Oligopolies with (Somewhat) Environmentally Conscious Consumers: Market Equilibrium and Regulatory Intervention[1]

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Abstract

This paper considers a duopoly operating in a market with consumers who care about both an environmental attribute and other brand-specific attributes of products. Consumers are assumed to have the same willingness to pay for incremental improvements in the environmental attribute (the product's "greenness"), though less than its social value, and differ in their total willingness to pay for the product of each firm. Firms can be asymmetric, in that holding the environmental quality of products the same, one firm's product is more desirable to the average consumer than that of the other firm due to differences in intrinsic product quality. We focus on effects driven purely by the strategic interaction of firms, and thus do not allow for an aggregate demand response to changes in product quality and prices. The paper examines the choice of environmental quality of products by firms in the absence of any public intervention and the implications of various forms of public intervention. We show that (i) in the absence of regulation, the higher intrinsic quality firm will produce the greener product, (ii) a subsidy on the fixed costs of improving the environmental attribute or on the sale of the green product increases enrvironmental quality of both firm's products only if the firms are sufficiently similar, (iii) a minimum quality standard leads the greener firm to lower its environmental quality, (iv) environmental quality would be under-provided even if consumers fully internalize the pollution externality, and (v) a MQS can reduce welfare even when environmental quality is underprovided. The effects of these interventions on firms profits are shown to differ qualitatively for different types of intervention and also for each of the two firms. Thus, a firm that lobbies for one type of intervention may lobby against another seemingly similar one, and a firm may lobby for an intervention while its competitor may lobby against it. Interestingly, a subsidy for the development costs of a green product can financial hurt both firms.

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1 Introduction

The development of green products is emerging as a strategy for reaching out to increasingly environmentally conscious consumers, with the intention of capturing a price premium, increasing market share or both. Willingness to pay for environmental attributes through product choice may arise for reasons that range from purely private motives (enhanced health/safety, energy savings) to purely altruistic motives and ideas of personal responsibility (e.g. recycling, purchase of dolphin safe tuna).[1] In sectors ranging from cosmetics to automobiles, green products, such as non-animal tested products, recyclable and refillable containers, ultra-concentrated detergents and fabric softeners, dolphin-safe tuna, recyclable batteries and hybrid cars compete with conventional ones and experience increasing demand (USEPA 1991).[2] Recent examples of firms that have introduced environmentally friendly products and practices abound. British Petroleum is defining itself as looking "Beyond Petroleum" and making efforts to mitigate the risks of global warming,[3] Toyota and Honda have introduced hybrid cars, and McDonalds has stepped to the forefront of the animal welfare movement.[4]

Products differ not only in terms of their environmental attributes (or "greenness"), but also in intrinsic product quality (e.g., safety and reliability) and in other attributes (e.g., design, style, and convenience). Some of the product attributes, such as "greenness" and intrinsic quality, are valued by all consumers and can be considered vertical attributes. Consumer preferences for horizontal attributes, such as design and style, differ.[5] Since there do not typically exist products of all possible

[1]For further discussion see Reinhardt (2000).

[2]For a discussion of the demand for hybrid cars see Greenwire, 25 March 2003. In general, a Gallup study found that 81% of Germans, 57% of Americans and 40% of Japanese actively avoided products perceived as environmentally harmful and that 65% of Americans, 59% of Germans and 31% of Japanese were willing to pay a premium on eco-safe products (Simon, 1992).

[3]"How Green Is BP?" by D. Frey, NY Times, December 8, 2002.

[4]"Animal Welfare's Unexpected Allies" by David Barboza, NY Times, June 25, 2003.

[5]Indeed, amongst all attributes, greenness is probably not the most important one; surveys show that only 14% of Americans regularly bought products because of recycled content or refillable packaging in 1990 (Simon, 1992). For example, surveys show that a larger percentage of respondents considered convenient location to be important than they

configurations, a consumer may choose a less green product over a green one (of the same price) if the other attributes of the former are more valued by this consumer than those of the latter product. The benefits to a firm of increasing the greenness of its product rise with the value that consumers attach to greenness as an attribute and with the degree of substitutability between its product and that of its rivals. These benefits must be balanced against the costs of increasing greenness. In an oligopolistic environment a firm must also consider any adverse competitive reaction by its rivals when choosing the greenness of its product. This adverse reaction could take the form of either an increase in the greenness of the rivals' products or lower prices of their existing products.

In this paper, we focus on the following five issues. First, we investigate whether firms with high intrinsic quality products would choose to produce more or less environmentally friendly products than their competitors. Second, we investigate how the environmental quality of the firms' products responds to (a) increased consumer willingness to pay for greener products or, equivalently, a subsidy on the green attribute of the products, (b) a cost-sharing of the development costs for improving the greenness of a firm's product (or, equivalently, a secular technical change that reduces the development costs of green products), and (c) a minimum environmental quality standard (MQS). Third, we examine the effect of the above three changes on equilibrium prices and firm profits, which would determine whether the firms would welcome or oppose such changes. Fourth, we examine whether consumer preferences for environmental quality would be sufficient by themselves to lead to the socially optimal provision of green products when consumers were to fully internalize the environmental externality. Finally, we examine the scope for and the effects of regulatory policy, either through taxes/subsidies (either on the sale of products with different output or on the product development costs) or minimum quality standards, in markets in which consumers fully internalize the environmental externality.

We investigate these questions using a duopoly model that recognizes that the products of the two firms differ both vertically and horizontally. Greenness is one of the vertical attributes, but not

considered gasoline quality or brand in their choice of gasoline stations [National Association of Convenience Stores Future Study Consumer Survey, 1999]. Moreover, the presence of convenience stores at the pump is also becoming increasingly important in influencing consumer choice among gasoline stations ([http://www.nacsonline.com]).

the only one. The remaining vertical attributes define the product's intrinsic quality. We extend the Hotelling duopoly model by allowing this intrinsic quality and therefore the average (over all consumers) willingness to pay for a product to differ for the two products. Furthermore, we allow the firms to further differentiate their products in the vertical dimension by increasing their product's greenness. Consumers are assumed to value product greenness to an equal extent, but may not fully internalize the environmental externality. We consider improvements in product greenness that arise from research and development and product re-design and thus lead to expenditures that are independent of the scale of production. Our framework recognizes that even in the absence of differences in the vertical attributes, the two products would not be perfect substitutes; firms would have downward-sloping demand curves because of differences in horizontal attributes. The degree of horizontal differentiation is fixed, with both firms being located at the end-points of the unit interval. Our aim is to focus on effects that arise from the strategic interaction between firms. Thus, changes in environmental quality are assumed not to affect aggregate demand, i.e., the market is fully covered even when products are of the lowest possible environmental quality. The sequence of moves is as follows. First, firms choose the degree of product greenness. Second, the firms choose prices. Third, consumers purchase the product that yields the highest surplus.

Consumer durables (e.g., large appliances, automobiles, etc.) fit the above framework well: they are differentiated products whose energy effiency is an attribute that consumers attach private value to, but which also yields environmental externalities (e.g., lower CO_2 emissions). Improvements in efficiency often involve R&D expenditure and product re-design (e.g., better engines, more aerodynamic body, development of new materials) which largely increase the up-front fixed cost of developing the product. These improvements may affect the marginal production cost to a lesser extent, possibly even reducing it: for example, one may develop a new design that reduces a vehicle's weight, thus simultaneously increasing its mileage and reducing the material useage.[6] Some non-durables also fit this framework. For example, forgoing animal testing is likely to raise the costs of developing a new cosmetic, but not the marginal cost of production.

[6]Though general improvements in car mileage fall under our framework, hybrid cars do not because (i) the marginal cost of production is affected in a non-negligible way, and (ii) some of them (e.g., the Prius) convey such a strong status, that they may be effectively a separate product category.

Our findings can be summarized as follows. Regardless of the degree of asymmetry in intrinsic quality, the firm with the higher intrinsic quality product will have a greater market share than its competitor, charge a higher price, and have a greener product. The last result is driven by the assumption that product greenness affects the fixed cost of production, but not the marginal cost: Since firms with relatively high market shares benefit more from the price premium associated with producing a greener product, they will have stronger incentives to produce such products. Moreover, we show that a minimum environmental quality standard will be opposed by the high intrinsic quality firm (though obstensibly not bound by it) but would increase the profits of the low quality firm (which would have to increase the greeness of its product). The explanation for this is that an MQS acts as a commitment device for the low quality firm, leading to a choice of environmental quality that is closer to that in a Stackelberg game in which it is the first mover.

When the degree of asymmetry in intrinsic quality is not too large, we find that both firms would oppose campaigns to enhance consumer awareness of the pollution externality and would also oppose any government cost-sharing of pollution reduction investments. This result is ensured by the absence of aggregate demand effects from increasing environmental quality and that development costs are a convex function of product greenness. Thus, a government development subsidy ends up leading to increased firm expenditures on developing greener products without yielding any benefits in terms of higher prices or sales. To put it another way, pollution reduction has features of a Prisoners' Dilemma: both firms would prefer that it were prohibitively expensive that neither would do much or any of it, but given that it is not, both find it privately optimal to engage in it.

When firms differ sufficiently in their intrinsic quality, a government subsidy (or secular technical change) that reduces the development costs of producing a greener product also reduces the incentives for the low quality firm to produce a greener product. The intuition for this perverse finding becomes clear once one realizes that a government subsidy is more valuable to the high quality firm because it produces the greener product and incurs a higher fixed cost. Thus, this firm will increase its product greenness by more than the low quality firm, leading to a reduction in the low quality firm's market share. Since low market shares reduce the incentives for investing in green products, the total net effect of the government subsidy is that the low quality firm produces an even less green product. For similar reasons, a government subsidy on the price of the greener product can reduce the equilibrium greenness of the low quality firm when asymmetries in intrinsic quality are large enough. These comparative statics also have implications for profits. When asymmetries in intrinsic product quality are large, the high quality firm will like a subsidy on the development costs or on the unit price of greener products, while the low quality firm will not. Thus, a market leader may find it privately optimal to "educate" consumers and increase their willingness to pay for greener products.

Lastly we find that educating the public and instilling them with sufficient altruism to fully internalize the externality (or, equivalently, taxing the sales of polluting products so that the social cost is fully incorporated in the price consumers pay) results in a sub-optimal provision of product greenness. The intuition for this result is as follows. When a firm increases the greenness of its product, it causes its competitor to decrease its price to prevent a large erosion of his market share. This adverse competitive response partially nullifies the benefits of increasing greenness. Thus, market pressure needs to be supplemented by regulatory intervention to achieve environmental quality levels closer to the social optimum. We show that a subsidy on development costs of green products will indeed increase welfare, and so will a subsidy on the sale of green products (or tax on polluting products). However, we show that a minimum environmental quality standard will only increase welfare if the firms are not too asymmetric.[7] The reason such a standard is not guaranteed to increase welfare is because it lowers the environmental quality of the high quality firm. Simply put, increasing the greenness of the low quality firm's product makes the firms more symmetric, thus reducing the incentives for the market leader to maintain high environmental quality.

Our paper is related to the literature on product quality and minimum quality standards. The early literature (Spence, 1975, Sheshinski, 1976 and White, 1977) focused on quality choice by a monopolist and showed conditions under which there would be underprovision of quality.[8]

[7]Such minimum quality standards have been adopted for a number of products and processes, e.g. Corporate Average Fuel Economy standards for automobiles and maximum thresholds on pesticide residues in food products. These mandatory standards are also complemented with voluntary standards, e.g., Energy Star.

[8]This work also shows that overprovision of quality is also possible. Whether overprovision or underprovision of quality is obtained in a monopoly depends on the nature of the demand and the cost of quality provision.

Subsequent literature focused on purely vertically differentiated duopolies. Generally this literature finds that there will be over-provision of quality by one of the firms and under-provision by the other firm in order to reduce price competition (Shaked and Sutton, 1982). Ronnen (1991) shows that a minimum quality standard would enhance welfare by narrowing the quality gap between firms and intensifying competition. The standard lowers the profits of the high quality firm but it increases profits of the low quality firm. Arora and Gangopadhyay (1995) emphasize that the high quality firm will exceed the minimum quality standard. Consumer welfare increases because the quality adjusted prices for both firms fall and social welfare increases. [9] Most recently, Amacher et al. (2004), Bansal and Gangopadhyay (2003) and Brouhle and Khanna (2007) extend this literature. The first of these papers considers asymmetric firms that differ in the investment costs of quality provision, and shows that if these costs are lower for the high quality firm than for the low quality then even the high quality firm may underprovide quality. The second of these papers the effects of regulation when environmentally quality is the only vertical characteristic, and shows that some seemingly equivalent policy interventions can have opposite results. The third of these papers considers the possibility that consumers are not informed about the environementaly quality, but rather infer it or obtain it from information transmitted to them, and compare the effects of greater information provision to the effects of more traditional regulation. Unlike this literature, our paper assumes that products differ not only vertically but also horizontally.[10] Moreover, it assumes that firms are not identical in initial quality and seeks to explain further changes in product quality.

[9] Crampes and Hollander (1995) show that this result depends on whether costs of enhancing quality are fixed or variable (that is they vary with the quantity of the good produced). When costs are variable, a minimum quality standard that leads to a large increase in quality of the high quality firm can lower consumer welfare by raising per unit costs and prices and lower social welfare.

[10] Other studies that have coupled vertical quality and horizontal (varietal) product differentiation include Economides (1989) and Neven and Thisse (1990). Economides (1989) assumes that consumers only differ in their preference for product variety and shows that firms would always choose maximum varietal differentiation and minimum quality differentiation. Neven and Thisse (1990) assume that consumers differ in their preferences for product variety and for product quality and show that firms will either choose to differentiate maximally in product variety or in product quality but not in both. These studies show that in equilibrium firms will choose maximum differentiation on one dimension and minimum differentiation in another.

Finally, our paper incorporates consumption externalities explicitly and analyzes the effects of the degree of internalization by consumers on quality provision by firms.

This paper is organized as follows. Section 2 describes the model and solves for the equilibrium outcomes in the absence of any public intervention. Section 3 considers the effects of regulatory and non-regulatory interventions on the market equilibrium, while section 4 investigates their welfare effects. The paper ends with a few concluding remarks. An appendix contains all the proofs.

2 The Model

2.1 Modeling Environment

The model is a modification of the standard Hotelling duopoly model. There are two firms, A and B, located at the two ends of the unit interval, at locations 0 and 1 respectively. Each firm j produces one product; therefore we will refer to firm j and product j interchangeably. Consumers differ in their preferences with respect to the two brands. In particular, following standard location models of product differentiation, consumer preferences are represented by a parameter x which is uniformly distributed on the unit interval. We depart from the standard Hotelling model in two ways. First, we assume that the two firms are not symmetric, in the sense that the average willingness to pay for the product of firm A is higher than the average willingness to pay for the product of firm B.[11] We do not endogenize this ex ante difference in the mean willingness to pay for the two products: it could be generated either by assuming that firms have different costs of increasing product quality, or by assuming that firms choose locations in the Hotelling line sequentially and one firm has a first mover advantage; rather we take these initial asymmetries as given and investigate their implications. Second, we assume that, in addition to the horizontal differentiation, a product j is distinguished by its environmental attribute (cleanliness) S_j, which is observed and valued by the consumers. This environmental attribute could represent energy efficiency, the degree to which the product can be recycled, the reduction in pollutants generated

[11] Economides (1989) and Neven and Thisse (1990) also develop similar extensions to the Hotelling model.

by production and/or use of the product, and possibly others. We assume that production costs are zero regardless of the level of product "greenness."[12] There is a cost of improving the environmental characteristics of the product, which is assumed to be a quadratic function of environmental quality, KS_j^2.[13] This modeling environment best reflects environmental attributes that are incorporated in the design of the product or are the outcome of a research and development effort. In such situations, the cost of improving environmental characteristics would (for the most part) be independent of the scale of production and is better thought of as a fixed rather than a variable cost.[14]

The environmental attribute creates both social and private benefits. All consumers attach the same value to the environmental characteristic. This assumption is best suited for markets in which horizontal differentiation is much more important in consumer preferences relative to the willingness to pay for the environmental attribute and in which differences in willingness to pay for greenness can be ignored. Moreover, incorporating into the model consumer heterogeneity in willingness to pay greenness would make our results of differential firm responses less interesting as firms would naturally cater to different niches of consumers.[15] A part of this value, λ_P, arises

[12]The results would readily generalize to the case of constant marginal production costs that are independent of the value of environmental attribute.

[13]Our framework can easily be generalized to allow for the cost of increasing environmental quality to differ across firms, as in vertical differentiation model of Amacher, Koskela, and Ollikainen (2004). Such a generalization would endogenize the asymmetry between the two firms, albeit at the cost of some complication in the analyis.

[14]There are products that do indeed fall in this category, e.g., improving auto mileage, appliance efficiency, and the development of biodegradable products. Though marginal costs of production may also depend on the value of S_j, this is often a second order effect relative to fixed cost of developing the more environmentally friendly or energy efficient product. Moreover, part of the increase in the marginal cost of production may be mitigated by reduced user costs (e.g., a more fuel efficient vehicle may indeed cost slightly more to produce than a less efficient vehicle, but the present discounted value of its production cost plus expected lifetime fuel cost may be the same or even lower than that of the less efficient vehicle).

[15]In principle there is consumer heterogeneity both in terms of preferences for the horizontal attribute and also in terms of preferences for the environmental attribute. There is a literature analyzing the case in which consumers differ only in terms of the willingness to pay for the vertical (environmental) characteristic. This literature abstracts from the existence of horizontal differentiation. The only papers that allow for both types of heterogeneity are Neven and Thisse (1990) and Economides (1989) and they are limited to the calculation of market equilibrium. Our incorporation

from the purely private benefit to the consumer, while a part, λ_I, arises from partial internalization of the environmental externality, which can arise purely altruistic or "warm glow" reasons.[16] We represent the sum of these by λ. The social value of the environmental attribute, λ_S, is the sum of λ and the uninternalized portion of the externality, λ_E. For example, increasing vehicle fuel efficiency results in lower fuel costs (private benefit) and also in lower emissions (externality). However, some consumers may altruistically prefer to "do their part" to protect the environment. In that case, the value they attach to fuel efficient vehicles includes the purely private benefit of reduced fuel consumption and the degree to which they are willing to pay to reduce the externality.

Let the location of consumer i be x_i which represents the value of his most preferred horizontal attribute, and let his distance from firm j in attribute space be d_{ij}. The consumer's utility from consuming product j is

$$U_{ij} = V_j + \lambda S_j - P_j - \theta d_{ij} \tag{1}$$

where P_j is the price of product j, θ is a parameter that measures the degree of horizontal product differentiation, V_j is high enough that all consumers will purchase a product in equilibrium regardless of whether the firms introduced clean products or not, and that $V_A \geq V_B$, so that the product of firm A is assumed to have a higher intrinsic quality.[17] Note that the incremental value consumers attach to the environmental attribute, S_j, is independent of the brand of the product.

The game the two firms play is as follows. First, the two firms independently and simultaneously choose the values of S_A and S_B. Second, after their choices are observed by each other and the consumers, the two firms independently and simultaneously set their prices.[18] Third, consumers

of horizontal differentiation into a richer model with environmental externalities and policy instruments necessitates, due to length considerations, the simplifying assumption of no heterogeneity with respect to the environmental attribute.

[16]See Andreoni (1988, 1990) for a discussion involving the interplay of altruism and "warm glow" as motivators of publicly minded actions of consumers.

[17]The parameter θ can also be interpreted as the extent of brand loyalty or the inverse of brand rivalry since it signifies the marginal reduction in utility as one gets farther away from its most preferred attribute location. The greater the reduction in utility, the higher the brand loyalty, hence, the weaker the extent of brand rivalry.

[18]This sequential nature of decision making reflects the fact that product characteristics are easy to change than

make their purchase decisions and profits are realized. To ensure that a pure-strategy duopoly equilibrium of this game exists we make three technical assumptions which we describe below (the second assumption is only operative when the firms are not symmetric).

Assumption 1. $V_A + V_B + \frac{\lambda^2}{6K} > 3\theta$

This assumption states that the value consumers attach to the products and to the environmental attribute (adjusted for the cost of producing it) is high relative to the degree of differentiation (i.e., relative to a consumer's disutility of not consuming his ideal product). The assumption ensures that, in equilibrium, all consumers have a positive utility from consuming one of the two products. This assumption is also a sufficient condition for the market to be covered.[19] The assumption of full market coverage eliminates any aggregate demand effects from changes in environmental greenness, and thus allows us to concentrate on the purely strategic effects of firm competition.

Assumption 2. If $V_A > V_B$, then $3(V_A - V_B) + \frac{\lambda^2}{K} < 9\theta$

This assumption states that the difference in the intrinsic quality of the two products and value consumers attach to the environmental attribute (adjusted for the cost of producing it) is not too high relative to the degree of horizontal product differentiation. The above condition ensures that the high quality firm (firm A) is not so much better than the low quality firm that it is able to eliminate its competition from the market. A high consumer willingness to pay for the environmental attributes (relative to the cost of producing it) facilitates the attempt of firm A to displace firm B by developing a very clean product in the first stage of the game. Therefore, both the difference in intrinsic product quality and the value of the environmental attribute relative to its cost, are relevant for the existence of a duopoly equilibrium.

Assumption 3. $\frac{\sqrt{18K\theta}}{\lambda} > 9K\theta + 3K(V_A - V_B) - \lambda^2$

product prices.

[19]The market will be covered even under a slightly weaker condition. However, under a weaker condition the utility of the consumer who is indifferent between purchasing from firm A and purchasing from firm B will be zero and the profit maximizing prices of the firms will be at the kink of their demand curves (as a slight increase of their price will result in an uncovered market). Such a possibility would complicate the analysis considerably without adding any insights.

This condition ensures that both firms have positive profits in equilibrium. It is less easy to immediately identify the link between this inequality and profitability, but we will provide some intuition here. One might at first conjecture that firms would always obtain positive profits, as producing products of zero environmental quality results in zero costs but allows them to obtain positive revenue. This conjecture is false because, holding one firm's quality at zero, the other firm has an incentive to increase the environmental quality of its product. Since both firms face these incentives, they enter into a "race," burning up profits in the process (as increased quality by both firms increases their costs but does not increase their revenue). This Prisoners' Dilemma type of race can result in negative profits if the environmental attribute is sufficiently valued and is costly (but not too costly) to produce. Observe that the Assumption 3 is satisfied when K or λ are small. But for large value of K and λ it can be violated. However, for very high values of K the condition also holds: with K very high, the firms choose not to invest too much in the environmental attribute.[20]

Note that assumptions 2 and 3 ensure that there is no exit in this market. Entry of a third firm is exogenously precluded. The presumption in our model is that firm competition in terms of the environmental attribute does not have a big enough effect on firm profits to lead to a structural change in the market. We next solve for the Subgame-Perfect Nash Equilibrium of the game, starting from the optimal consumer choice.

2.2 Market Equilibrium

Consumers purchase the product that gives them the highest utility. Those located near $x = 0$ purchase from firm A, while those located close to $x = 1$ purchase from firm B. There is a consumer at some intermediate value of x who is indifferent between purchasing from firm A or firm B. The location, x_c, of this consumer is given by

$$V_A + \lambda S_A - P_A - \theta x_c = V_B + \lambda S_B - P_B - \theta(1 - x_c) \tag{2}$$

[20]Note that from Assumption 2, the right hand side of the condition in Assumption 3 is positive.

Solving for x_c, we obtain the location of the indifferent (or critical) consumer to be

$$x_c = \frac{\lambda\Delta S + \Delta V - \Delta P + \theta}{2\theta}$$

where $\Delta S = S_A - S_B$, $\Delta V = V_A - V_B$, and $\Delta P = P_A - P_B$. It immediately follows, since consumers are uniformly distributed and those to the left of x_c purchase from firm A while those to the right of x_c purchase from firm B, that the quantities sold by the two firms are given by $q_A = x_c$ and $q_B = 1 - x_c$. If both firms charge the same prices, offer identical products, and have the same inherent quality, they will split the market down the middle. The value of x_c (and hence, the market share for firm A) is increasing with the intrinsic quality and environmental attribute of firm A's product (relative to that of firm B) and decreasing in the price of firm A's product (relative to that of firm B). The sensitivity to the quality and price differences is higher the lower the value of θ, i.e., the less differentiated are the products. Further, the sensitivity with respect to the environmental characteristic depends on the value consumers attach to it.

The profit function of firm A is

$$\begin{aligned} \Pi_A &= P_A x_c - K S_A^2 \\ &= P_A \left(\frac{\lambda\Delta S - \Delta P + \Delta V + \theta}{2\theta} \right) - K S_A^2 \end{aligned} \tag{3a}$$

while that for firm B is

$$\begin{aligned} \Pi_B &= P_B(1 - x_c) - K S_B^2 \\ &= P_B \left(1 - \frac{\lambda\Delta S - \Delta P + \Delta V + \theta}{2\theta} \right) - K S_B^2 \end{aligned} \tag{3b}$$

Conditional on their choice of product environmental cleanliness, the two firms choose prices to maximize profits. The first order conditions of profit maximization yield the system

$$\frac{\partial \Pi_A}{\partial P_A} = 0 \Rightarrow \frac{\lambda(S_A - S_B) + P_B - P_A + V_A - V_B + \theta}{2\theta} - \frac{1}{2\theta} P_A = 0 \tag{4a}$$

$$\frac{\partial \Pi_B}{\partial P_B} = 0 \Rightarrow -\frac{\lambda(S_A - S_B) + P_B - P_A + V_B - V_A + \theta}{2\theta} - \frac{1}{2\theta} P_B = 0 \tag{4b}$$

Solving the (4a) for P_A we obtain:

$$P_A = \frac{\lambda(S_A - S_B) + P_B + V_A - V_B + \theta}{2} \tag{5}$$

Substituting into (5) into (4b) and solving for P_B we get

$$P_B = \theta - \frac{\lambda(S_A - S_B) + (V_A - V_B)}{3} \tag{6}$$

This is the price of firm B conditional on the levels of the enviromental attribute chosen by the two firms. Substituting this into (5) and simplifying we obtain below the equilibrium price of firm A conditional on the levels of the enviromental attribute.

$$P_A = \theta + \frac{\lambda(S_A - S_B) + (V_A - V_B)}{3} \tag{7}$$

Substituting the solutions into the expression for the location of the critical consumer, derived in (2), and simplifying we obtain

$$x_c = \frac{1}{2} + \frac{\lambda(S_A - S_B) + (V_A - V_B)}{6\theta} \tag{8}$$

Notice that both the sales and the price of a firm are increasing in the quality of its product and decreasing in the quality of its competitors product. As shown in the proof of Proposition 1, Assumption 2 ensures that $0 < x_c < 1$.

We next turn to the calculation of the profit maximizing choice of the enviromental attribute. Substituting the equilibrium prices into (3) we obtain the profit functions of the firms at the first stage of the game, i.e., at the time that they decide on the environmental quality of their product. These profits functions are given by

$$\Pi_A = \left(\frac{3\theta + \lambda(S_A - S_B) + \Delta V}{3}\right)\left(\frac{3\theta + \lambda(S_A - S_B) + \Delta V}{6\theta}\right) - KS_A^2 \tag{9}$$

$$\Pi_B = \left(\frac{3\theta - \lambda(S_A - S_B) - \Delta V}{3}\right)\left(\frac{3\theta - \lambda(S_A - S_B) - \Delta V}{6\theta}\right) - KS_B^2 \tag{10}$$

Increasing product quality increases the revenue of a firm (since both the equilibrium price and quantity increases), but leads to initial positive outlays. Therefore, the optimal choice of environmental attribute trades off the increase in revenue with the increase in the fixed cost. Incidently, an increase in the environmental quality of a firm's product leads to a decrease in the profits of its rival (provided that prices and quantities are positive, as ensured by Assumptions 1 through 3). In other words, an increase in a firm's environmental attribute confers a negative pecuniary externality on its competitor. The Nash Equilibrium of the simultaneous choices of S_A and S_B by the two firms and the associated equilibrium values of prices, quantities, and profits are given in Proposition 1 below.

Proposition 1. *The equilibrium environmental quality, prices, market shares and profits are:*

$$S_A = \frac{\lambda}{6K} + \frac{\lambda \Delta V}{2(9K\theta - \lambda^2)} \qquad S_B = \frac{\lambda}{6K} - \frac{\lambda \Delta V}{2(9K\theta - \lambda^2)} \tag{11}$$

$$P_A = \theta + \frac{3K\theta \Delta V}{9K\theta - \lambda^2} \qquad P_B = \theta - \frac{3K\theta \Delta V}{9K\theta - \lambda^2} \tag{12}$$

$$q_A = \frac{1}{2} + \frac{3K}{2}\left(\frac{\Delta V}{9K\theta - \lambda^2}\right) \qquad q_B = \frac{1}{2} - \frac{3K}{2}\left(\frac{\Delta V}{9K\theta - \lambda^2}\right) \tag{13}$$

$$\Pi_A = \frac{(18K\theta - \lambda^2)(9K\theta + 3K\Delta V - \lambda^2)^2}{36K(9K\theta - \lambda^2)^2} \qquad \Pi_B = \frac{(18K\theta - \lambda^2)(9K\theta - 3K\Delta V - \lambda^2)^2}{36K(9K\theta - \lambda^2)^2} \tag{14}$$

Under Assumptions 1 through 3, the equilibrium environmental quality, price, quantity, and profit of each firm is positive. Moreover, the price, market share, environmental quality and profits of firm A are higher than those of firm B.

Proof. See the Appendix.

The intuition for why the higher intrinsic quality firm charges a higher price, has a bigger market share, and earns higher profits is clear. The intuition of why its environmental quality is also higher is as follows. An increase in environmental quality does not affect marginal production costs, but increases the willingness-to-pay of all consumers equally. Given that firm A has a bigger market share, a price increase resulting from an increase in environmental quality yields a higher increase in revenue for firm A than for firm B. Thus, around a symmetric environmental quality level, firm A has more powerful incentives to provide a green product than firm B.[21]

This completes the derivation of the equilibrium. In the next two sections we examine the effects of public policy on equilibrium outcomes and discuss the welfare implications of these policies.

[21] A link between market size and innovation, arising through a somewhat different channel, has also been identified in the growth literature (see Desmet and Parente, 2007, and references therein.

3 Equilibrium Response to Policy Interventions

The model formulated above allows for the investigation of three types of public policy interventions or initiatives.[22] The first initiative involves education campaigns, organized by governmental or non-governmental organizations, designed to inform consumers of the environmental externality imposed by the product firms A and B produce. Such a campaign may lead consumers to partially internalize this externality and take it into consideration when choosing between the two products. As a result, consumers would be willing to pay more for an environmentally green product than for a less green one. Given that we consider a market that is completely "covered" in equilibrium, it makes no difference whether we model the effect of this education campaign as making consumers be less willing to pay for a less environmentally friendly product or more willing to pay for a more environmentally friendly product. Thus, an education campaign can be modeled as an increase in λ. Similarly, because in this model there are no aggregate demand effects, an increase in λ is also equivalent to a tax on the environmental disamenity of the product or a subsidy on its environmental quality.

The second public initiative involves a government subsidy on the development of environmentally clean products. If this subsidy takes the form of a simple proportional cost-sharing formula, then it would be equivalent to a reduction in K. Notice that a reduction in K can also be the result of secular technical change or technical change that is induced by publically-funded research by third parties (e.g., universities, govevernment labs).

The third policy intervention is the imposition of minimum environmental quality standards (MQS) that the two firms must meet. This intervention is qualitatively different from the first two: rather than affect firm behavior by changing their incentives to undertake environmentally friendly investments, it directly stipulates a minimum level of the environmental attribute. Though only one of the firms may be directly impacted by this standard (as the other may already exceed it),

[22] The analysis in this paper is in the form of comparative statics. A fully dynamic treatment would not change the flavor of the results if, say, K was steadily falling or λ rising over time so that firms were always considering the degree to which they would increase their environmental quality in the margin. In such a framework, the comparative statics might be framed in terms of changes in the rate of change of K or λ.

we show that the equilibrium (and profits) of both firms will be affected.

Investigating the effect of these public initiatives on firm behavior and profits, and hence on whether firms are likely to support them or oppose them, requires the computation of the comparative statics of environmental quality, price, market shares, and profits with respect to λ and K. Some of the expressions derived in Proposition 1 above are somewhat complicated, but become much simpler when the products A and B are of the same intrinsic quality, i.e., when $V_A = V_B$. Therefore, we first examine the response of firms in the symmetric case, and then turn to the examination of the asymmetric case of $V_A > V_B$.

As can be seen from Proposition 1, when $V_A = V_B$, equilibrium environmental quality is increasing in λ, decreasing in K and independent of the other parameters. Equilibrium prices are equal to θ and the two firms split the market down the middle; externalities and the degree of internalization by consumers have no effect on prices and quantities. Profits are decreasing in λ. As consumers increasingly value the environmental attribute, firms seek to provide more of it, incurring costs in the process of doing so; prices and equilibrium quantities, however, are independent of the value of the environmental attribute. As a result, profits decline. This suggests that the two firms would oppose any public initiative for educating the public and sensitizing it to the environmental cost of these products. One might have thought that profits also decline as the cost function of improving the environmental attribute of the product shifts up. The converse is true. Observe that when $\Delta V = 0$, $S_A = S_B = \frac{\lambda}{6K}$, i.e., environmental quality declines with an increase in K. Because total costs are a quadratic function of quality, total costs also decline with a rise in K. This shows that the firms would actually, and somewhat unexpectedly, *oppose* a public subsidy on the cost of developing environmentally green products (or any government or university research initiative the lowers the developement costs of green products). Indeed, firms would prefer that developing green products were prohibitively expensive.

These last two results are largely driven by the fact that, in this model, we purposefully eliminated any aggregate demand effects to focus on the strategic interaction between the two firms. Improvements in quality, therefore, do not increase the aggregate sales of the two firms or their ability to extract revenue from the consumers. As a result, their competition with respect to the environmental attribute has features of a Prisoners' Dilemma: Both firms would be better off if they were able to commit to not producing an environmentally friendly product, but they each have private incentives to do so, in order to gain an advantage (both in terms of higher price and higher quality) over their competitor. In equilibrium, their efforts cancel each other out and they lead to a reduction in their profits. It follows that as the incentives for each firm to unilaterally increase the environmental attribute of its product are reduced (either because consumers value it less or because it costs more to provide it), equilibrium profits go up.

One might expect that a similar intuition and reasoning would also characterize the comparative statics of the more complicated expressions of the equilibrium outcomes in the asymmetric case, i.e., when firms differ in terms of intrinsic quality. It turns out that the fundamental ex ante asymmetry in the two firms leads to a far richer set of effects. These are described in a set of corollaries below.

Corollary 1. *The equilibrium environmental quality of the high intrinsic quality firm (firm A) is increasing in* λ *and decreasing in* K. *The equilibrium environmental quality of the low intrinsic quality firm (firm B) is increasing in* λ *and decreasing in* K *only for relatively small values of* ΔV, *and decreasing in* λ *and increasing in* K *for high values of* ΔV *(that are still low enough to satisfy Assumptions 1 through 3). Moreover,* $\frac{\partial S_B}{\partial K} > 0$ *implies* $\frac{\partial S_B}{\partial \lambda} < 0$, *but not vice versa.*

Proof. See the Appendix.

The most interesting finding in Corollary 1 is that the environmental quality of firm B can actually increase as the cost of providing that quality increases, and decrease as the willingness of consumers to pay for it increases. We discuss the intuition for this seemingly perverse result, starting with the comparative statics with respect to K. For very low values of K, increasing environmental quality is sufficiently cheap that firm A invests in it to such an extent that firm B is pushed off the market. [Off course, the values of K that result in a monopoly by firm A would violate Assumption 2, but they are a useful starting point to understand the mechanics of this result.] Firm B does not find it profitable to mimic firm A because the instrinsic quality of its product is lower. As K increases from these very low values, firm A no longer finds it profitable to push firm B out of the market, and the latter firm obtains a toehold. This toehold is increasing in

K (see Corollary 2 below). As the market share of firm B increases from zero, it finds it worthwhile to increase the environmental quality of its product, admittedly from a near-zero level. When K becomes sufficiently high, the incentives for firm B to further increase S_B, arising from a further expansion in its market share, are more than counteracted by the higher cost of improving the environmental quality of its product. Such a non-monotonic relationship between S_B and K exists for sufficiently high asymmetry between firms A and B. The intuition for how S_B can be decreasing in λ is similar. For sufficiently high ΔV, the market share of A is sufficiently larger than that that of firm B, that an increase in λ provides far stronger incentives for firm A to increase its quality, than it does for firm A. This leads firm A to increase its market share sufficiently (at the expense of that of firm B), that firm B ends up with such a small market share that (on net) its incentives to maintain high environmental quality are diminished. Corollary 1 also shows that the environmental quality of firm A is decreasing in K and is increasing in λ, as expected given the discussion above.

The comparative statics of price and output are straighforward to derive and are summarized below.

Corollary 2. *The equilibrium price and market share of firm A are increasing in λ and decreasing in K. The equilibrium price and market share of firm B are decreasing in λ and increasing in K.*

Proof. Omitted as it follows directly from straightforward differentiation of (12) and (13).

An increase in λ increases the market share and price of firm A because firm A has stronger incentives to increase environmental quality compared to firm B (because its initial market share is higher). Thus, an increase in λ triggers a positive feedback effect on firm A's price and market share by making the product of firm A relatively more desirable than that of firm B. A decrease in K operates in exactly a similar fashion. Notice that a change in the market environment that leads to an increase in the price of firm A also leads to an increase in its market share (and vice versa). Essentially, firm A optimally chooses to use any advantage it obtains from an increase in λ or decrease in K both in enlarging its market share and increasing the price it charges to its customers. The response of firm B's price and market share to changes in the market environment is exactly the opposite to that of firm A; the intuition for this mirrors the arguments made above.

Since increases in firm prices and market shares are positively correlated as shown in Corollary 2, one might conlude that the comparative statics of firm profits are straightforward. However, this is not the case because firm profits are also affected by the costs of attaining the equilibrium level of quality. Indeed, the corollary below shows that there are some surprises.

Corollary 3. *Profits of firm B are decreasing in* λ *and increasing in* K. *Profits of firm A are decreasing in* λ *and increasing in* K *only for small enough values of* ΔV, *and are increasing in* λ *and decreasing in* K *for higher values of* ΔV *(that are still low enough to satisfy Assumptions 1 through 3). Moreover, when* $\partial\Pi_A/\partial\lambda > 0$, $\partial\Pi_A/\partial K < 0$, *and vice versa.*

Proof. See the Appendix.

The most surprising finding of the above corollary is that the profits of firm A can actually *increase* with λ when firm A's product is of sufficiently high intrinsic quality relative to that of firm B. This implies that firm A may actually welcome public initiatives to "educate" consumers about the pollution externalities of these products which leads them to internalize part of them through product choice. Corollary 3 also shows that an increase in K may have a differential effect on firm profits when firm A's product is of sufficiently high intrinsic quality relative to that of firm B. The intuition for this is as follows. A higher value of λ or a lower value of K reduces the market share of firm B, and more so the bigger the asymmetry between the two firms.

Therefore, when ΔV is sufficiently large, firm A's gain at the expense of firm B (from an increase in λ or decrease in K) is sufficiently large that it outweighs the direct (negative) effect on firm A's profits. Corollary 3 implies that the two firms may differ in how they view a public subsidy on the cost of developing environmentally friendly products (or a government or university research that lowers the costs of developing such products). Recall that a cost-sharing program between the government and the firms is equivalent to a reduction in K. It then follows that firm A will support such a cost-sharing subsidy and firm B will oppose it if ΔV is sufficiently large.

The policy interventions described above are indirect; they affect equilibrium environmental quality by affecting the incentives of the firms to provide it. Policy intervention can also be direct through the use of minimum environmental quality standards that all firms must meet. In practice, such a standard, when it mandates only a marginal increase in quality, will apply to the firm with the lowest environmental quality (firm B) unless the two firms are symmetric. One may think that such an intervention will qualitatively equivalent to the two interventions that we have already examined. It turns out that there are important differences. In particular, a minimum quality standard (MQS) has the following impact on market equilibrium:

Proposition 2. *A Minimum Quality Standard that raises the environmental quality of firm B from its "free-market" equilibrium level decreases the environmental quality and profits of firm A, and increases the profits of firm B. Moreover, the equilibrium price and quantity of firm B increase, while those of firm A decrease.*

Proof. See the Appendix.

This proposition shows that a minimum quality environmental standard does not increase the environmental attribute of all firms, not even weakly. Rather, the environmental attribute of the high quality firm decreases with the standard. The intuition for this result can be explained by the observation that the levels of environmental quality of the two firms are strategic substitutes: the higher the quality of the competing firm, the lower the incentives a firm has to increase its own quality. With the minimum quality standard pushing up the environmental quality of firm B, that of firm A goes down. The effects on price and quantity readily follow, as increase in quality leads to increases in both the sales and prices of a firm.

Less easy to immediately see is the effect on profits. Why would the profits of firm B go up after its behavior is constrained? This effect is the opposite of what a casual observer would expect. The firm that is constrained by the standard experiences an increase in profits, while the firm that is not constrained by the standard experiences a decline in profits. The reason is that the standard forces firm B to increase the greenness of its product, and does so in a way that is common knowledge. This leads firm A to lower its quality (as a higher quality of firm B would reduce equilibrium market shares of firm A and thus reduce the benefits of firm A from maintaining high quality). In the absence of the standard, firm B would not choose to unilaterally increase its environmental quality from the Nash equilibrium level of the simultaneous quality choice game. However, because the environmental qualities of the two firms are strategic substitutes, firm B would have chosen a higher quality level in a sequential game in which it could commit to a quality level first. Effectively, the minimum quality standard acts as a commitment device for firm B, and gives it a first mover advantage.[23]

In some respects, this result is similar to that obtained by Ronnen (1991) and Crampes and Hollander (1995) in a vertical product differentiation framework. The high quality firm will be worse off under a more stringent minimum quality standard, while the low quality firm will be better off because the low quality firm's product becomes a closer substitute to the product of the high quality rival. This shifts part of the high quality firm's market share to the low quality firm, and allows the low quality firm to charge a higher price. With costs increasing in the quality level, the high quality firm does not choose to undo the regulator's standard and maintain the initial degree of product differentiation by increasing its quality one-for-one with the increase in the standard. In other respects our results differ from those in Ronnen (1991), Crampes and Hollander (1995) and Arora and Gangopadhyay (1995), since an increase in the standard leads to a *reduction* in the environmental quality of the high quality firm (the welfare results also differ, as we discuss in the next section). These differences highlight the importance of the nature of consumer heterogeneity. When consumer heterogeneity is primarily in willingness to pay for product greenness, then the world is best described by the three papers cited above, and firm environmental qualities are strategic complements. When consumer heterogeneity is primarily in terms of brand specific horizontal attributes, firm environmental qualities are strategic substitutes.

In the next section, we turn to the analysis of the welfare implications of this model and investigate whether the level of environmental quality is optimal. We then investigate whether an environmental policy based on raising consumer awareness about the externality can lead to optimal product environmental quality, and discuss the effects of a minimum quality standard.

[23]Of course, the regulator's choice of S_B would not coincide with the choice of S_B in a sequential game in which firm B chooses quality first, but it moves S_B in "the right direction" relative to the simultaneous game values.

4 Welfare Analysis

In this section we first derive the total welfare generated in this market. We then investigate the effects of exogenous changes in consumer altruism on welfare, focusing on the possibility that increasing consumer awareness and imparting altruism on consumers (such that $\lambda = \lambda_S$) can induce the socially optimal level of the environmental attribute. Finally, we consider giving a tax on less green products, an R&D subsidy or the imposition of a minimum quality standard in a market with fully aware and totally altruistic consumers, i.e., in a market in which $\lambda = \lambda_S$. We investigate the effect of these policies on the environmental quality choice of the high intrinsic quality firm, on total welfare, and on firm profits. We assume throughout that the regulator cannot control the prices at which firms sell their product (the prices are chosen by the firms given the values of the environmental attribute).

Given that every consumer purchases a product from one of the two firms and given that prices paid by consumers are merely a welfare neutral transfer, the total welfare consists of four components: (i) The value, V_j, that consumers attach to the product they purchase, (ii) the total social value, $\lambda_S S_j$, of the environmental attribute of the purchased products, (iii) the "transport" costs of each consumer, θd_{ij}, and (iv) the cost of providing the environmental attribute, KS_j^2, for each of the two products. Therefore, total welfare is given by

$$W = \int_0^{x_c} V_A + \lambda_S S_A - \theta x \; dx + \int_{x_c}^1 V_B + \lambda_S S_B - \theta(1-x) \; dx - KS_A^2 - KS_B^2 \qquad (15)$$

Evaluating the integrals and collecting terms, we can write the welfare function as:

$$W = (V_A + \lambda_S S_A)x_c + (V_B + \lambda_S S_B)(1 - x_c) - \theta \left(\frac{1}{4} + \left(x_c - \frac{1}{2} \right)^2 \right) - K(S_A^2 + S_B^2) \qquad (16)$$

Substituting the equilibrium values given in Proposition 1, and recalling that $q_A = x_c$ and $q_B = 1 - x_c$, we obtain the "reduced form" expression for the welfare function, which we omit as it is lengthly and not very insightful. Before we consider a formal analysis of the welfare function for the general formulation of the model, it is instructive to first consider the symmetric case of

$V_A = V_B = V$. For this case, the above expression simplifies to

$$W = \left(V + \lambda_S \frac{\lambda}{6K}\right) - \frac{\theta}{4} - 2K\left(\frac{\lambda}{6K}\right)^2 \tag{17}$$

Observe that welfare is increasing in λ if

$$\frac{\lambda_S}{6K} - \frac{\lambda}{9K} > 0 \Rightarrow \lambda < \frac{2}{3}\lambda_S \tag{18}$$

This implies that even if consumers fully internalize the externality, environmental quality is sub-optimal. In other words, it is actually socially optimal to convince consumers that the product produced by the two firms is more damaging in the environment that it really is to put pressure on the firms to produce a product that has optimal "greenness." The intuition for why full internalization of the externality by the consumers is not sufficient to lead to the socially optimal outcome is as follows. When a firm raises its environmental quality, thus making its product more attractive to consumers, its competitor responds by cutting its price to stem the erosion of market share. Therefore, an increase in the environmental quality of a firm's product has an adverse effect on the competitive environment that this firm operates in (even holding the environmental quality of its competitor fixed); this partially mitigates any benefits that firm may reap from having a product that is more valued by consumers. For this reason, firms under-abate even if individual consumers have the preferences of the social planner.[24]

When firms are of asymmetric intrinsic quality, it is no longer clear that the above intuition holds. As consumers become more averse to polluting products, the two firms react differently in terms of increasing product quality. In particular, it can be easily seen from Proposition 1 that firm A responds more strongly to an increase in λ than firm B, further changing the relative shares of the two firms, increasing consumer transport costs and the marginal cost of quality for the two

[24]If firms competed by commiting to output rather than prices, then, following the reasoning in Fudenberg and Tirole (1984) and Bulow, Geanakoplos and Klemperer (1985), equilibrium product greenness would have been higher than the level given in Proposition 1. Product greeness can be thought of as a first-stage investment that affects the nature of second stage competition between the firms. First stage investment is higher when the strategic instruments of second stage competition are strategic substitutes (quantities) than if they were strategic complements (prices). However, this line of reasoning does not result in an unambiguous comparison of first-stage investment levels with the socially optimal values.

firms. Proposition 3 below shows that the result shown in equation (18) holds more generally for asymmetric firms.

Proposition 3. *Total welfare is increasing in λ even when consumers fully internalize the pollution externality, i.e., even when $\lambda = \lambda_S$.*

Proof. See the Appendix.

The above results suggest that there is scope for effective government intervention beyond educating the public about the adverse environmental effects of this product. One such intervention would be a tax on products that are not green or, equivalently, a subsidy for green products. This policy would be isomorphic to increasing λ and, when applied to a fully educated and altruistic public, it would be equivalent to a policy of convincing the public that the externality is worse than it actually is. The discussion in the preceding section shows that firm B would oppose it such policies and so would firm A, unless its product is of sufficiently high intrinsic quality. Another possible intervention could take the form of a partial subsidy of the development costs of producing greener versions of this product.

The following proposition summarizes the aggregate welfare impact of the cost-sharing policy whose impact on firm profits we have analyzed earlier.

Proposition 4. *If consumers fully internalize the pollution externality, subsidizing the private cost of quality will improve aggregate social welfare for all levels of K and all levels of λ.*

Proof. See the Appendix.

Similar to the result in the previous proposition, a policy that targets both firms symmetrically and induces both to raise their levels of greenness will be opposed by the less green firm but would be welfare-increasing. All consumers enjoy the higher environmental quality that results from the technical assistance aimed at helping defray the cost of technology development of both, thereby, unambiguously increasing social welfare.

A third possible intervention would be to impose a minimum environmental quality standard that would raise the "greenness" of firm B's product. This type of regulation is asymmetric in nature in that it directly affects only one of the two firms. The corollary below examines the effects of such a standard on welfare and firm profits.

Proposition 5. *Suppose that consumers fully internalize the pollution externality. Then, an Minimum Quality Standard increases total welfare when firms A and B have products of similar intrinsic quality, but decreases total welfare when the intrinsic quality of firm A's product is much better than that of firm B's.*

Proof. See the Appendix.

This result stands in contrast to those above. Even though it appears that the market underprovides environmental quality, an attempt to increase it through an MQS can be counterproductive. The reason is that a mandated increase in the quality of firm B (the low quality firm) leads to a decrease in the quality of firm A (the high quality firm). The high quality firm sells more units, especially if its product is far superior to that of firm B. It follows then, that if the quality difference (and thus market share difference) between firms A and B is large enough, a minimum quality standard can reduce aggregate quality sufficiently to reduce total welfare. Note that this finding is in contrast to those in much of the quality literature (Ronnen 1991, Crampes and Hollander 1995, and Arora and Gangopadhyay 1995), a difference that highlights the importance of the nature of consumer heterogeneity. When consumer heterogeneity is primarily in willingness to pay for product greenness, then the world is best described by these three pure vertical differentiation models: firm environmental qualities are strategic complements and thus a minimum quality standard increases quality and is socially desirable. When consumer heterogeneity is primarily in terms of brand specific horizontal attributes, firm environmental qualities are strategic substitutes (as discussed earlier) and minimum quality standard may be socially undesirable.[25]

Comparing the findings in Proposition 5 with the results in Corollary 3 show that firm attitudes toward seemingly equivalent public interventions depend qualitatively on the nature of such

[25] Recent work by Uchida (2007) analyzes vertically differentiated markets, and arrives at the similarly counter-intuitive conclusion that eco-labeling can actually increase pollution by leading to reduced price and increased sales of the product that does not meet the eco-labeling standard.

interventions. The intrinsically high quality firm will welcome an environmental policy that targets both firms symmetrically, when the intrinsic quality difference is high enough, but will definitely oppose a policy that forces them to choose more similar environmental quality levels.

Finally, it is worth contrasting the results of Propositions 3, 4, and 5, which together show that the welfare implications of public policy also depend crucially on the nature of the public intervention. Even when consumers fully internalize the pollution externality, further intervention, that is targeted to both firms, through a (per-unit) tax on polluting products, (or through a (per-unit) subsidy on cleaner products), or by inducing the public to over-estimate the extent of the exernality, or through a cost-sharing subsidy, increases welfare. This increase in welfare is due to the higher level of environmental quality enjoyed by all consumers, despite having one or both firms opposing such a policy because of the adverse impact on their profits. However, a minimum quality standard that only targets the low quality firm does not necessarily increase social welfare.

5 Further Discussion and Policy Implications

The primary contribution of this paper is to increase our understanding of firm behavior in markets with consumers who care both about product greenness and other brand-specific product attributes. It sheds light on the choice of environmental quality of products by firms in the absence of any regulatory intervention and the response of firms to various types of regulatory and non-regulatory interventions to increase product greenness. Moreover, the paper also discusses the political economy implications of these interventions, in particular whether firms would lobby for or against them, and the impact of these interventions on social welfare. The framework we adopt is stylized, so as to clearly highlight the sources of various results, but sufficiently general to allow for firm heterogeneity in intrinsic quality, and thus heterogeneity in firm responses.

In conclusion, we'd like to focus on the policy implications of our results for markets with consumers who fully internalize the environmental damage either, possibly because consumers are altruistic and believe in "doing the right thing," or because taxation of the product is sufficient so that consumers fully bear the non-internalized portion of the environmental damage caused by the product. We show that environmental quality will still be underprovided in such markets, because oligopolistic interaction between firms can dissipate the incentives for raising product greenness. This implies that there is scope for regulatory intervention even in these markets. We examine the implications of government intervention and show that a technology development subsidy for green products or a taxation of polluting products (equivalently, subsidy of green produts) are two instruments that can unambiguously increase social welfare. We then examine the efficacy of minimum product environmental quality standards. Our analysis shows that the effects of such a standard on social welfare is ambiguous. It improves welfare only when firms are similar in intrinsic quality. In fact, a minimum quality standard would lead the high quality firm to lower the greenness of its product although it would continue to overcomply with the standard (for standards that are not too high). This result differs from those obtained by models in which products are only vertically differentiated by their environmental attribute. These models find that a minimum quality standard would also increase the environmental quality of the product offered by the high quality firm and it would increase social welfare (for standards that are not too high).

Equally importantly from the political economy standpoint, we are able to show that firm preferences for various policy instruments vary, regardless of whether or not the consumers fully internalize the externality. In fact firm responses can be diametrically opposite. A firm that would welcome a tax or an environmental awareness program may oppose a minimum quality standard, even if it is not binding to that firm, while the preferences of its competitor may be reversed.

A secondary contribution of this paper is to provide a framework that helps explain some observed patterns of firm behavior in the presence of environmentally conscious consumers. This may explain the real world observations that market leaders such as Unilever, Japanese automobile firms (Toyota and Honda) and McDonalds also lead in the production of products that are more environmentally efficient. [26]

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[26]Unilever which ranks high in initial customer satisfaction is also leading in improving the environmental efficiency of their manufacturing operations, products and services by reducing chemical oxygen demand, hazardous and non-hazardous waste generation, water use and energy use and sulfur dioxides. In 2003 Unilever ranked at the top in UK's Corporate Responsibility Index (http://www/unilever.com/environmentsociety/newsawards]. Similarly, McDonalds which is the biggest burger seller (http://www.thejournalnews.com/newsroom/012904/d0229burgerwarswp.html) is

6 Appendix: Proofs of Propositions

Proof of Proposition 1. Maximizing the profit function of firm A with respect to its choice of product quality we obtain the first order condition

$$\frac{\partial \Pi_A}{\partial S_A} = 0 \Rightarrow \frac{\lambda}{3} + \frac{2}{18}\frac{\lambda^2}{\theta}(S_A - S_B) + \frac{2}{18}\frac{\lambda}{\theta}(V_A - V_B) - 2KS_A = 0 \tag{19a}$$

$$\frac{\partial \Pi_B}{\partial S_B} = 0 \Rightarrow \frac{\lambda}{3} - \frac{2}{18}\frac{\lambda^2}{\theta}(S_A - S_B) - \frac{2}{18}\frac{\lambda}{\theta}(V_A - V_B) - 2KS_B = 0 \tag{19b}$$

The second-order conditions imply:

$$\frac{\partial^2 \Pi_A}{\partial S_A^2} = \frac{\partial^2 \Pi_A}{\partial S_B^2} < 0 \Rightarrow \frac{\lambda^2}{9\theta} - 2K < 0 \tag{20}$$

Solving for S_A in (19a) and for S_B in (19b) respectively yields:

$$S_A = \frac{\lambda(3\theta - \lambda S_B + (V_A - V_B))}{18K\theta - \lambda^2} \tag{21a}$$

$$S_B = \frac{\lambda(3\theta - \lambda S_A - (V_A - V_B))}{18K\theta - \lambda^2} \tag{21b}$$

Substituting the expression for S_B into the right hand side of the expression for S_A and solving for S_A yields

$$S_A = \frac{\lambda(9K\theta - \lambda^2 + 3K(V_A - V_B))}{6K(9K\theta - \lambda^2)} \tag{22}$$

Substituting this into the expression for S_B and writing the expression conformably to that for S_A yields

$$S_B = \frac{\lambda(9K\theta - \lambda^2 - 3K(V_A - V_B))}{6K(9K\theta - \lambda^2)} \tag{23}$$

Simplifying these expressions yields the results in (11). Substituting these into equation (8) yields the expressions for the market shares in (13). The equilibrium environmental quantity differential

also leading in efforts to use bio-degradable packaging, in reducing unhealthy trans-fats in food and in transporting and slaughtering animals in more humane ways (New York Times, June 25, 2003). Finally, Toyota and Honda, which lead in terms of market share among passenger cars, are more likely to lead in fuel efficiency (Greenwire, 2002). [Toyota Camry and Honda Accord ranked higher than Ford Tauras and Ford Focus in sales in 2001 and they had the highest ratio of sales per model in the automobile industry in 2002 (http://www/automotivedigest.com). These shares were 2.1 and 2.3 for Toyota and Honda respectively followed by 1.5 for Chrysler, 1 for GM and 0.8 for Ford. Honda and Toyota models were given the highest Green Scores by ACEEE in 2002 (http//: www.greenercars.com/pr8.html).]

is thus computed as

$$q_A - q_B = \frac{3K\Delta V}{9K\theta - \lambda^2}$$

Substituting back the equilibrium environmental quality differential to equations (7) and (6) and simplifying yields the expressions for price in (12). The price differential is

$$P_A - P_B = \frac{6K\theta\Delta V}{9K\theta - \lambda^2}$$

Substituting back the equilibrium values of prices, quantities and environmental quality into the profit functions, we derive the profit equations in (14). The profit differential is

$$\Pi_A - \Pi_B = \frac{\Delta V(18K\theta - \lambda^2)}{3(9K\theta - \lambda^2)}$$

To compare quality levels, prices and market shares between firms, we need to sign the denominator of the above differences. Observe that by Assumption 2 $3K\Delta V + \lambda^2 < 9K\theta$ which implies that $9K\theta - \lambda^2 > 0$. Thus, implying that the price, market share and quality chosen by firm A are higher than those chosen by firm B. The high quality firm also earns higher profits than the low quality firm (since, by Assumption 2, $-9K\theta + 3K\Delta V + \lambda^2 < 0$ and thus an increase in ΔV increases the numerator of Π_A and decreases that of Π_B). □

Proof of Corollary 1. The derivative of S_A with respect to λ is clearly positive. The derivative of S_B with respect to λ can be written as

$$\frac{\partial S_B}{\partial \lambda} = \frac{1}{6}\left(\frac{1}{K} - \frac{3\Delta V(9K\theta + \lambda^2)}{(-9K\theta + \lambda^2)^2}\right) \tag{24}$$

The firm B's choice of environmental quality increases with λ if ΔV is low. For S_B to be increasing in λ, it is required that

$$\Delta V < \frac{(-9K\theta + \lambda^2)^2}{3K(9K\theta + \lambda^2)} \tag{25}$$

Otherwise, S_B falls with λ. The upper bound of the values of ΔV that satisfy Assumption 2 (which is equal to $3\theta - \frac{\lambda^2}{3K}$) is higher than right hand side of the above inequality. This can be demonstrated as follows:

$$3\theta - \frac{\lambda^2}{3K} - \frac{(-9K\theta + \lambda^2)^2}{3K(9K\theta + \lambda^2)} = \frac{(9K\theta - \lambda^2)(9K\theta + \lambda^2) - (81K^2\theta^2 - 18K\theta\lambda^2 + \lambda^4)}{3K(9K\theta + \lambda^2)} \tag{26}$$

$$= \frac{2\lambda^2(9K\theta - \lambda^2)}{3K(9K\theta + \lambda^2)} > 0. \tag{27}$$

Thus, S_B increases with λ if

$$\frac{9K\theta - \lambda^2}{3K} > \frac{(-9K\theta + \lambda^2)^2}{3K(9K\theta + \lambda^2)} > \Delta V \tag{28}$$

And S_B decreases with λ if

$$\frac{9K\theta - \lambda^2}{3K} > \Delta V > \frac{(-9K\theta + \lambda^2)^2}{3K(9K\theta + \lambda^2)} \tag{29}$$

Since $9K\theta - \lambda^2 > 0$ by Assumption, the above two conditions can be simplified as $1 > \frac{9K\theta-\lambda^2}{9K\theta+\lambda^2} > \Delta V$ and $1 > \Delta V > \frac{9K\theta-\lambda^2}{9K\theta+\lambda^2}$, respectively.

The derivative of S_A with respect to K is clearly negative. That of S_B is as follows

$$\frac{\partial S_B}{\partial K} = -\frac{\lambda}{6K^2} + \frac{9\theta\lambda\Delta V}{2(-9K\theta + \lambda^2)^2} \tag{30}$$

This expression is negative if $(-9K\theta + \lambda^2)^2 > 27\theta\Delta V K^2$ and is positive otherwise. Given that $9K\theta - \lambda^2 > 3K\Delta V \geq 0$ by Assumption 2, a sufficient condition for $(-9K\theta + \lambda^2)^2 < 27\theta\Delta V K^2$ (so that S_B increases with K) is

$$9K\theta - \lambda^2 < 3K\sqrt{3\theta\Delta V} \Rightarrow \tag{31}$$

$$\Delta V > \left(\frac{9K\theta - \lambda^2}{3K}\right)^2 \frac{1}{3\theta} \tag{32}$$

But we know from Assumption 2 that $9K\theta - \lambda^2 > 3K\Delta V \geq 0$. Thus, in order for ΔV to be low enough such that Assumption 2 is satisfied and high enough so that (32) is satisfied, we need

$$\left(\frac{9K\theta - \lambda^2}{3K}\right)^2 \frac{1}{3\theta} < \frac{9K\theta - \lambda^2}{3K} \Rightarrow \tag{33}$$

$$\frac{9K\theta - \lambda^2}{3K} < 3\theta \Rightarrow \tag{34}$$

$$9K\theta - \lambda^2 < 9K\theta \tag{35}$$

which holds. Moreoever, Assumption 1 will be satisfied for high enough values of V_A and V_B, and assumption 3 will be satisfied for low enough values of λ, neither of which impacts the validity of the above inequality. Therefore, S_B is decreasing in K for low ΔV, but increasing in K for sufficiently high ΔV, and both signs are consistent with the Assumptions 1 through 3.

Now, we can actually show that the right hand side of (25) is less than the right hand side of (32)

$$\frac{(-9K\theta+\lambda^2)^2}{3K(9K\theta+\lambda^2)} < \left(\frac{9K\theta-\lambda^2}{3K}\right)^2\frac{1}{3\theta} \tag{36}$$

$$\frac{(9K\theta-\lambda^2)^2}{3K(9K\theta+\lambda^2)} < \frac{(9K\theta-\lambda^2)^2}{9K^2}\frac{1}{3\theta} \tag{37}$$

$$\frac{1}{9K\theta+\lambda^2} < \frac{1}{9K\theta} \tag{38}$$

This means that if $\frac{\partial S_B}{\partial K} > 0$ then it follows that $\frac{\partial S_B}{\partial \lambda} < 0$, but not vice versa. □

Proof of Corollary 3. Proof for Corollary 3 involves taking the derivative of the profit functions indicated in equations (14) with respect to ΔV, λ and with respect to K. The comparative statics with respect to ΔV are straightforward.

We first derive the conditions under which derivative of Π_A with respect to λ is positive. Observe that

$$\frac{\partial \Pi_A}{\partial \lambda} = \frac{\lambda(-3K(\Delta V+3\theta)+\lambda^2)(-81K^2(\Delta V-\theta)\theta+3K(\Delta V-6\theta)\lambda^2+\lambda^4)}{18K(9K\theta-\lambda^2)^3} \tag{39}$$

Assumption 2 can be expressed as $3K\Delta V+\lambda^2-9K\theta < 0 \rightarrow 3K(3\theta-\Delta V)-\lambda^2 > 0 \rightarrow 9K\theta-3K\Delta V-\lambda^2 > 0$. Since $\Delta V \geq 0$, this implies that the denominator is positive. The first expression in the numerator can be expressed as $3K(-\Delta V-3\theta)+\lambda^2$ which is less than $3K(\Delta V-3\theta)+\lambda^2$, which is negative, by Assumption 2. Thus, the first expression in the numerator is negative. Therefore, Π_A is increasing in λ if the second expression in the numerator is negative, which holds for

$$\Delta V > \frac{(9K\theta-\lambda^2)^2}{3K(27K\theta-\lambda^2)} \tag{40}$$

Note that the denominator of the above fraction is guaranteed to be positive by Assumption 2 as well. It remains to show that the right hand side of the above inequality can be sufficiently small, so that there exist values of ΔV that satisfy the above inequality and also Assumption 2, which requires $\Delta V < \frac{9K\theta-\lambda^2}{3K}$. This is indeed the case, as we show below.

$$\frac{(9K\theta-\lambda^2)^2}{3K(27K\theta-\lambda^2)} < \frac{9K\theta-\lambda^2}{3K} \rightarrow \frac{9K\theta-\lambda^2}{27K\theta-\lambda^2} < 1 \tag{41}$$

given that $9K\theta - \lambda^2 > 0$ by Assumption 2. The right hand side is trivially true, since the numerator is smaller than the denominator. Note that holding all other parameters constant, Assumption 1 will be satisfied for high enough values of V_A and V_B and Assumption 3 will also be satisfied for small enough values of λ. Thus, profit of firm A increases with λ if $\Delta V > \frac{(9K\theta-\lambda^2)^2}{3K(27K\theta-\lambda^2)}$ and this condition can be satisfied simultaneously with Assumptions 1 through 3.

The derivative of Π_A with respect to K can also be shown to be negative under the same condition that guarantees that profit of A increases with λ. Observe that:

$$\frac{\partial \Pi_A}{\partial K} = \frac{\lambda^2(3K(\Delta V + 3\theta) - \lambda^2)(-81K^2(\Delta V - \theta)\theta + 3K(\Delta V - 6\theta)\lambda^2 + \lambda^4)}{36K^2(9K\theta - \lambda^2)^3} \tag{42}$$

Following arguments developed above, Assumption 2 implies that the denominator and the first term in the numerator are both positive. The second expression in the numerator is negative if $\Delta V > \frac{(9K\theta-\lambda^2)^2}{3K(27K\theta-\lambda^2)}$, which is the same condition that guarantees that $\frac{\partial \Pi_A}{\partial \lambda}$ is positive. Thus, when $\Delta V > \frac{(9K\theta-\lambda^2)^2}{3K(27K\theta-\lambda^2)}$, Π_A increases with λ and falls with K. The reverse are true if $\Delta V < \frac{(9K\theta-\lambda^2)^2}{3K(27K\theta-\lambda^2)}$. Moreover, Assumptions 1 and 3 will also be satisfied simultaneously with Assumption 2 for high values of V_A and V_B and small enough values of λ.

We likewise derive and sign the comparative statics of Π_B with respect to λ and K. We first show the profit of firm B is declining in λ. Observe that

$$\frac{\partial \Pi_B}{\partial \lambda} = \frac{\lambda(3K(\Delta V - 3\theta) + \lambda^2)(81K^2\theta(\Delta V + \theta) - 3K(\Delta V + 6\theta)\lambda^2 + \lambda^4)}{18K(9K\theta - \lambda^2)^3} \tag{43}$$

By Assumption 2 and following arguments made above, the denominator is positive and the first term in the numerator is negative. The profit of firm B, therefore will be decreasing in λ if the second term in the numerator is positive. Note that this second term can be re-written as $(9K\theta - \lambda^2)^2 + 3K(27K\theta - \lambda^2)\Delta V$ which is always positive since $9K\theta - \lambda^2 > 0$ (true by arguments made above) implies $27K\theta - \lambda^2 > 0$, and since $\Delta V \geq 0$. Thus, $\frac{\partial \Pi_B}{\partial \lambda} < 0$.

We will finally show that the profits of firm B are increasing in K. Observe that:

$$\frac{\partial \Pi_B}{\partial K} = \frac{-\lambda^2(3K(\Delta V - 3\theta) + \lambda^2)(81K^2\theta(\Delta V + \theta) - 3K(\Delta V + 6\theta)\lambda^2 + \lambda^4)}{36K^2(9K\theta - \lambda^2)^3} \tag{44}$$

Repeating earlier arguments, the denominator and the first term in the numerator (which includes

$-\lambda^2$) are both positive by Assumption 2. The second term in the numerator has already be shown to be positive immediately above. Hence, $\frac{\partial \Pi_B}{\partial K} > 0$

□

Proof of Proposition 2. We start by recalling from the proof of Proposition 1 that

$$S_A = \frac{\lambda(3\theta - \lambda S_B + (V_A - V_B))}{18K\theta - \lambda^2}$$

Clearly, an exogenous increase in S_B would reduce S_A, since the denominator of the expression above is positive by Assumption 2. From equations (6), (7), and (8), it readily follows that the price and quantity sold of firm B will increase, while those of firm A will decrease.

We final turn to evaluating the effect of increasing the minimum quality standard on profits. The minimum quality standard is effectively equivalent to treating the minimum quality of firm B as a parameter rather than as a decision variable of firm B. Multiplying the numerators and denominators of the fractions in the profit functions (9) and (10) and substituting (21a) for S_A, we obtain

$$\Pi_A = \frac{\left(3\theta + \lambda\left(\frac{\lambda(3\theta + \Delta V - \lambda S_B)}{18K\theta - \lambda^2} - S_B\right) + \Delta V\right)^2}{18\theta} - K\left(\frac{\lambda(3\theta + \Delta V - \lambda S_B)}{18K\theta - \lambda^2}\right)^2$$

$$\Pi_B = \frac{\left(3\theta - \lambda\left(\frac{\lambda(3\theta + \Delta V - \lambda S_B)}{18K\theta - \lambda^2} - S_B\right) + \Delta V\right)^2}{18\theta} - KS_B^2$$

Taking the derivative with respect to S_B we have:

$$\frac{\partial \Pi_A}{\partial S_B} = \frac{2K\lambda(-3\theta + \lambda S_B - \Delta V)}{18K\theta - \lambda^2}$$

$$\frac{\partial \Pi_B}{\partial S_B} = \frac{-2K(324K^2\theta^2 S_B - 54K\theta\lambda(\theta + \lambda S_B) + \lambda^3(6\theta + \lambda S_B) + 18K\theta\lambda\Delta V)}{(18K\theta - \lambda^2)^2}$$

Since we are considering increases in the minimum quality standard from the Nash equilibrium level of S_B, we evaluate the above derivatives at the value of S_B given in Proposition 1. The above derivatives, then, can be simplified to yield

$$\frac{\partial \Pi_A}{\partial \overline{S}} = -\frac{\lambda(9K\theta - \lambda^2 + 3K\Delta V)}{3(9K\theta - \lambda^2)} \quad (45)$$

$$\frac{\partial \Pi_B}{\partial \overline{S}} = \frac{\lambda^3(9K\theta - \lambda^2 - 3K\Delta V)}{3(9K\theta - \lambda^2)(18K\theta - \lambda^2)} \quad (46)$$

All terms in (45) and (46) are positive by Assumption 2, which means that the profits of firm A are decreasing in the minimum quality standard, while the profits of firm B are increasing.

□

Proof of Proposition 3. Differentiating (16) with respect to λ, while observing that $q_A = x_c$ and $q_B = 1 - x_c$, we obtain

$$\begin{aligned}\frac{\partial W}{\partial \lambda} &= (V_A + \lambda_S S_A)\frac{\partial q_A}{\partial \lambda} + \lambda_S q_A \frac{\partial S_A}{\partial \lambda} \\ &+ (V_B + \lambda_S S_B)\frac{\partial q_B}{\partial \lambda} + \lambda_S q_B \frac{\partial S_B}{\partial \lambda} \\ &- 2\theta\left(q_A - \frac{1}{2}\right)\frac{\partial q_A}{\partial \lambda} - 2K\left(\frac{\partial S_A}{\partial \lambda} + \frac{\partial S_B}{\partial \lambda}\right)\end{aligned} \tag{47}$$

By substituting in the Nash equilibrium values for quality and market shares for firms A and B from Proposition (1) and performing the required differentiations, we obtain

$$\begin{aligned}\frac{\partial W}{\partial \lambda} &= \left(V_A + \lambda_S\left(\frac{\lambda(9K\theta - \lambda^2) + 3K\lambda\Delta V}{6K(9K\theta - \lambda^2)}\right)\right)\frac{3K\lambda\Delta V}{(9K\theta - \lambda^2)^2} \\ &+ \left(V_B + \lambda_S\left(\frac{\lambda(9K\theta - \lambda^2) - 3K\lambda\Delta V}{6K(9K\theta - \lambda^2)}\right)\right)\frac{-3K\lambda\Delta V}{(9K\theta - \lambda^2)^2} \\ &+ \lambda_S\left(\frac{1}{2} + \frac{3K\Delta V}{2(9K\theta - \lambda^2)}\right)\left(\frac{1}{6K} + \frac{3\Delta V(9K\theta + \lambda^2)}{6(9K\theta - \lambda^2)^2}\right) \\ &+ \lambda_S\left(\frac{1}{2} - \frac{3K\Delta V}{2(9K\theta - \lambda^2)}\right)\left(\frac{1}{6K} - \frac{3\Delta V(9K\theta + \lambda^2)}{6(9K\theta - \lambda^2)^2}\right) \\ &- 4K\left(\frac{\lambda}{36K^2} + \frac{\lambda\Delta V^2(9K\theta + \lambda^2)}{4(9K\theta - \lambda^2)^3}\right) - \frac{18K^2\Delta V^2\theta\lambda}{2(9K\theta - \lambda_S^2)^3}\end{aligned}$$

Combining the first two terms and setting $\lambda = \lambda_S$ we get

$$\begin{aligned}\frac{\partial W}{\partial \lambda}|_{\lambda=\lambda_S} &= \left(\Delta V + \lambda_S\frac{\lambda_S^2\Delta V}{9K\theta - \lambda_S^2}\right)\frac{3K\lambda_S\Delta V}{(9K\theta - \lambda_S^2)^2} \\ &+ \lambda_S\left(\frac{1}{2} + \frac{3K\Delta V}{2(9K\theta - \lambda_S^2)}\right)\left(\frac{1}{6K} + \frac{3\Delta V(9K\theta + \lambda_S^2)}{6(9K\theta - \lambda_S^2)^2}\right) \\ &+ \lambda_S\left(\frac{1}{2} - \frac{3K\Delta V}{2(9K\theta - \lambda_S^2)}\right)\left(\frac{1}{6K} - \frac{3\Delta V(9K\theta + \lambda_S^2)}{6(9K\theta - \lambda_S^2)^2}\right) \\ &- 4K\left(\frac{\lambda_S}{36K^2} + \frac{\lambda_S\Delta V^2(9K\theta + \lambda_S^2)}{4(9K\theta - \lambda_S^2)^3}\right) - \frac{18K^2\Delta V^2\theta\lambda_S}{2(9K\theta - \lambda_S^2)^3}\end{aligned}$$

After successive manipulations, this expression simplifies to

$$\frac{\partial W}{\partial \lambda}|_{\lambda=\lambda_S} = \frac{\lambda_S(81K^3\theta(5\Delta V^2 + 9\theta^2) + 9K^2\lambda_S^2(\Delta V^2 - 27\theta^2) + 27K\theta\lambda_S^4 - \lambda_S^6)}{18K(9K\theta - \lambda_S^2)^3}$$

The denominator is positive. The numerator is also positive if

$$81K^3\theta(5\Delta V^2+9\theta^2)+9K^2\lambda_S^2(\Delta V^2-27\theta^2)+27K\theta\lambda_S^4-\lambda_S^6>0\Rightarrow$$

$$(9K^2\lambda_S^2+405K^3\theta)\Delta V^2+(9K\theta-\lambda_S^2)^3>0$$

which is always satisfied given that the second term is positive by Assumption 2 (recall that we are considering the case of $\lambda=\lambda_S$). Thus, increasing λ increase welfare for all levels of ΔV. □

Proof of Proposition 4. After substituting in the Nash values for S_A, S_B, q_A and q_B in (16) and letting the private cost of quality be C be distinct from the social cost, K in the expressions for S_A, S_B, q_A and q_B, the welfare function is:

$$\begin{aligned}W=&\left(V_A+\lambda_S\left(\frac{\lambda}{6C}+\frac{\lambda\Delta V}{2(9C\theta-\lambda^2)}\right)\right)\left(\frac{1}{2}+\frac{3C\Delta V}{2(9C\theta-\lambda^2)}\right)\\&+\left(V_B+\lambda_S\left(\frac{\lambda}{6C}-\frac{\lambda\Delta V}{2(9C\theta-\lambda^2)}\right)\right)\left(\frac{1}{2}-\frac{3C\Delta V}{2(9C\theta-\lambda^2)}\right)\\&-\theta\left(\frac{1}{4}+\left(\left(\frac{1}{2}+\frac{3C\Delta V}{2(9C\theta-\lambda^2)}\right)-\frac{1}{2}\right)^2\right)\\&-K\left(\frac{\lambda}{6C}+\frac{\lambda\Delta V}{2(9C\theta-\lambda^2)}\right)^2-K\left(\frac{\lambda}{6C}-\frac{\lambda\Delta V}{2(9C\theta-\lambda^2)}\right)^2\end{aligned}$$

Differentiating the above expression with respect to the private cost C and combining the derivative of the first two terms, we obtain

$$\begin{aligned}\frac{\partial W}{\partial C}=&\frac{\lambda(-(9C\theta-\lambda^2)^3\lambda_S-(9C^2\Delta V^2)(9C\theta\lambda-\lambda^3+(9C\theta+\lambda^2)\lambda_S))}{6C^2(9C\theta-\lambda^2)^3}\\&+\frac{9C\Delta V^2\theta\lambda^2}{2(9C\theta-\lambda^2)^3}+K\lambda^2\left(\frac{(9C\theta-\lambda^2)^3+81C^3\theta\Delta V^2)}{9C^3(9C\theta-\lambda^2)^3}\right)\end{aligned}$$

Now, equating $C=K$, letting $\lambda=\lambda_S$, and simplifying further, we have

$$\frac{\partial W}{\partial K}=\frac{\lambda^2(-(9K\theta-\lambda^2)^3-243K^3\theta\Delta V^2)}{18K^2(9K\theta-\lambda^2)^3}<0$$

By Assumption 2, the above expression is unambiguously negative, which shows that a subsidy that reduces the cost will always improve social welfare at all levels of K and λ, even when consumers fully internalize the externality, i.e., $\lambda=\lambda_S$. □

Proof of Proposition 5. Using equations 21a and 8, the market shares can be expressed in terms of the minimum quality standard as:

$$q_A = \frac{3\theta + \lambda\left(\frac{\lambda(3\theta+\Delta V-\lambda\overline{S})}{18K\theta-\lambda^2} - \overline{S}\right) + \Delta V}{6\theta}$$
$$q_B = \frac{3\theta - \lambda\left(\frac{\lambda(3\theta+\Delta V-\lambda\overline{S})}{18K\theta-\lambda^2} - \overline{S}\right) - \Delta V}{6\theta}$$

The welfare function in (16) can be divided into the consumer surplus, cost of environmental quality, transport cost parts as follows:

$$CS = (V_A + \lambda_S S_A)q_A + (V_B + \lambda_S S_B)q_B$$
$$Cost = -K(S_A^2 + S_B^2)$$
$$TC = -\theta\left(\frac{1}{4} + \left(q_A - \frac{1}{2}\right)^2\right)$$

Substituting in the expressions for q_A and q_B from above and the expression for S_A from (21a) into the components of the welfare function, taking the derivative of the welfare function with respect to S_B, and evaluating the derivative at the Nash Equilibrium values of S_B given in Proposition 1, we have

$$\frac{\partial CS}{\partial \overline{S}} = \frac{\lambda(9K\theta - \lambda^2)^2 - 54K^2\theta\Delta V}{(18K\theta - \lambda^2)(9K\theta - \lambda^2)}$$
$$\frac{\partial Cost}{\partial \overline{S}} = -\frac{2\lambda(9K\theta - \lambda^2)^2 - 27K^2\theta\Delta V}{3(18K\theta - \lambda^2)(9K\theta - \lambda^2)}$$
$$\frac{\partial TC}{\partial \overline{S}} = -\frac{9K^2\theta\lambda\Delta V}{(18K\theta - \lambda^2)(9K\theta - \lambda^2)}$$

Adding these up and simplifying results in:

$$\frac{\partial W}{\partial \overline{S}} = \frac{\lambda((9K\theta - \lambda^2)^2 - 81K^2\theta\Delta V}{3(18K\theta - \lambda^2)(9K\theta - \lambda^2)}$$

The welfare increases with the minimum quality standard when ΔV is low, i.e.,

$$\Delta V < \frac{(9K\theta - \lambda^2)^2}{81K^2\theta}$$

There are values of ΔV that are higher than the right hand side of this inequality and which also satisfy Assumptions 1 through 3, and thus there are high values of ΔV such that the minimum quality standard decreases welfare.

□

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