WORKING PAPERS

N° 1513

February 2024

"Environmental policies with green network effect and price discrimination"

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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 in both their willingness to pay for intrinsic quality and 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 both from consumption and production, we compute total welfare and evaluate the impact of an emission tax and 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 restores the optimal sorting of consumers.

JEL classification: D21, L13, H21, Q51, Q58.

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

*We are grateful to Marie Gautier, Giovanni Maccarrone, Martin Obradovits, Gonzalo Olcina, Tommaso Rughi, Luca Sandrini, Lennard Sund, and to the audiences at the EARIE Conference 2023 (LUISS University, Rome), EAERE 2022 (University of Bologna, Rimini), IAERE 2022 (University of Cagliari), Asset Meeting 2022 (University of Rethymno, Crete), Oligo Workshop 2022 (University of Cyprus, Nicosia), and SIE Meeting 2022 (University of Turin). Finally, we thank Lucy Scioscia for professional editing. The usual disclaimer applies.

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1 Introduction

Over the past years, the degree of consumer environmental concern has substantially increased around the globe. According to the 2023 Eurobarometer survey, more than three quarters (77%) of all respondents view climate change as a very serious problem, and more than a half (56%) believe that the European Union and national governments (56%) should be held responsible for tackling climate change. Moreover, 58% of respondents think that the transition to a green economy should be sped up.[1] A survey by the Pew Research Center in 2020 found that, compared with a decade ago, more US citizens claim protecting the environment is a top priority.[2] Additionally, a follow-up survey conducted by the same think tank in 2023 revealed that three-quarters of Americans endorse a US role in global efforts to combat climate change.[3] This is accompanied by a desire for the US to take proactive steps toward achieving carbon neutrality by 2050.[4]

Some recent events have not only strengthened consumer environmental awareness, but have also helped citizens realize that environmental issues have a global nature and that coordinated actions are needed to reduce pollution. During the lockdown caused by the Covid pandemic, the notable reduction in pollution allowed many citizens to experience first-hand an increase in the quality of urban air and water.[5] The energy crisis that followed Russia's invasion of Ukraine triggered a shift towards green electricity production as a means of reducing the dependence on Russian natural gas but also of contributing to climate change mitigation. Since then, the European Commission has been encouraging the Member States to improve energy efficiency, *e.g.*, incentivizing citizens to insulate their homes, install solar panels or buy electric cars. Finally, the severe heat waves registered in the summer 2023 have further convinced people that climate change is real and that urgent remedies must be taken to contrast global warming.[6]

This growing environmental concern of consumers is accompanied with significant changes in governments' actions and firms' strategies across the globe. Governments are adopting different policies to promote the use of eco-friendly and energy-efficient products. Firms from diverse industries are developing

[1] https://europa.eu/eurobarometer/surveys/detail/2954

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

[3] https://www.pewresearch.org/science/wp-content/uploads/sites/16/2022/02/PS_2022.03.01_carbon-neutral-2050_REPORT.pdf

[4] Recent contributions show that environmental consciousness significantly increased in China. See the recent book by Zhong and Shi (2020, especially Chapters 6 and 7) and the 2018 report by Tsingyan Research: https://chinadevelopmentbrief.cn/reports/report-shows-beijing-publics-environmental-awareness-and-satisfaction-are-growing/

[5] He *at al.* (2020) and Dang and Trinh (2021), *inter alios*, provide evidence of improved air quality following COVID-19 restrictions. Moreover, the study conducted in China by Kahn *et al.* (2020) shows that citizen environmental concern increased during the first wave of coronavirus.

[6] See Hyde and Albarracín (2023).

and launching products characterized by a significant reduction of their pollution emissions. Increasing attention is also given to the environmental costs associated to the production process. As reported by the aforementioned 2020 Eurobarometer survey, respondents considered that the most effective ways of tackling environmental problems are 'changing the way we consume' and 'changing the way we produce'.

Accordingly, in this paper we consider a duopoly in which one firm offers a standard good whereas its rival offers an environmentally friendly version of the same good, which is produced at a higher cost. This distinction categorizes firms (and their products) into *brown* and *green*, respectively. Moreover, each firm offers a range of quality-differentiated varieties of the good to attract consumers characterized by heterogeneous willingnesses 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 also incorporate environmental concerns in 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 aggregate 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. We assume that firms are able to collect detailed information about consumer WTP for quality but lack insight into consumer environmental consciousness.

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. A crucial role is played by consumer environmental concern, whose intensity determines which firm they patronize. Therefore, our modelling strategy differs from the mainstream literature (see, *e.g.*, Cremer and Thisse, 1999; Moraga-Gonzalez and Padron-Fumero, 2002; and Bansal and Gangopadhyay, 2003; among others) in that we take into account that a product is a bundle of attributes which are hedonic as well as environmental, and that firms compete along multiple quality dimensions. In particular, each firm offers a continuum of type-contingent qualities and price schedules, rather than a single quality and a single price. Moreover, in our model the ranking of qualities is endogenous and is not *a priori* determined.

At 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 equilibria: 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 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 restores the optimal sorting of consumers between the two firms. Our analysis reveals that such a subsidy exists when the market equilibrium features interior solutions, and it is strictly decreasing in consumer WTP for hedonic quality. Given that consumer WTP for 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 greater equity in the adoption of environmentally friendly practices. The increasing adoption of income-based subsidies for green consumption in real-world contexts aligns with our findings, confirming their relevance for guiding effective policy implementation. Programs such as My Green Home Program in South Africa[8] and Home Energy Scotland[9] offer subsidies and incentives to low-income households to make energy-efficient improvements to their homes.

However, there are many instances of subsidies which are inversely proportional to the price charged by the green firm. For example, incentives for purchasing all-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.[10] In our model, we find that prices charged by the green firm are non-monotonic in the valuation for intrinsic quality. This indicates that current government subsidies are not optimal when prices for green goods decrease with consumer WTP for quality, as in such case our policy prescription that the subsidy should be inversely related to consumer valuation for intrinsic quality is violated.

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 consider optimal fiscal policies. Section 5 concludes.

[7] See https://elbil.no/english/norwegian-ev-policy/

[8] http://mygreenhome.org.za/about-us/

[9] https://www.homeenergyscotland.org/

[10] For more information, we refer the reader to https://www.acea.auto/files/Electric_cars-Tax_benefits_ _purchase_incentives_2023.pdf

1.1 Related Literature

Our paper contributes to the stream of research on behavioral economics that investigates the pro-environmental behavior of consumers embedded in a social context with other consumers (Croson and Treich, 2014; Dasgupta *et al.*, 2016). There are many important papers considering how moral motivation and personal/social norms explain the recent surge of green consumerism (see *e.g.*, Stern, 1999; Clark *et al.,* 2002; Brekke *et al.*, 2003; Kaufman, 2014; Czajkowski *et al.*, 2014) and analyze the impact of environmentally friendly behavior on market equilibrium (Conrad, 2005; Eriksson, 2004; García-Gallego and Georgantzís, 2009; Moraga-Gonzalez and Padron-Fumero, 2002; Nyborg *et al.*, 2006; Rodriguez-Ibeas 2007). These contributions share the idea that environmental concern is driven by a "warm glow" motivation (Andreoni, 1989 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 consumers enjoy when buying the green variety of a good (see, among others, Ostrom, 2000; Carlsson *et al.*, and 2010; 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". As in Brécard (2013), we use the term *green network effect* to describe the fact that consumer satisfaction from buying the green variety is proportional to the market share of the green good.[11] Apart from Brécard (2013) and Grover and Bansal (2021), not much theoretical research has been carried out in this direction, even though recent studies acknowledge the importance of imitating the decisions of others.[12]

A large body of theoretical literature followed Cremer and Thisse (1999) using models of vertical differentiation to study the provision of environmental quality, under the assumption that the green good is of high quality and the brown good is of low quality (Moraga-Gonzales and Padron-Fumero, 2002; Lombardini-Riipinen, 2005; Deltas *et al.*, 2013; among others). In our paper, consumers value both the intrinsic performance of a good and its environmental footprint. They are heterogeneous in the valuations for these two product characteristics, which are independently distributed. As a consequence, whether the green good is of superior intrinsic quality is not *a priori* determined. This modelling framework is common to Burani and Mantovani (2021), that disregards the bandwagon effect and concentrates on the consequences of asymmetric information about consumer WTP for intrinsic quality on the market equilibrium. Our model is also close to Marini *et al.* (2022), where consumers are heterogeneous in their attitude towards the environment but homogeneous in their valuation for the intrinsic quality of a good.

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

[12] 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.

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).[13] Bansal and Gangopadhyay (2003) consider environmentally concerned consumers and compare uniform policies versus policies that discriminate firms depending on the environmental quality of their products. A similar issue is investigated by Bansal (2008), who uses a vertical differentiated model to examine the welfare implications of *ad valorem* taxes/subsidies and emissions taxes. These authors find that the optimal policy depends on various factors, including the magnitude of pollution emissions and their degree of environmental awareness.

Sartzetakis *et al.* (2012) consider information provision on environmental damages associated to consuming certain products as a policy instrument supplementing environmental taxation. Van der Made and Schoonbeek (2009) propose a campaign that increases 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 together with a subsidy or tax on green products, depending on the intensity of the network effect. 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.

We depart from most of the aforementioned literature not only because we consider environmental policies in the presence of a green network effect, but also because 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.

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

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

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

where $p_i(q)$ is the price set by firm i for quality q_i and $C_i(q_i)$ is the cost of providing one unit of the good with quality q_i.

Following Mussa and Rosen (1978), 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.[14] 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.[15] 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 quality θ is assumed to be continuous and uniformly distributed on the support $\left[\overline{\theta} - 1, \overline{\theta}\right]$, with $\overline{\theta} > 1$. The support of unit length is chosen for simplicity, and a sufficiently high upper bound $\overline{\theta}$ 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.

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

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

Consumer environmental consciousness γ is continuously and uniformly distributed in the interval $[0,1]$.[16,17] 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 from firm $i = B, G$, her utility is given by

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

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. 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 given 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.

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

[17] Given our assumptions about the distribution of consumer attributes, consumer preferences will depend on the relative weight of the valuation for intrinsic quality *vis-à-vis* environmental consciousness. 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 equation 2).

We further assume that consumer valuation θ is fully observable by each firm, while environmental consciousness γ is private information. This is consistent with the fact that consumers' WTP for intrinsic quality can be viewed as the inverse of their marginal utility of income. Hence, 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). An alternative framework in which consumer valuation θ is privately known and assumes only two values has been analyzed by Burani and Mantovani (2021). Conversely, firms' knowledge about consumers' environmental consciousness is much less precise.

Firms' strategic interaction

Take the consumers' decision to buy from one firm as given, and suppose that firms offer price schedules that are conditional on hedonic quality. In other words, consider non-linear price schedules $p_i(q_i)$ offered by each firm $i = B, G$. Given that a consumer of type θ, who buys one unit of the good, has preferences over quality-price pairs which are independent of γ, offering price schedule $p_i(q_i)$ is equivalent to offering menus of θ-contingent contracts consisting in a hedonic quality target and a price, *i.e.*, $\{q_i(\theta), p_i(\theta)\}_{i=B,G}$. Upon observing such contracts, each customer selects the preferred pair. We can thus treat the firms' problem as independent of the consumers' choice about which firm to patronize, which in turn is determined by their degree of environmental consciousness γ. In order to simplify the exposition, it is more convenient to reason in terms of consumers' indirect utility and to focus on quality-utility schedules of the form $\{q_i(\theta), U_i(\theta)\}_{i=B,G}$.

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

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

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

$$U_i(\theta) = \theta q_i(\theta) - p_i(q_i(\theta)). \tag{3}$$

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, a consumer of type (θ, γ) 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*

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

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

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

Similarly, the market share of the brown firm is

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

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

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

and then

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

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 $U_B(\theta) - U_G(\theta) \leq \frac{1}{4}$.[18]

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

$$p_i(\theta) = \theta q_i(\theta) - U_i(\theta), \tag{9}$$

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

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

[18] See Condition 1 at page 12.

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 programme of each firm $i = B, G$ consists then in maximizing its 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 programme

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

Notice that environmental concern γ does not appear in the above programme, because it is replaced by the fraction $M_i(\theta)$ of type θ consumers buying from firm $i = B, G$, which in turn depends on the difference between indirect utilities. Moreover, in firm i's programme, the utility offered to consumers by the other firm, *i.e.* $U_{-i}(\theta)$, is treated as given. Thus, firms compete against each other in the utility space. Notice that programme 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 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 which quality to purchase and which firm to patronize. An equilibrium of the game is such that each firm chooses a menu of contracts that maximizes its expected profit, given the contracts offered by the rival firm and given the equilibrium choices of consumers. Each consumer chooses the contract that maximizes her utility, including her environmental concern 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 in order to maximize P_i pointwise and it is then set at the level

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

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 firm i's objective function, there remains to maximize profits with respect to net utilities U_i. This delivers the reaction functions of the two firms, which describe the optimal utility left by firm $i = B, G$ to a θ-type consumer given the utility $U_{-i}(\theta)$ that the same consumer receives from the competing firm $-i$. For firm G, we have

$$U_G(U_B) = \frac{6U_B + 3S_G - 1 - \sqrt{3S_G - 3U_B + 1}}{9}, \qquad (RF_G)$$

where $S_G = \frac{\theta^2}{2k}$, whereas for firm B we obtain

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

with $S_B = \frac{\theta^2}{2}$. 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.[19] 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, indirect utilities $U_i(\theta)$, with $i = B, G$, must be such that: (i) $U_B(\theta) - U_G(\theta) > 0$; (ii) $U_B(\theta) - U_G(\theta) \leq \frac{1}{4}$; (iii) $\pi_i(\theta) \geq 0 \Leftrightarrow U_i(\theta) \leq S_i(\theta)$; (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 $\mathcal{U}_G(\theta) = U_G(\theta) + \gamma M_G(\theta)$.

[19] Further details are provided in Appendix A.1.

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 total surpluses S_B and S_G which in turn depend on θ.

Interior solution

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

$$U_B^{II} = \frac{1+6S_B+4S_G-\sqrt{5(1-4(S_B-S_G))}}{10} \quad \text{and} \quad U_G^{II} = \frac{4S_B+6S_G-1-\sqrt{5(1-4(S_B-S_G))}}{10} \ . \tag{12}$$

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

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

where $\theta^I < \theta^{II}$. It then follows that the solution given by (12) only holds for $\theta^I < \theta \leq \theta^{II}$, in which case we have $\max\left\{U_G^{II}, 0\right\} < U_B^{II}$. In other words, the interior solution realizes in the interval $\theta \in \left(\theta^I, \theta^{II}\right]$ 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

$$U_B^I = 0 \quad \text{and} \quad U_G^I = \frac{3S_G-1-\sqrt{1+3S_G}}{9} \ , \tag{13}$$

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 $\theta \in \left(\overline{\theta} - 1, \theta^I\right]$, provided that $\overline{\theta} - 1 < \theta^I$. When $\overline{\theta} < \theta^I + 1$, 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

$$U_B^{III} = \frac{6S_G+3S_B+1+\sqrt{1-3(S_B-S_G)}}{9} \quad \text{and} \quad U_G^{III} = S_G \ . \tag{14}$$

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 $\theta \in \left(\theta^{II}, \min\left\{\theta^{III}, \overline{\theta}\right\}\right]$. When $\overline{\theta} > \theta^{III}$ and $\theta \in \left(\theta^{III}, \overline{\theta}\right]$, a solution in pure strategies does not exist.

The following proposition summarizes the results obtained so far.

Proposition 1 ***Pure-strategy Nash equilibria*** *(i) In Region I, i.e., when* $\theta \in \left[\overline{\theta} - 1, \theta^I\right]$*, there is a corner solution such that* $U_B^I = 0$*; (ii) In Region II, i.e.,* $\theta \in \left(\theta^I, \theta^{II}\right]$*, there is an interior solution given by (12); (iii) In Region III, i.e., when* $\theta \in \left(\theta^{II}, \min\left\{\theta^{III}, \overline{\theta}\right\}\right]$*, 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.

Finally, 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 $\lim_{k \to 1} \theta^{II} = \lim_{k \to 1} \theta^{III} = \infty$ whereas $\lim_{k \to 2} \theta^{II} = \lim_{k \to 3} \theta^{III} = 1$. 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 $\overline{\theta} \geq \theta^I + 1$. Conversely, all three solutions are relevant when k is sufficiently high and $\overline{\theta}$ is small enough. The following assumption ensures that a Nash equilibrium in pure strategies always exists.

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

Under the above assumption, Region III is characterized by $\theta \in \left(\theta^{II}, \overline{\theta}\right]$.

3.3 Consumer self-selection

Given indirect utilities $U_i^R(\theta)$ set by each firm $i = B, G$ in each region $R = I, II, III$ at equilibrium, prospective consumers decide which firm to patronize according to their degree of environmental concern. This determines how consumers characterized by different valuations for hedonic quality 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 $\theta \in \left[\overline{\theta} - 1, \theta^I\right]$ indifferent between firm B and G. Such indifferent consumer is

$$\widehat{\gamma}^I(\theta) \equiv \quad \tfrac{1}{3}\left(2 - \sqrt{1 + 3S_G}\right) \quad = \tfrac{1}{3}\left(2 - \sqrt{\tfrac{2k+3\theta^2}{2k}}\right). \tag{15}$$

It is easy to check that $\widehat{\gamma}^I(\theta)$ 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

$$\widehat{\gamma}^{II}(\theta) \equiv \quad \tfrac{1}{2}\left(1 - \tfrac{\sqrt{5}}{5}\sqrt{1 - 4(S_B - S_G)}\right) \quad = \tfrac{1}{2}\left(1 - \sqrt{\tfrac{k-2\theta^2(k-1)}{5k}}\right) \quad . \tag{16}$$

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

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

$$\widehat{\gamma}^{III}(\theta) \equiv \quad \tfrac{1}{3}\left(1 + \sqrt{1 - 3(S_B - S_G)}\right) = \tfrac{1}{3}\left(1 + \sqrt{\tfrac{2k-3(k-1)\theta^2}{2k}}\right) \tag{17}$$

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

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

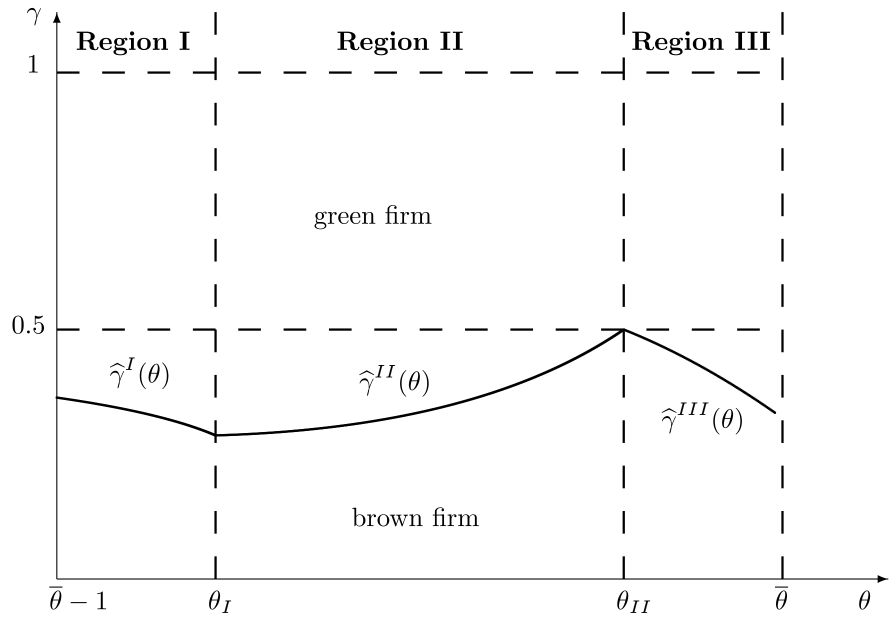

Figure 1: Consumer type space and consumer sorting

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 $\widehat{\gamma} = \frac{1}{2}\left(1 - \frac{\sqrt{5}}{5}\right)$ which is independent of θ, meaning that sorting of consumers into firms would be neutral.

Consumer sorting patterns can be then 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 $\theta \in \left[\overline{\theta} - 1, \theta^I\right]$, 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 $\theta \in \left(\theta^{II}, \overline{\theta}\right]$, 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. The opposite holds for intermediate values of θ, *i.e.* when $\theta \in \left(\theta^I, \theta^{II}\right]$.

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 a graphical representation.

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

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

with $\theta^I < \widetilde{\theta} < \theta^{II}$. Notice that $\widetilde{\theta}$ 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

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

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* $\theta \in \left[\overline{\theta} - 1, \widetilde{\theta}\right)$*, the green firm charges higher prices and enjoys higher profits relative to the brown rival;* (ii) *when* $\theta \in \left[\widetilde{\theta}, \theta^{II}\right]$*, the green firm charges lower prices but still enjoys higher profits relative to the brown rival;* (iii) *when* $\theta \in \left(\theta^{II}, \overline{\theta}\right]$*, 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".[20] 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.[21] A recent study

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

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

by Kroll shows that companies with better ESG ratings outperform companies with lower rankings.[22] 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 good, which neither firms nor consumers internalize.

In particular, let e_i^C denote the per-unit emissions related to the *consumption* of the good. Such emissions are assumed to be increasing in the hedonic quality of the good, in such a way that $e_i^C(\theta) = \phi_i q_i(\theta)$, 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 CO_2 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 good, 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 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.[23]

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

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

[22] Kroll 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

[23] Tarola and Zanaj (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.

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:

$$e_B(\theta) - e_G(\theta) = \frac{\theta(k\mu_B - \mu_G)}{k}, \tag{18}$$

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

$$E_i(\theta) = \int_\theta \left[e_i^C(\theta) + e_i^P(\theta)\right] M_i^R(\theta)\, d\theta = \int_\theta \mu_i q_i(\theta) M_i^R(\theta)\, d\theta, \tag{19}$$

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. Moreover, 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.[24]

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, as in Ambec and De Donder (2022), Heyes and Martin (2017) that in turn draw on Andreoni (2006) and Diamond (2006). We also assume that the marginal social damage of environmental pollution is equal to one. The expression for social welfare is therefore given by

$$\begin{aligned} W = \quad & W_B + W_G = \textstyle\int_\theta (S_B(\theta) - \mu_B q_B(\theta))\, M_B(\theta)\, d\theta \\ & + \textstyle\int_\theta (S_G(\theta) - \mu_G q_G(\theta))\, M_G(\theta)\, d\theta. \end{aligned} \tag{20}$$

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

[24] The algebraic calculations have been done using Mathematica and resorting to first-order Taylor approximations of market shares, when needed. They are available upon request.

market share of firm $i = G, B$ is given by $M_i(\theta)$ for each θ, the surplus $S_i(\theta)$ 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 $\widehat{\gamma}^R(\theta) = M_B^R(\theta)$, $R = I, .., III$, it becomes necessary to compute the above integrals separately for each region.

4.1 Social Planner

The social planner maximizes (20). Firstly, it chooses optimal qualities $q_i(\theta)$ to maximize total surplus pointwise net of the pollution externalities generated by production and consumption of both the brown and green good. The optimization problem for firm $i = B, G$:

$$\max_{q_i(\theta)} \left(\theta q_i(\theta) - \frac{1}{2} k_i q_i^2(\theta) - \mu_i q_i(\theta) \right),$$

whose solution yields the optimal qualities

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

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

$$q_B^o(\theta) - q_G^o(\theta) = \underbrace{\frac{(k-1)\theta}{k}}_{q_B^* - q_G^*} - \frac{k\mu_B - \mu_G}{k}, \tag{21}$$

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

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

Secondly, the social planner chooses market shares $M_i(\theta)$ for $i = B, G$. 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 consider prices set at marginal costs so that each firm's profit is equal to zero and total 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:

$$p_i(\theta) = \frac{1}{2} k_i q_i^2(\theta) + \mu_i q_i(\theta). \tag{22}$$

Given (22), the unit surplus for variety $i = G, B$ is given by

$$S_i^o(\theta) = U_i^o(\theta) = \theta q_i^o(\theta) - \frac{1}{2}k_i q_i^o(\theta)^2 - \mu_i q_i^o(\theta) = \frac{(\theta - \mu_i)^2}{2k_i}. \tag{23}$$

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

$$\widehat{\gamma}^o(\theta) \quad = \frac{1}{2}\left(1 - \sqrt{1 - 4\left(S_B^o - S_G^o\right)}\right) = \frac{1}{2}\left(1 - \sqrt{1 - \frac{2\left(k(\theta-\mu_B)^2 - (\theta-\mu_G)^2\right)}{k}}\right) = M_B^o(\theta) \ . \tag{24}$$

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

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

It's 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

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

with $\theta_2^o > \theta_1^o$. In summary, we can identify two distinct regions, denoted as $\mathcal{R} = 1, 2$. In Region 1, which holds when $\theta \in \left[\overline{\theta} - 1, \theta_1^o\right]$, we observe that $\widehat{\gamma}_1^o(\theta) = 0$. Conversely, in Region 2, which holds when $\theta \in \left(\theta_1^o, \min\left\{\theta_2^o, \overline{\theta}\right\}\right]$, $\widehat{\gamma}_2^o(\theta)$ is given by expression 24, with $\widehat{\gamma}_2^o(\theta_2^o) = \frac{1}{2}$.[25] Furthermore, within Region 2, $\widehat{\gamma}_2^o(\theta)$ exhibits strict monotonicity and convexity with respect to θ. It follows that the social planner induces a negative selection for the green firm, if any.

In Figure 2, we set $k = 1.5$, $\overline{\theta} = 1.3$, $\mu_B = 0.1$ and $\mu_G = 0.05$, in which case $\overline{\theta} < \theta_2^o$. We proceed to plot function $\widehat{\gamma}^o(\theta)$ in the two identified regions.

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 $\widehat{\gamma}^o(\theta)$ into expression (20), and integrating. Given that $W^o > W^*$, a natural question arises: which policy mix should the regulator adopt in order for the market equilibrium to converge to the first-best optimum? The literature has considered various instruments to address the multiplicity of market failures that are present in our framework. These include: an emission tax on the two goods, aimed at curbing environmental pollution from both consumption and production, an *ad valorem* tax on both goods, designed to reduce product differentiation, and a subsidy for the consumption of the green good, intended to enhance the green network effect.

[25] Notice 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 θ_1^o and θ_2^o belong to the unit interval $[\overline{\theta} - 1, \overline{\theta}]$.

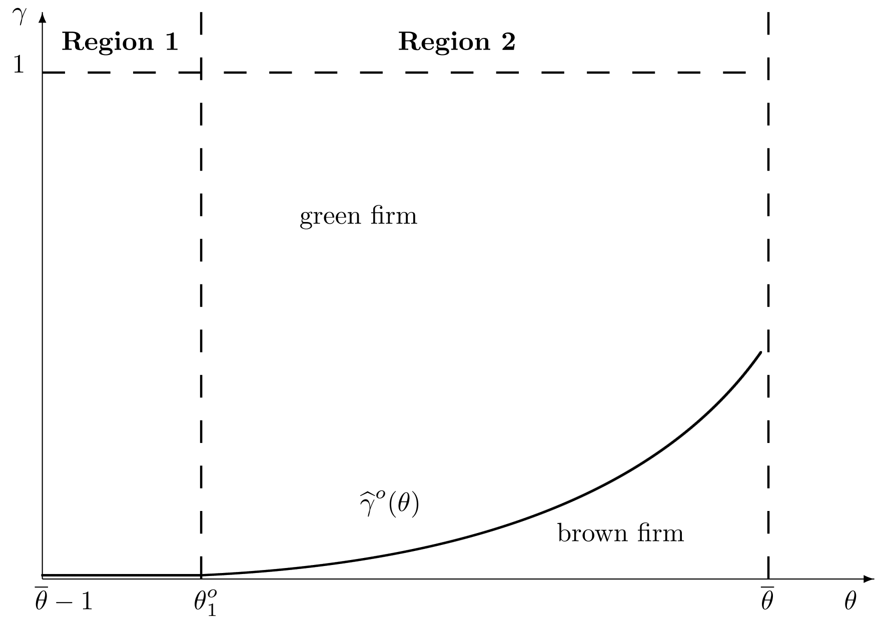

Figure 2: Consumer optimal sorting

4.2 Optimal Fiscal Policies

Abstracting from budget balancedness, let us consider an *ad valorem* tax $t_v\,[0,1]$ 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,

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

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

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

Following the methodology outlined in Section 3, firms firstly maximize PR_i pointwise and determine optimal qualities while incorporating taxes. These 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. Optimal qualities remain strictly positive provided that θ is sufficiently high. Moreover, they always fall below those at the 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: $q_B^r(\theta) - q_G^r(\theta) < q_B^*(\theta) - q_G^*(\theta)$, with $q_B^r(\theta) - q_G^r(\theta)$ decreasing with respect to τ_v and τ_e. Also observe that qualities remain unaffected by the introduction of a subsidy. Given that, it is possible to solve the system of equations $q_B^r(\theta) = q_B^o(\theta)$ and $q_G^r(\theta) = q_G^o(\theta)$ in order 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, meaning that this tax is not relevant in our context. This comes from the fact that firms can observe consumer WTP for intrinsic quality. Consequently, the excessive quality differentiation at the market equilibrium, relative to the solution of social planner, does not depend on imperfect competition but solely attributable to firms' failure to internalize the negative externalities associated with pollution. Hence, it is the emission tax $\tau_e^* = 1$ that aims to correct this kind of market failure. Indeed, τ_e^* equals the social marginal cost of the negative externality and functions akin to a Pigouvian tax.

Secondly, firms choose the utilities to be left to consumers. At this stage, firms take into account that the policy maker can resort to a subsidy σ for the purchase of the green good, in order to restore the socially optimal consumer sorting. When consumers buy from the green firm, they benefit from the subsidy as they end up paying $p_G - \sigma$ and enjoy total utility $U_G + \sigma$.[26] 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 such that

$$\widehat{\gamma}(\theta, \sigma) \equiv \frac{U_B(\theta) - U_G(\theta) - \sigma}{M_G}, \tag{25}$$

where $U_i(\theta)$ are still given by (3). Therefore, firms' market shares are

$$\begin{aligned} M_G(\theta, \sigma) = & \quad \frac{1}{2} + \frac{\sqrt{1 - 4(U_B(\theta) - U_G(\theta) - \sigma)}}{2}, \\ M_B(\theta, \sigma) = \widehat{\gamma}(\theta, \sigma) = & \quad \frac{1}{2} - \frac{\sqrt{1 - 4(U_B(\theta) - U_G(\theta) - \sigma)}}{2}. \end{aligned}$$

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

$$\max_{U_i(\theta)} \left(S_i^o(\theta) - U_i(\theta)\right) M_i(\theta, \sigma), \tag{26}$$

[26] Given 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.

where S_i^o is given by (23) 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 such that $U_B^r = 0$, an interior solution, and a corner solution such that $U_G^r = S_G^o$. Accordingly, there are three regions, that we label Region Ir, IIr and $IIIr$, corresponding to three different expressions for the indifferent consumer at the regulated market equilibrium, $\widehat{\gamma}^R(\sigma, \theta)$.[27]

Finally, let us analyze whether or not the subsidy induces consumers to sort in the socially optimal way. The optimal subsidy would make the indifferent consumer at the regulated market equilibrium $\widehat{\gamma}^R(\sigma, \theta)$, with $R = I, II, III$, converge to the socially optimal indifferent consumer, namely $\widehat{\gamma}^o_{\mathcal{R}}(\theta)$ with $\mathcal{R} = 1, 2$. In Appendix A.3, we show that no optimal subsidy exists in Regions Ir and $IIIr$, whereas in Region IIr, we have

$$\sigma^{II}(\theta) = 1 - 4\left(S_B^o - S_G^o\right) \quad = \tfrac{k + 2(\theta - \mu_G)^2 - 2k(\theta - \mu_B)^2}{k} \quad .$$

The proposition that follows summarizes our results so far.

Proposition 5 *The policy maker can induce the socially optimal sorting of consumers by setting a discriminatory subsidy* $\sigma^* = \sigma^{II}(\theta)$.

Importantly, notice that the optimal subsidy is decreasing in consumer valuation for intrinsic quality θ, which can be interpreted as a proxy for the marginal utility of income (see Tirole, 1988). In particular, a high θ may signal a high income. Therefore, the optimal subsidy should mostly favor low-income consumers and progressively fade away for high earners.

There is evidence of governmental programs which target low- and moderate-income households to provide incentives for renewable energy adoption, energy efficiency upgrades, and other aspects of the green transition. For instance, the Low-Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP) in the US provide financial assistance to low-income households to make their homes more energy-efficient. As for incentives promoting the adoption of electric vehicles, some 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 electric vehicle purchases. Our results suggest that these programs are heading in the right direction toward favoring the green transition and should be further encouraged.

Our results also warn against the widespread introduction of price-based subsidies (see the incentives for the purchase of full-electric vehicles in most EU countries), which might be far from being optimal. Indeed, in Appendix A.3, we show that the price charged by the green firm at the regulated equilibrium

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

is non-monotonic in consumer valuation θ. Therefore, a subsidy which is decreasing in the price of the green good is at odds with our prescriptions (namely, the subsidy should be decreasing in θ) when such price is decreasing in θ.

5 Concluding remarks

In this paper, we have analyzed competition between a green and a brown firm along two different dimensions, namely hedonic and environmental quality. We have assumed consumers are heterogeneous in their willingness to pay for intrinsic quality and their environmental consciousness. A crucial element of our model is the presence of a green network effect such that the market share of the green firm positively affects consumers' utility when buying green. This is meant to capture the idea that environmentally concerned consumers really want to make the difference with their purchasing behavior, and enjoy an additional satisfaction in proportion to how many other consumers patronize the green good. Therefore, we depart from the standard warm-glow motivation to buy green.

The analysis carried out in this paper has relied on some simplifying assumptions, such as consumer valuation being fully observable by each firm. 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 replaced the vertical quality attribute with environmental-friendliness, we have taken a step forward as we have considered products embedding both a hedonic and an environmental attribute.

We have characterized how consumers with different valuations for hedonic quality sort between the green and the brown firm at the market equilibrium and contrast this outcome with the social optimum. We have 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. In particular, the emission tax should be equal to a Pigouvian tax corresponding to the marginal social cost of pollution, whereas the subsidy should be decreasing in consumer willingness to pay for hedonic quality, or else in consumer income. Our results may then provide useful guidance in terms of indicating how to better direct the green transition that many important initiatives are supporting, such as the EU Green Deal. In particular, our policy prescription advocates for the adoption of income-based subsidies and warns against the use of 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 programme of firm G is given by (P_i), with $i = G$, and its associated first-order condition, simplifying and omitting the dependence of indirect utilities on θ, is

$$2S_G + 4U_B - 1 - 6U_G - \sqrt{1 - 4(U_B - U_G)} = 0, \tag{27}$$

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

It follows that a necessary condition for equation (27) to hold is that $2S_G + 4U_B - 1 - 6U_G \geq 0$ or else that

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

Solving (27) for U_G as a function of U_B yields

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

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, being $U_G^+(U_B) > U_G^0(U_B)$, whereas the first solution is such that $U_G^-(U_B) < U_G^0(U_B)$.

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

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

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 to programme (P_i), with $i = B$, one can obtain the reaction function of firm B which is defined implicitly, omitting again the dependence of indirect utilities on θ, by

$$1 + 4U_G - 6U_B + 2S_B - \sqrt{1 - 4(U_B - U_G)} = 0. \tag{28}$$

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 satisfied. Solving (28) for U_B as a function of U_G yields

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

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), substituting for optimal qualities, given by $q_i^*(\theta) = \frac{\theta}{k_i}$, and for optimal indirect utilities, that vary according to which region is relevant. 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 $\theta \in \left[\overline{\theta} - 1, \theta^I\right]$, where the corner solution (13) applies. We obtain

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

with $p_G^I > p_B^I$ being always satisfied, 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 $\theta < \sqrt{\frac{2k}{9(k-1)}} = \widetilde{\theta}$, with $\theta^I < \widetilde{\theta} < \theta^{II}$, 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 $k = 1.5$, $\overline{\theta} = 1.3$ and plot the prices in the three regions.

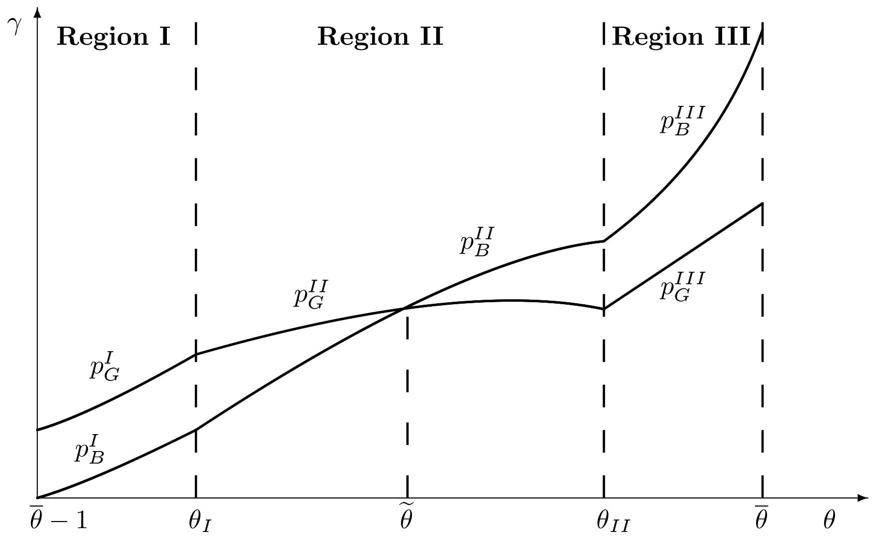

Figure A: Price difference in the three regions

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

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

and

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

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

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

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 $k = 1.5$, $\overline{\theta} = 1.3$ and plot the profits in the three regions.

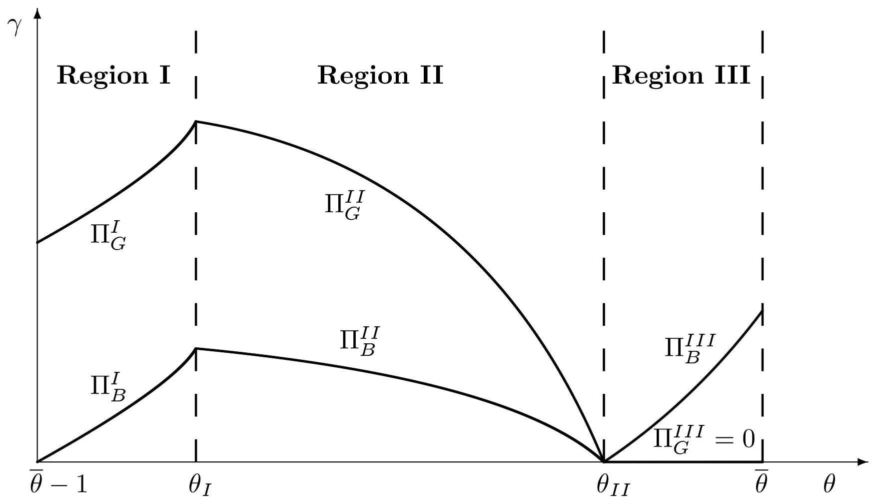

Figure B: Profit difference in the three regions

A.3 Optimal subsidy

The programme of firm G is given by (26) with $i = G$ and its associated first-order condition, simplifying and omitting the dependence of indirect utilities on θ, is

$$2S_G^o - 4\sigma - 6U_G + 4U_B - 1 - \sqrt{1 - 4\left(U_B - U_G - \sigma\right)} = 0, \tag{29}$$

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 (29) to hold is that $2S_G^o - 4\sigma - 6U_G + 4U_B - 1 \geq 0$. Solving (29) for U_G as a function of U_B, and taking into account the necessary condition, yields

$$U_G\left(U_B\right) \;=\; \frac{3S_G^o - 6\sigma + 6U_B - 1 - \sqrt{1 - 3\left(U_B - S_G^o - \sigma\right)}}{9} \tag{30}$$

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 (30) simplifies as

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

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 programme (26) with $i = B$, one can obtain the reaction function of firm B, which is defined implicitly, omitting again the dependence of indirect utilities on θ, by

$$1 + 4U_G + 4\sigma - 6U_B + 2S_B^o - \sqrt{1 - 4\left(U_B - U_G - \sigma\right)} = 0. \tag{31}$$

Solving (31) 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, solving (29) and (31) simultaneously for U_B and U_G yields the interior solution, which is such that

$$U_B^{IIr} = \frac{6S_B^o+4(S_G^o+\sigma)+1-\sqrt{5\left(1-4\left(S_B^o-S_G^o-\sigma\right)\right)}}{10} \quad \text{and} \quad U_G^{IIr} = \frac{4S_B^o-4\sigma+6S_G^o-1-\sqrt{5\left(1-4\left(S_B^o-S_G^o-\sigma\right)\right)}}{10} , \quad (32)$$

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 (32) 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.[28] 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 (25), we can obtain the indifferent consumer at the regulated market equilibrium in the different regions:

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

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

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

[28] Notice 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

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

which holds for $\sigma_C \leq \sigma < \sigma_B$. Continuity in $\widehat{\gamma}(\sigma, \theta)$ 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 $\widehat{\gamma}^o(\theta) = \widehat{\gamma}^R(\sigma, \theta)$. In order to have a common framework in which to analyze both solutions, let us proceed in the following manner. Recall that $\widehat{\gamma}_1^o(\theta) = 0$ 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, $\widehat{\gamma}_2^o(\theta) > 0$ holds for $\theta > \theta_1^o$ or else for $\sigma_F > 0$. Similarly, $\widehat{\gamma}_2^o(\theta)$ is real-valued for $1 - 4\left(S_B^o - S_G^o\right) \geq 0$, which is equivalent to consumers' WTP being such that $\theta \leq \theta_2^o$. Given that $\sigma_B = \left(S_B^o - S_G^o\right) - \frac{1}{4}$, we can rewrite condition $\theta \leq \theta_2^o$ as $\sigma_B \leq 0$.

Now, $\widehat{\gamma}^I(\sigma, \theta) = \widehat{\gamma}_1^o(\theta) = 0$ for $\sigma = 1 - S_G^o$, but this solution can be discarded because it does not belong to the relevant range. Next, $\widehat{\gamma}^I(\sigma, \theta) = \widehat{\gamma}_2^o(\theta)$ if and only if

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

however, this solution is not admissible because it does not belong to the relevant region.

Moreover, $\widehat{\gamma}^{II}(\sigma, \theta) = \widehat{\gamma}_1^o(\theta) = 0$ if and only if $\sigma = \sigma_A$ but this solution can be discarded because it coincides with the boundary for the existence of $\widehat{\gamma}^{II}(\sigma, \theta)$. Conversely, $\widehat{\gamma}^{II}(\sigma, \theta) = \widehat{\gamma}_2^o(\theta)$ if and only if

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

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

Finally $\widehat{\gamma}^{III}(\sigma, \theta) = \widehat{\gamma}_1^o(\theta) = 0$ is never the case, whereas $\widehat{\gamma}^{III}(\sigma, \theta) = \widehat{\gamma}_2^o(\theta)$ if and only if

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

which belongs to the relevant region and is such that, when inserted into $\widehat{\gamma}^{IIIr}(\sigma, \theta)$, it delivers the desired solution $\widehat{\gamma}_2^o(\theta)$ 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

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

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 that 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 $IIIr$.

Figure 3 represents optimal subsidies/taxes within each region when $k = 1.5$, $\mu_B = 0.1$ and $\mu_G = 0.05$.[29] In Figure 3, we did not explicitly represent the unit interval $\left[\overline{\theta} - 1, \overline{\theta}\right]$, but one could assume that $\overline{\theta} = \theta_2^o = 1.43$, so that Region Ir would almost entirely disappear.

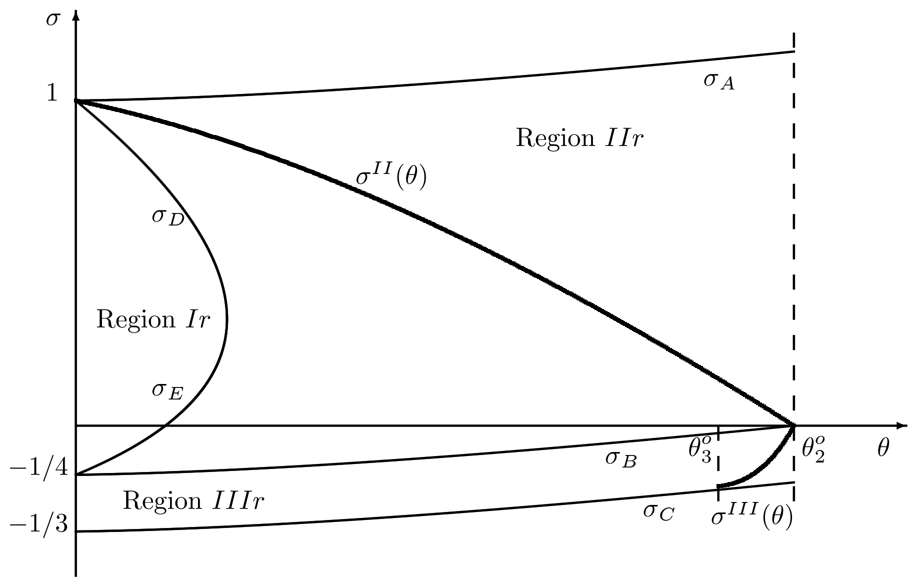

Figure 3: Optimal subsidies/taxes

The fact that, in Region $IIIr$, a tax rather than a subsidy has to be levied on the purchase of the green good is rather striking. This occurs because, while negative selection always emerges at the social optimum, there is positive selection at the regulated market equilibrium. Therefore, in this region, the market share of the green firm is excessively high relative to the optimal one, and a tax is needed in order to decrease green consumption and induce consumers with relatively limited environmental concern to patronize the brown rather than the green firm. However, such a policy intervention would 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 of better quality provided by the brown firm) would offset efficiency gain stemming from the reduction in pollution when consuming the green instead of the brown variety; (ii) consumers with relatively similar WTP for hedonic quality might be subject to two opposite policy instruments, which could jeopardize the effective implementation of the policy.

Also notice that, whenever the planner faces the choice between a subsidy and a tax on green consumption, the resulting sorting of consumers is always the optimal one. What changes is the way in which total welfare is divided between firms and consumers. It can be shown that the brown firm and its

[29] To ease the graphical representation, the scale along the y axis changes according to whether σ is positive or negative.

clientele are indifferent between $\sigma^{II}(\theta)$ and $\sigma^{III}(\theta)$, and so is the clientele of the green firm. The only difference is that the green firm is better 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 policies of this kind are usually meant to favor the green transition.

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

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

and

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

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

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

and

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

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

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

and

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

It is possible to show that the price set by the green firm in Region IIr is non-monotonic in θ. In particular, $p_G^{IIr}(\theta)$ is increasing in θ for sufficiently low values of k, whereas it is decreasing in θ for sufficiently high k.

Consumers who patronize the green firm end up paying $p_G^{Rr}(\theta) - \sigma^R(\theta)$, where

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

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