²² Furthermore, within Region 2, $\hat{\gamma}^o(\theta)$ is strictly monotonically increasing and convex in θ . It follows that the social planner induces a negative selection for the green firm, if any. In Figure 2, we set $k = 1.5$, $\bar{\theta} = 1.3$, $\mu_B = 0.1$ and $\mu_G = 0.05$ (in which case $\bar{\theta} < \theta_2^o$), and then proceed to plot the function $\hat{\gamma}^o(\theta)$ in the two identified regions.

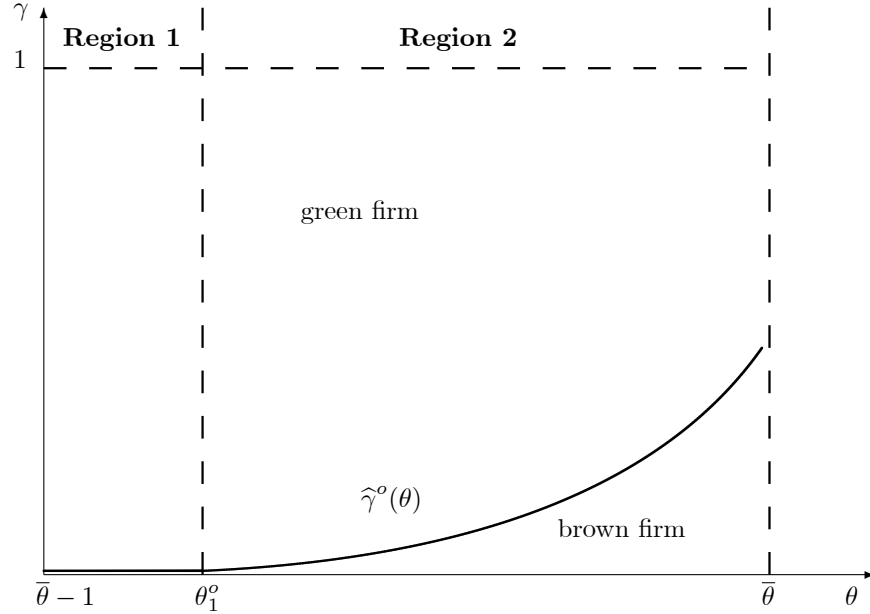


Figure 2: Consumer optimal sorting

As a final step, we compute the optimal social welfare, denoted as W^o , by inserting the socially optimal qualities $q_i^o(\theta)$ and the market share $\hat{\gamma}^o(\theta)$ into expression (21), and integrating. Given that

²²Notice that $\theta_2^o - \theta_1^o > 1$ if and only if $\mu_B - \mu_G < \frac{(2-k)}{4\sqrt{k}}$. Hence, when the difference in unit emissions is sufficiently low, it is never the case that both thresholds θ_1^o and θ_2^o belong to the unit interval $[\bar{\theta} - 1, \bar{\theta}]$.

$W^o > W^*$, a natural question arises: which policy mix should the regulator adopt to steer the market equilibrium towards the first-best optimum? There are various instruments that can be adopted to address the multiplicity of market failures present in our framework: an emission tax on the two goods to curb environmental pollution from both consumption and production, an *ad valorem* tax on both goods to reduce product differentiation, and a subsidy for the consumption of the green good to enhance the green network effect. We will examine these instruments in the following subsection.

4.2 Optimal Fiscal Policies

Abstracting from budget balancedness, let us consider an *ad valorem* tax $t_v \in [0, 1]$ and an emission tax $\tau_e \in [0, \infty)$, so that profit margins for firm $i = B, G$ become

$$\pi_i(\theta) = (1 - t_v) p_i(\theta) - C_i(q_i(\theta)) - \tau_e \mu_i q_i(\theta),$$

or, using $\tau_v = \frac{1}{1-t_v} \in [1, \infty)$ as an index of the *ad valorem* tax,

$$\pi_i(\theta) = \frac{1}{\tau_v} (p_i(\theta) - \tau_v C_i(q_i(\theta)) - \tau_v \tau_e \mu_i q_i(\theta)).$$

Using (9) to eliminate the price from the above expression, one can write the program of firm i as

$$\max_{q_i(\theta), U_i(\theta)} \frac{1}{\tau_v} \left[\theta q_i(\theta) - U_i(\theta) - \tau_v \frac{1}{2} q_i(\theta)^2 - \tau_v \tau_e \mu_i q_i(\theta) \right] M_i(\theta) \quad (PR_i)$$

for each θ . Optimal qualities are given by

$$q_B^r(\theta) = \frac{\theta - \tau_v \tau_e \mu_B}{\tau_v} \quad \text{and} \quad q_G^r(\theta) = \frac{\theta - \tau_v \tau_e \mu_G}{\tau_v k},$$

where superscript r indicates that we are considering the *regulated* market equilibrium. They remain strictly positive provided that θ is sufficiently high. Moreover, they always fall below the optimal qualities at the unregulated market equilibrium, *i.e.*, $q_i^r(\theta) < q_i^*(\theta)$ for $i = B, G$. It is evident that the introduction of both the *ad valorem* tax and the emission tax reduces the quality differential, such that $q_B^r(\theta) - q_G^r(\theta) < q_B^*(\theta) - q_G^*(\theta)$. Furthermore, $q_B^r(\theta) - q_G^r(\theta)$ decreases with respect to both τ_v and τ_e . Also, observe that the qualities remain unaffected by the introduction of a subsidy. Given this, it is possible to solve the system of equations $q_B^r(\theta) = q_B^o(\theta)$ and $q_G^r(\theta) = q_G^o(\theta)$ to determine the optimal combination of the *ad valorem* tax and the emission tax that induces firms to supply the socially optimal quality levels.

Proposition 4 *The policy maker can induce firms to produce the socially optimal qualities by levying an ad valorem tax $\tau_v^* = 1$ and an emission tax $\tau_e^* = 1$.*

The fact that $\tau_v^* = 1$ implies that the *ad valorem* tax has no effect on product differentiation, firms' market shares, and profits, making it irrelevant in our context. This is because firms can observe consumers' WTP for intrinsic quality. Consequently, the excessive quality differentiation at the market equilibrium, relative to the social planner solution, does not depend on imperfect competition, but is solely

attributable to firms' failure to internalize the negative externalities associated with pollution. Thus, it is the emission tax $\tau_e^* = 1$ that addresses this market failure. Indeed, τ_e^* equals the social marginal cost of the negative externality and functions as a Pigouvian tax.

Firms also choose the utilities $U_i(\theta)$ left to consumers to solve program PR_i . They consider that the policy maker can resort to a subsidy σ for the purchase of the green good to restore the socially optimal sorting of consumers. When consumers buy from the green firm, they benefit from the subsidy as they end up paying $p_G - \sigma$ and enjoy utility $U_G + \sigma$, absent the benefit accruing from environmental concern.²³ The subsidy does not influence equilibrium qualities $q_i^r(\theta)$, although it affects both firms' market shares M_i because it alters the relative attractiveness of the two firms for customers. Indeed, the consumer of type (θ, γ) who is indifferent between buying from firm G or firm B is now defined by

$$\hat{\gamma}(\theta, \sigma) \equiv \frac{U_B(\theta) - U_G(\theta) - \sigma}{M_G}, \quad (27)$$

where $U_i(\theta)$ are still given by (3). Firms' market shares are therefore given by

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

$$M_B(\theta, \sigma) = \hat{\gamma}(\theta, \sigma) = \frac{1}{2} - \frac{\sqrt{1 - 4(U_B(\theta) - U_G(\theta) - \sigma)}}{2}.$$

Then, firm $i = B, G$ solves the reduced problem

$$\max_{U_i(\theta)} [S_i^o(\theta) - U_i(\theta)] M_i(\theta, \sigma), \quad (28)$$

where S_i^o is given by (25), which already incorporates the effect of optimal commodity and emission taxes. In Appendix A.3, we replicate the analysis carried out in Section 3 and obtain three candidate solutions: a corner solution where $U_B^r = 0$, an interior solution, and a corner solution where $U_G^r = S_G^o$. Accordingly, there are three regions, labeled as Region *Ir*, *IIr* and *IIIr*, corresponding to three different expressions for the indifferent consumer at the regulated market equilibrium, $\hat{\gamma}^R(\sigma, \theta)$.²⁴

Lastly, let us analyze whether the subsidy induces consumers to sort in the socially optimal manner. The optimal subsidy would make the indifferent consumer at the regulated market equilibrium $\hat{\gamma}^R(\sigma, \theta)$, with $R = I, II, III$, converge to the socially optimal indifferent consumer $\hat{\gamma}^o(\theta)$. In Appendix A.3, we show that no optimal subsidy exists in Region *Ir*, whereas in Region *IIr*, the optimal subsidy corresponds to

$$\sigma^{II}(\theta) = 1 - 4(S_B^o - S_G^o) = \frac{k+2(\theta-\mu_G)^2-2k(\theta-\mu_B)^2}{k},$$

²³Given that prices and utilities are non-linear and depend on θ , we expect the subsidy to be conditional on consumer WTP for intrinsic quality as well.

²⁴The actual expressions of $\hat{\gamma}^R(\sigma, \theta)$ for the three regions can be found in Appendix A.3, together with the relevant threshold values of σ that define such regions.

which is positive and strictly decreasing in θ . Finally, in Region *IIIr* the optimal subsidy is

$$\sigma^{III}(\theta) = \frac{1-4(S_B^o - S_G^o) - \sqrt{(1-4(S_B^o - S_G^o))}}{2} = \frac{k+2(\theta-\mu_G)^2-2k(\theta-\mu_B)^2}{2k} - \frac{1}{2}\sqrt{\frac{k+2(\theta-\mu_G)^2-2k(\theta-\mu_B)^2}{k}}$$

which is negative, strictly increasing in θ but only relevant when $\frac{2}{9} \leq S_B^o - S_G^o \leq \frac{1}{4}$, *i.e.*, when $\theta \in [\theta_3^o, \theta_2^o]$ (we refer the reader to Appendix A.3 for the actual expression of θ_3^o). Figure 3 represents optimal subsidies/taxes within each region when $k = 1.5$, $\mu_B = 0.1$ and $\mu_G = 0.05$.²⁵

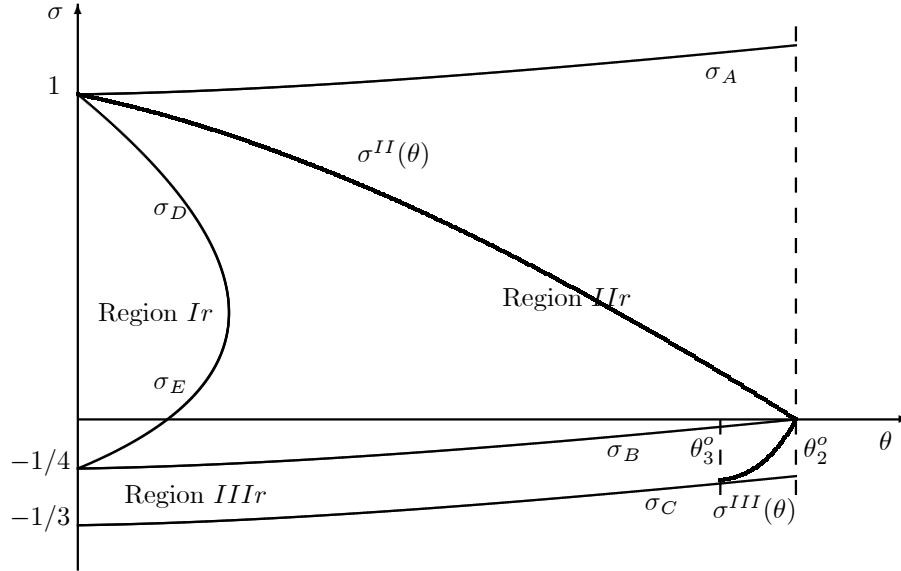


Figure 3: Optimal subsidies/taxes

The proposition that follows summarizes our results so far.

Proposition 5 (a) *No optimal subsidy exists such that the policy maker can induce all consumers to buy the green good;* (b) *The policy maker can induce the socially optimal sorting of consumers by setting either the discriminatory subsidy $\sigma^{II}(\theta)$ or the discriminatory tax $\sigma^{III}(\theta)$ for the consumption of the green good.*

Notice that the optimal subsidy in Region *IIr* is decreasing in consumer valuation for intrinsic quality θ . This result has important policy implications. Indeed, θ can be interpreted as a proxy for the marginal utility of income (see Tirole, 1988), where a high θ may signal a high income. Therefore, our findings suggest that the optimal subsidy should primarily benefit low-income consumers and progressively diminish

²⁵For ease of graphical representation, the scale along the y axis changes according to whether σ is positive or negative. Also notice that we do not explicitly represent the unit interval $[\bar{\theta} - 1, \bar{\theta}]$, but one could assume that $\bar{\theta} = \theta_2^o = 1.43$, so that $\theta_1^o = 0.32 < \bar{\theta} - 1 = 0.43$. As a result, Region *Ir* would shrink whereas Region *IIIr* would be relevant from $\theta_3^o = 1.36$ to $\bar{\theta} = 1.43$.

for high earners. There is indeed evidence of governmental programs targeting low- and moderate-income households to provide incentives for renewable energy adoption, energy efficiency upgrades, and other aspects of the green transition. For instance, in the US, the Low-Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP) provide financial assistance to low-income households to make their homes more energy-efficient.²⁶ Additionally, programs such as My Green Home Program in South Africa and Home Energy Scotland offer subsidies to low-income households to make energy-efficient improvements to their homes.²⁷ In terms of incentives promoting the adoption of EVs, programs such as the California Clean Vehicle Assistance Program (CVAP) or the Massachusetts MOR-EV Program specifically target low- and moderate-income individuals with additional financial incentives, rebates, or discounts on EVs purchases.²⁸ Our results suggest that these programs are moving in the right direction towards favoring the green transition and should be further encouraged.

Our results also caution against the widespread use of price-based subsidies, which might be far from being optimal. For example, incentives for purchasing full-electric vehicles in most European countries are decreasing in the gross sales price of the car, with a cap ranging between 44 and 65 thousand euros.²⁹ In Appendix A.3, we show that the price $p_G^r(\theta)$ charged by the green firm at the regulated equilibrium is non-monotonic in the valuation for intrinsic quality. This indicates that current government subsidies that decrease with the price of the green good violate our prescriptions when such price is decreasing in θ . This is because the resulting subsidy would be indirectly increasing in θ whereas our optimal subsidy should be decreasing in θ .

Finally, observe that in Region *IIIr*, a tax rather than a subsidy has to be levied on the purchase of the green good. This is rather striking and it occurs because, while negative selection always emerges at the social optimum, there is positive selection at the regulated market equilibrium. Consequently, in this region, the market share of the green firm is excessively high relative to the optimal one, necessitating a tax to decrease green consumption and to induce consumers with relatively limited environmental concern to patronize the brown rather than the green firm. Such a policy intervention would however be highly controversial for two reasons: (i) the efficiency loss caused by the “quality mismatch” (namely, consumers with high θ and low γ should buy the products with higher intrinsic quality provided by the brown firm) would offset the efficiency gain stemming from the reduction in pollution when consuming the green instead of the brown variety; (ii) consumers with the same WTP for hedonic quality might be subject to two opposite policy instruments, potentially jeopardizing the effective implementation of the policy.

²⁶See <https://www.acf.hhs.gov/ocs/programs/liheap> and <https://www.energy.gov/scep/wap/weatherization-assistance-program>, respectively.

²⁷See <http://mygreenhome.org.za/about-us/> and <https://www.homeenergyscotland.org/>, respectively.

²⁸See <https://cleanvehiclegrants.org/> and <https://mor-ev.org/>, respectively.

²⁹For more information, see <https://www.acea.auto/fact/electric-cars-tax-benefits-purchase-incentives-2023/>

Whenever the policy maker faces the choice between the optimal subsidy or the optimal tax on green consumption, the resulting sorting of consumers is always socially optimal. What changes is the way in which surplus is shared between firms and consumers. It can be shown that the brown firm and its clientele are indifferent between $\sigma^{II}(\theta)$ and $\sigma^{III}(\theta)$, as is the clientele of the green firm. The only difference is that the green firm is better off (and the policy maker worse off) with a subsidy rather than a tax on green consumption. This could represent another factor in favor of the adoption of a subsidy, as such policies are typically designed to promote the green transition, rather than to collect tax revenues.

5 Concluding remarks

We have analyzed competition between a green and a brown firm along two different dimensions: hedonic and environmental quality. We have considered a scenario in which green products are costlier to produce than brown products, and consumers are heterogeneous in their WTP for intrinsic quality and their environmental consciousness. A crucial element of our model is the presence of a green network effect, wherein the market share of the green firm positively affects consumers' utility when buying green. This captures the idea that environmentally concerned consumers derive additional satisfaction from their purchasing behavior in proportion to how many other consumers also choose the green good. Thus, our methodological approach departs from the standard warm-glow motivation for buying green, which is based on the self-gratification individuals feel when they make environmentally friendly choices. Indeed, we have developed a theoretical framework that integrates collective choices into the analysis of competition between green and brown firms. Moreover, we have explored the policy tools that governments can adopt to encourage optimal consumption of the green good within this framework.

In the first part of the paper, we have characterized how consumers sort between the green and the brown firm at the market equilibrium, finding regions in which either positive or negative selection for either firm occur. This crucially depends on the relative weight of the valuation for intrinsic quality *vis-à-vis* environmental consciousness. We have then examined price and profits at equilibrium, revealing that there exists situations in which the green firm can charge a higher price and earn higher profits than the brown rival, notwithstanding its cost disadvantage. This is more likely to occur when consumer WTP for hedonic quality is relatively low.

In the second part, we have examined the environmental impact of the market equilibrium by taking into account the negative externalities related to both the consumption and the production of the good, which neither firms nor consumers internalize. At the aggregate level, the emission differential between the two firms can take either sign, and there are circumstances in which the green firm ends up polluting more than the brown firm. This occurs when the green firm dominates in terms of market share, due to the green network effect. However, as our model does not allow for market expansion, a shift in demand

from the brown to the green good always diminishes total pollution.

In the third part of the paper, we have considered social welfare and demonstrated the presence of excessive quality differentiation at the market equilibrium. We then examined which policy interventions would restore efficiency. Interestingly, we have shown that a combination of an emission tax and a discriminatory subsidy for green consumption would achieve this goal. Specifically, the emission tax should be equal to a Pigouvian tax corresponding to the marginal social cost of pollution, while the subsidy should decrease in consumer WTP for hedonic quality, or in other words, with consumer income.

The analysis that we have carried out relies on some simplifying assumptions, such as firms being able to fully observe consumer valuation for hedonic quality, and consumers being able to exactly assess the intensity of the network effect. On the one hand, data collection and analytics about consumer behavior have lately made great strides, as we also indicated in the introduction, rendering consumer profiling and personalized pricing more and more a reality, at least in terms of the hedonic quality. On the other side, consumers are increasingly informed not only about the consequences of their actions on the environment but also on the consumption behavior of others, thanks to the rise of social media, online reviews, blogs, online forums, and the proliferation of specialized digital channels.

Notwithstanding the possible limitations, our methodological approach has enabled us to investigate a relevant issue from a different perspective. Indeed, whereas the traditional theoretical literature replaces the vertical quality attribute with environmental friendliness, we have taken a step forward by considering products that embed both a hedonic and an environmental attribute, and have incorporated the importance of collective choices. Taken with the necessary caution, our results provide useful guidance for better directing the green transition supported by many important initiatives, such as the EU Green Deal. In particular, our policy prescription advocates for the adoption of income-based subsidies while advising against price-based subsidies.

A Appendix

A.1 Firms' reaction functions

Let us first derive the reaction function of firm G , namely $U_G(U_B)$. The program of firm G is given by (P_i) , with $i = G$. The associated first-order condition, simplifying and omitting the dependence of indirect utilities on θ , is

$$2S_G + 4U_B - 1 - 6U_G - \sqrt{1 - 4(U_B - U_G)} = 0, \quad (29)$$

which implicitly defines the reaction function of firm G . Notice that the quantity under square root is non-negative. This follows from constraint (ii) in Condition 1 in the main text, which requires that $U_B - U_G \leq \frac{1}{4}$.

It follows that a necessary condition for equation (29) to hold is $2S_G^* + 4U_B - 1 - 6U_G \geq 0$, or equivalently that

$$U_G \leq \frac{2S_G^* + 4U_B - 1}{6} \equiv U_G^0(U_B).$$

Solving (29) for U_G as a function of U_B yields

$$U_G^-(U_B) = \frac{6U_B + 3S_G^* - 1 - \sqrt{3S_G^* - 3U_B + 1}}{9} \quad \text{and} \quad U_G^+(U_B) = \frac{6U_B + 3S_G^* - 1 + \sqrt{3S_G^* - 3U_B + 1}}{9},$$

whose determinants are strictly positive for $U_B < \frac{1}{3} + S_G^*$. Observe that the second solution, $U_G^+(U_B)$, can be discarded because it does not satisfy the necessary condition, as $U_G^+(U_B) > U_G^0(U_B)$, whereas the first solution satisfies $U_G^-(U_B) < U_G^0(U_B)$.

The above expression is useful when considering possible corner solutions. For instance, when $U_B = 0$, $U_G^-(U_B)$ simplifies as

$$U_G^-(0) = \frac{3S_G^* - 1 - \sqrt{1 + 3S_G^*}}{9},$$

with $U_G^-(0) < S_G^*$ 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 with program (P_i) , with $i = B$, one can derive the reaction function of firm B , which is defined implicitly (again omitting the dependence of indirect utilities on θ) by

$$1 + 4U_G - 6U_B + 2S_B^* - \sqrt{1 - 4(U_B - U_G)} = 0. \quad (30)$$

Since the quantity under square root is non-negative under requirement (ii) in Condition 1, the necessary condition for the above equation to be satisfied, namely $1 + 4U_G - 6U_B + 2S_B^* > 0$, is always met.

Solving (30) for U_B as a function of U_G yields

$$U_B^-(U_G) = \frac{6U_G + 3S_B^* + 1 - \sqrt{1 + 3U_G - 3S_B^*}}{9} \quad \text{and} \quad U_B^+(U_G) = \frac{6U_G + 3S_B^* + 1 + \sqrt{1 + 3U_G - 3S_B^*}}{9},$$

corresponding to expressions (RF_B) in the main text, whose determinants are strictly positive for $U_G > S_B^* - \frac{1}{3}$. Moreover, the second solution $U_B^+(U_G)$ is such that $U_B^+(U_G) \leq S_B^*$ if and only if $U_G \leq S_B^* - \frac{1}{4}$. When $U_G = S_G^*$, we obtain

$$U_B^-(S_G^*) = \frac{6S_G^* + 3S_B^* + 1 - \sqrt{1 - 3(S_B^* - S_G^*)}}{9} \quad \text{and} \quad U_B^+(S_G^*) = \frac{6S_G^* + 3S_B^* + 1 + \sqrt{1 - 3(S_B^* - S_G^*)}}{9} ,$$

whose determinants is non-negative for $\theta \leq \sqrt{\frac{2k}{3(k-1)}} = \theta^{III}$. Moreover, $S_G^* < U_B^-(S_G^*) < S_B^*$ always holds, whereas $U_B^+(S_G^*) < S_B^*$ is satisfied if and only if $\theta > \sqrt{\frac{k}{2(k-1)}} = \theta^{II}$. Hence, the second solution $U_B^+(S_G^*)$ is relevant for $\theta^{II} < \theta \leq \theta^{III}$.

A.2 Price schedules and profits

Equilibrium prices can easily be recovered from (3) by substituting for optimal qualities, given by $q_i^*(\theta) = \frac{\theta}{k_i}$, and for optimal indirect utilities, which vary according to the relevant region. Recall that we use superscript $R = I, II, III$ to distinguish between the different regions, and subscript $i = B, G$ to indicate the two different firms.

Let us start from Region I , *i.e.* from $\theta \in [\bar{\theta} - 1, \theta^I]$, where the corner solution (14) applies. We obtain

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

with $p_G^I > p_B^I$, meaning that a price premium for the green firm is always in place in Region I . In Region II , *i.e.* when $\theta \in (\theta^I, \theta^{II}]$, equilibrium prices are given by

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

It is immediate to check that $p_G^{II} > p_B^{II}$ if and only if $\theta < \sqrt{\frac{2k}{9(k-1)}} = \tilde{\theta}$, with $\theta^I < \tilde{\theta} < \theta^{II}$, thus confirming the results of Proposition 3 in terms of the price difference. Finally, in Region III , equilibrium prices are given by

$$p_B^{III} = \frac{1}{9} \left(\frac{9\theta^2 - 2k + 15(k-1)\theta^2}{2k} - \sqrt{\frac{2k - 3\theta^2(k-1)}{2k}} \right) \quad \text{and} \quad p_G^{III} = \frac{\theta^2}{2k} ,$$

where $p_B^{III} > p_G^{III}$ always holds.

In Figure A, we set $k = 1.5$, $\bar{\theta} = 1.3$ and plot the prices in the three regions.

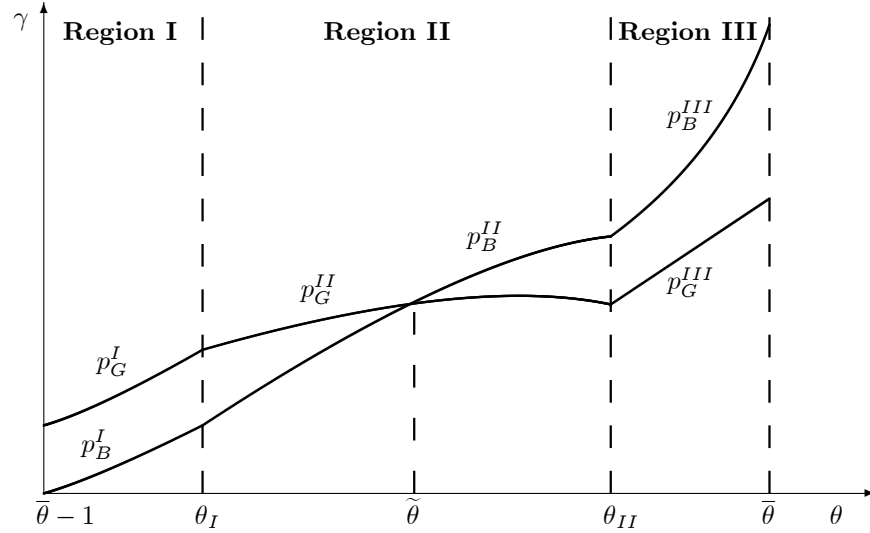


Figure A: Price difference in the three regions

Next, let's 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

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

and

$$\Pi_G^I = \frac{1}{3} \left(\frac{2(3\theta^2+k) + \sqrt{2k(3\theta^2+2k)}}{18k} \right) \left(1 + \sqrt{\frac{2k+3\theta^2}{2k}} \right)$$

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

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

and

$$\Pi_G^{II} = \left(\frac{k-2\theta^2(k-1) + \sqrt{5k(k-2\theta^2(k-1))}}{10k} \right) \left(\frac{5k + \sqrt{5k(k-2\theta^2(k-1))}}{10k} \right)$$

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

Finally, in Region III we have

$$\Pi_B^{III} = \frac{1}{3} \left(\frac{6(k-1)\theta^2 - 2k - \sqrt{2k(2k-3(k-1)\theta^2)}}{18k} \right) \left(1 + \sqrt{\frac{2k-3(k-1)\theta^2}{2k}} \right)$$

and $\Pi_G^{III} = 0$ and $\Pi_B^{III} > \Pi_G^{III}$ always holds in this interval.

In Figure B, we set again $k = 1.5$, $\bar{\theta} = 1.3$ and plot the profits in the three regions.

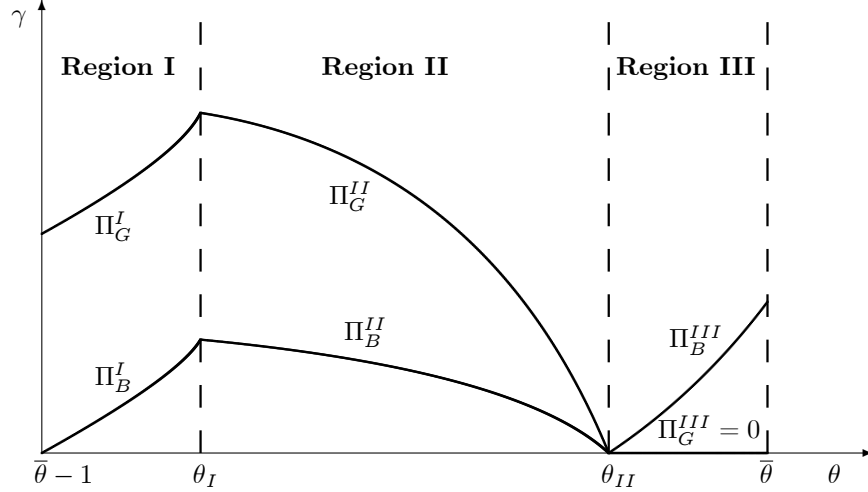


Figure B: Profit difference in the three regions

A.3 Optimal subsidy

The program of firm G is given by (28) with $i = G$ and its associated first-order condition, simplifying and omitting the dependence of indirect utilities on θ , is

$$2S_G^o - 4\sigma - 6U_G + 4U_B - 1 - \sqrt{1 - 4(U_B - U_G - \sigma)} = 0, \quad (31)$$

which defines implicitly the reaction function of firm G . Given that the quantity under square root must be non-negative, the necessary condition for equation (31) to hold is that $2S_G^o - 4\sigma - 6U_G + 4U_B - 1 \geq 0$. Solving (31) for U_G as a function of U_B , and taking into account the necessary condition, yields

$$U_G(U_B) = \frac{3S_G^o - 6\sigma + 6U_B - 1 - \sqrt{1 - 3(U_B - S_G^o - \sigma)}}{9} \quad (32)$$

whose determinant is non-negative for $U_B \leq \frac{1}{3} + S_G^o + \sigma$. The above expression is useful when one wants to take into account possible corner solutions. For instance, when $U_B = 0 = U_B^{Ir}$, expression (32) simplifies as

$$U_G(0) = \frac{3S_G^o - 6\sigma - 1 - \sqrt{1 + 3(S_G^o + \sigma)}}{9} \equiv U_G^{Ir},$$

with $U_G^{Ir} + \sigma < U_B^{Ir} = 0$ if and only if $\sigma < 1 - S_G^o$.

Secondly, let us consider firm B . From the first-order condition associated to program (28) with $i = B$, one can obtain the reaction function of firm B , which is defined implicitly, omitting once more the dependence of indirect utilities on θ , as follows:

$$1 + 4U_G + 4\sigma - 6U_B + 2S_B^o - \sqrt{1 - 4(U_B - U_G - \sigma)} = 0. \quad (33)$$

Solving (33) for U_B as a function of U_G yields

$$U_B^-(U_G) = \frac{6(U_G+\sigma)+3S_B^o+1-\sqrt{1+3(U_G+\sigma)-3S_B^o}}{9} \quad \text{and} \quad U_B^+(U_G) = \frac{6(U_G+\sigma)+3S_B^o+1+\sqrt{1+3(U_G+\sigma)-3S_B^o}}{9}.$$

When $U_G = S_G^o \equiv U_G^{IIIr}$, the above solution specializes as

$$U_B(S_G^o) = \frac{6(S_G^o+\sigma)+3S_B^o+1+\sqrt{1-3(S_B^o-S_G^o-\sigma)}}{9} \equiv U_B^{IIIr},$$

whose determinant is non-negative for

$$\sigma \geq (S_B^o - S_G^o) - \frac{1}{3} \equiv \sigma_C.$$

Finally, simultaneously solving (31) and (33) for U_B and U_G yields the interior solution, which is such that

$$U_B^{IIr} = \frac{6S_B^o+4(S_G^o+\sigma)+1-\sqrt{5(1-4(S_B^o-S_G^o-\sigma))}}{10} \quad \text{and} \quad U_G^{IIr} = \frac{4S_B^o-4\sigma+6S_G^o-1-\sqrt{5(1-4(S_B^o-S_G^o-\sigma))}}{10}, \quad (34)$$

where the determinant is non-negative for

$$\sigma \geq (S_B^o - S_G^o) - \frac{1}{4} \equiv \sigma_B,$$

and where $U_B^{IIr} > U_G^{IIr} + \sigma$ if and only if

$$\sigma < (S_B^o - S_G^o) + 1 \equiv \sigma_A.$$

The solution in (34) is always such that $U_B^{IIr} > 0$ provided that $S_B^o > \frac{1}{8}$, whereas for $S_B^o \leq \frac{1}{8}$ we have $U_B^{IIr} > 0$ if and only if

$$\sigma < \frac{3-8S_G^o-12S_B^o-5\sqrt{1-8S_B^o}}{8} \equiv \sigma_E \quad \text{and} \quad \sigma > \frac{3-8S_G^o-12S_B^o+5\sqrt{1-8S_B^o}}{8} \equiv \sigma_D.$$

Summing up, when $S_B^o \leq \frac{1}{8}$ and $\sigma_E \leq \sigma \leq \sigma_D$ we have a corner solution such that $U_B^{Ir} = 0$. When $S_B^o \leq \frac{1}{8}$ and $\sigma < \sigma_E$ or $\sigma > \sigma_D$, or when $S_B^o > \frac{1}{8}$ and $\sigma_B \leq \sigma < \sigma_A$, then the interior solution holds.³⁰ Finally, when $\sigma_C \leq \sigma < \sigma_B$, we have a corner solution such that $U_G^{IIIr} = S_G^o$.

Substituting equilibrium indirect utilities U_i^{Rr} for $R = I, II, III$ and $i = G, B$ into expression (27), we can obtain the indifferent consumer at the regulated market equilibrium in the different regions:

$$\hat{\gamma}^I(\sigma, \theta) = \frac{1}{3} (2 - \sqrt{1 + 3(S_G^o + \sigma)}) = \frac{1}{3} \left(2 - \sqrt{\frac{2k(1+3\sigma)+3(\theta-\mu_G)^2}{2k}} \right),$$

which is valid for $S_B^o \leq \frac{1}{8}$ and $\sigma_E \leq \sigma \leq \sigma_D$; or

$$\hat{\gamma}^{II}(\sigma, \theta) = \frac{1}{2} \left(1 - \sqrt{\frac{1-4(S_B^o-S_G^o-\sigma)}{5}} \right) = \frac{1}{2} \left(1 - \sqrt{\frac{k(1+4\sigma)-2k(\theta-\mu_B)^2+2(\theta-\mu_G)^2}{5k}} \right),$$

³⁰Notice that $S_B^o = \frac{(\theta-\mu_B)^2}{2} > \frac{1}{8}$ if and only if $\theta > \frac{1}{2} + \mu_B$.

which attains for $\sigma_B \leq \sigma < \sigma_A$; and finally

$$\hat{\gamma}^{III}(\sigma, \theta) = \frac{1}{3} (1 + \sqrt{1 - 3(S_B^o - S_G^o - \sigma)}) = \frac{1}{3} \left(1 + \sqrt{\frac{2k(1+3\sigma) - 3k(\theta - \mu_B)^2 + 3(\theta - \mu_G)^2}{2k}} \right),$$

which holds for $\sigma_C \leq \sigma < \sigma_B$. Continuity in $\hat{\gamma}(\sigma, \theta)$ is guaranteed across all regions.

The optimal subsidy equates the indifferent consumer at the social planner solution with the indifferent consumer at the regulated market equilibrium. Therefore, one has to check for which values of the subsidy σ it holds that $\hat{\gamma}^o(\theta) = \hat{\gamma}^R(\sigma, \theta)$. In order to have a common framework in which to analyze both solutions, let us proceed in the following manner. Recall that $\hat{\gamma}^o(\theta) = 0$ whenever $S_B^o - S_G^o \leq 0$, which in turn is equivalent to consumers' WTP being such that $\theta \leq \theta_1^o$. Now, denote $\sigma_F \equiv S_B^o - S_G^o$, whereby condition $\theta \leq \theta_1^o$ can be equivalently stated as $\sigma_F \leq 0$; conversely, $\hat{\gamma}^o(\theta) > 0$ holds for $\theta > \theta_1^o$ or else for $\sigma_F > 0$. Similarly, $\hat{\gamma}^o(\theta)$ is real-valued for $1 - 4(S_B^o - S_G^o) \geq 0$, which is equivalent to consumers' WTP being such that $\theta \leq \theta_2^o$. Given that $\sigma_B = (S_B^o - S_G^o) - \frac{1}{4}$, we can rewrite condition $\theta \leq \theta_2^o$ as $\sigma_B \leq 0$.

Next, $\hat{\gamma}^I(\sigma, \theta) = \hat{\gamma}^o(\theta) = 0$ for $\sigma = 1 - S_G^o$, but this solution falls outside the relevant parameter range and therefore cannot be considered. Additionally, $\hat{\gamma}^I(\sigma, \theta) = \hat{\gamma}^o(\theta) > 0$ if and only if

$$\sigma^I(\theta) = \frac{1 + 4S_G^o - 6S_B^o + \sqrt{1 - 4(S_B^o - S_G^o)}}{2};$$

however, this solution is inadmissible as well, as it lies outside the relevant parameter region.

Moreover, $\hat{\gamma}^{II}(\sigma, \theta) = \hat{\gamma}^o(\theta) = 0$ if and only if $\sigma = \sigma_A$ but this solution can be discarded because it coincides with the boundary for the existence of $\hat{\gamma}^{II}(\sigma, \theta)$. Conversely, $\hat{\gamma}^{II}(\sigma, \theta) = \hat{\gamma}^o(\theta) > 0$ if and only if

$$\sigma^{II}(\theta) = 1 - 4(S_B^o - S_G^o),$$

where $\sigma^{II}(\theta)$ is such that $\sigma_B \leq \sigma^{II}(\theta) \leq \sigma_A$.

Finally, $\hat{\gamma}^{III}(\sigma, \theta) = 0$ is never the case; however, $\hat{\gamma}^{III}(\sigma, \theta) = \hat{\gamma}^o(\theta) > 0$ if and only if

$$\sigma^{III}(\theta) = \frac{1 - 4(S_B^o - S_G^o) - \sqrt{(1 - 4(S_B^o - S_G^o))}}{2}$$

which belongs to the relevant region and is such that, when inserted into $\hat{\gamma}^{IIIr}(\sigma, \theta)$, it delivers the desired solution $\hat{\gamma}^o(\theta)$ provided that $\frac{2}{9} \leq S_B^o - S_G^o \leq \frac{1}{4}$. So, $\sigma^{III}(\theta)$ is only relevant when $S_B^o - S_G^o \leq \frac{1}{4}$, which corresponds to $\theta \leq \theta_2^o$, and when $S_B^o - S_G^o \geq \frac{2}{9}$, which is equivalent to

$$\theta > \frac{3(k\mu_B - \mu_G) + \sqrt{k(4(k-1) + 9(\mu_B - \mu_G)^2)}}{3(k-1)} = \theta_3^o.$$

Notice that $\sigma^{III}(\theta)$ is always negative and strictly increasing in θ in the range $\frac{2}{9} \leq S_B^o - S_G^o \leq \frac{1}{4}$.

Therefore, there exists values of θ , namely $\theta \in (\theta_3^o, \theta_2^o]$, for which the government has two different options: it can choose $\sigma^{II}(\theta) > 0$, in such a way that the regulated equilibrium falls within Region *IIr*, or it can choose $\sigma^{III}(\theta) < 0$, in which case the regulated equilibrium falls within Region *IIIr*.

To conclude, let us compute utilities, prices and profit margins at the regulated market equilibrium, focusing attention on Region IIr . Indirect utilities are such that

$$U_B^{IIr}(\theta) = \frac{k(1-(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{2k} - \frac{1}{2}\sqrt{\frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{k}}$$

and

$$U_G^{IIr}(\theta) = \frac{-k(1-2(\theta-\mu_B)^2)-(\theta-\mu_G)^2}{2k} - \frac{1}{2}\sqrt{\frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{k}};$$

profit margins are such that $\pi_i^{Rr} = S_i^o - U_i^{Rr}$, therefore

$$\pi_B^{IIr} = \frac{-k(1-2(\theta-\mu_B)^2)-2(\theta-\mu_G)^2}{2k} + \frac{1}{2}\sqrt{\frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{k}}$$

and

$$\pi_G^{IIr} = \frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{2k} + \frac{1}{2}\sqrt{\frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{k}}.$$

Prices that firms set at the regulated market equilibrium are such that

$$p_i^{IIr}(\theta) = \theta q_i^o(\theta) - U_i^{IIr}(\theta),$$

whereby

$$p_G^{IIr}(\theta) = \frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2+(\theta-\mu_G)(\theta+\mu_G)}{2k} + \frac{1}{2}\sqrt{\frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{k}}$$

and

$$p_B^{IIr}(\theta) = \frac{k(\theta-\mu_B)(\theta+\mu_B)-k(1-2(\theta-\mu_B)^2)-2(\theta-\mu_G)^2}{2k} + \frac{1}{2}\sqrt{\frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{k}}.$$

In Region IIr , the price set by the green firm exhibits a non-monotonic relationship with θ . Specifically, $p_G^{IIr}(\theta)$ increases with θ for sufficiently low values of k , while it decreases with θ for sufficiently high k .

Consumers who choose the green firm ultimately pay $p_G^{Rr}(\theta) - \sigma^R(\theta)$, where

$$p_G^{IIr}(\theta) - \sigma^{II}(\theta) = \frac{(\theta-\mu_G)(\theta+\mu_G)-k(1-2(\theta-\mu_B)^2)-2(\theta-\mu_G)^2}{2k} + \frac{1}{2}\sqrt{\frac{k(1-2(\theta-\mu_B)^2)+2(\theta-\mu_G)^2}{k}}.$$

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