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Price Competition and Product Differentiation when Consumers Care for the Environment

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Abstract

Increasing environmental awareness may affect the pleasure of consuming a good for which an environmental friendly substitute is available. When deciding to buy differentiated products, a compromise is sometimes made between preferred characteristics of the good and its environmental properties. In this paper we investigate the market implication of product differentiation when customers are concerned about environmental aspects of the good. We use the spacial duopoly model to determine how environmental concern affects prices, product characteristics and market shares of the competing firms. Our analysis is based on a two-stage game where at the first stage each firm chooses the characteristic of its product. At the second stage each firm chooses its price. The unique equilibrium prices and market shares are affected by consumer awareness of the environment and by the higher costs for producing those goods. As for the Nash equilibria in the characteristics we find three equilibria depending on the parameter constellation. In order to find out whether the market functions in an optimal way we determined the choice of environmental characteristics by a welfare maximizing authority. The result of this analysis is that characteristics differ under private decision making and social one. It can be shown, however, that it is possible to choose environmental policy instruments in order to stimulate private firms to produce the social optimal qualities.

Keywords: Price competition; Quality competition; Environmental awareness; Environmentally friendly products.

JEL classification: L 11, Q 38, H 23

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1. Introduction*

Although nowadays ecologically relevant behavior is expected from a consumer, there are still consumers who buy canned beer or bottled juice under a no refund claim system instead of buying beverages under the deposit-refund system. Consumers also buy paper produced from trees instead of paper recovered from waste paper or normal food instead of eco- or bio-food. They buy cars with a big engine and a bad mileage per liter gasoline instead of a three-liter car. They prefer to use the airplane instead of the train although of a relatively short travel distance, they purchase conventional bulbs instead of electricity saving bulbs or they prefer energy-inefficient halogen light instead of neon tubes. Consumers' individual decisions are based on utility maximizing behavior, but there is a trade-off between utility derived from preferred characteristics of a product and between the moral behavior of buying "green", expected by part of the society. There is product differentiation with respect to environmental friendly characteristics with positive market shares for producers who care about these characteristics and for producers who don't. If a consumer buys a product which lacks any environmental friendly characteristics, he might have a bad conscience because environmental awareness is expected from him. His environmental attitude is influenced by friends, parents, partners, or by the media, but it is often not strong enough to push the market share of environmentally incompatible products towards zero and that one of the environmentally friendly substitute towards one. One reason is that producers are aware of the conflict of consumers between preferred characteristics and their environmental incompatibility. They know that customers, getting their preferred characteristics from an environmentally friendly product, welcome that coincidence but if environmental aspects are missing, they might anyhow buy the product.

Producers respond to consumer's utility from a product and his disutility from not being environmentally friendly in various ways. In addition to offering different characteristics, producers can choose prices such as to prevent the loss of market shares.

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A price could be attractive to the consumer because characteristics of the product offered are similar. In that case, price competition is high. But consumers may also accept higher prices because environmentally friendly products are costlier to produce, making these products more expensive. We will develop a standard model of price competition and product differentiation[1] incorporating the aforementioned environmental awareness of the consumers. The model is similar in spirit to a paper by Grilo, Shy and Thisse (2001) in which equilibrium prices are determined when consumer behavior is characterized by phenomena like conformity or vanity.[2] We will describe market equilibria in which firms choose the characteristics of their respective products as well as their prices. Our analysis is based on a two-stage non-cooperative game. In the first stage, each firm chooses the characteristic of its product (more or less environmental friendly). Then, having observed its rival's characteristics, in the second stage of the game each firm chooses its price. The set of players therefore consists of two firms and a continuum of potential customers represented by the unit interval. They choose from which firm to buy having observed prices and characteristics.

Our objective is to confront our results with those derived in the literature on price competition through product differentiation (e.g. Shaked and Sutton (1982)). In these models the two firms will choose distinct qualities and both will enjoy positive profits at equilibrium. The intuitive idea behind this result is that, as their qualities become close, price competition between the increasingly similar products reduces the profit of both firms. The open question is whether under environmental awareness the equilibrium will be still unique, whether product differentiation will be maximal, and whether profits will be still positive when the costs of production increase with quality, i.e. with environmental properties. The paper is organized as follows. In section 2 we present the model of price and product differentiation and characterize the Nash equilibria. In section 3 we look for social welfare maximizing environmental characteristics and for policy instruments to affect firms' decisions on characteristics towards social ones. Section 4 concludes the paper.

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[1] The standard model has been set out by D'Aspremont et al. (1979) by correcting Hotelling's (1929) "principle of minimum differentiation". They show that no equilibrium price solution exists when both sellers are not far enough from each other. They consider a slightly modified version of Hotelling's model for which there exists a price equilibrium solution everywhere. In this version there is a tendency for both sellers to maximize their differentiation.

[2] See also a model of social distance by Akerlof (1997) that is useful for understanding social decisions.

2. The model

We consider an oligopolistic (duopolistic) market where the two firms compete not only in prices but also in quality. Quality here means that the product differs in terms of its environmental characteristics. When the firm decides on the degree of environmental friendliness of its product, it has to anticipate the strategic effects of its decision on price and attribute of its competitor's product. Our non-cooperative game considers two stages: In the first stage the firms simultaneously choose their respective characteristics. In the second stage they compete in prices. At this stage the characteristics are fixed and irreversible, so that price competition is influenced by the degree of product differentiation. Firms will take this into account when deciding on the characteristics. Our model differs from standard models of product differentiation because of the introduction of a consumption externality. The model is in spirit of models of social interaction in which individuals care about status (belonging to the group of environmentally concerned people) as well as "intrinsic utility" which refers to utility derived directly from consumption.[3] We consider two firms selling a heterogeneous product with characteristics $q_i \in [0,1]$, $i = 1,2$, with $q_1 \leq q_2$. The products are labeled in increasing order of environmental friendliness, i.e. firm 1 is less concerned about not producing environmentally friendly goods. In our model of horizontal product differentiation each consumer buys one unit of the product. There is a continuum of consumers uniformly distributed over the interval [0, 1]. The willingness to pay of consumer $\theta \in [0,1]$ for a unit of the good of property q is defined by:

(1) $$v(q,\theta) = r - t(q-\theta)^2 - d(1-q)$$

in which r stands for the gross, intrinsic utility a consumer derives from consuming one unit of the product. In the tradition of spacial models of product differentiation, it is assumed that r is sufficiently large to ensure that all consumers prefer buying rather than dropping out of the market. The term $t(q-\theta)^2$ represents the costs a consumer, located at $\theta \in [0,1]$, bears if he does not get his preferred characteristic's because he has to buy from firm i selling characteristic's $q_i\,(i=1,2)$. With $d(1-q_i)$ we express the social status of the consumer. It is modeled by the bad conscious of not having purchased the environmentally most friendly product at the end of the characteristic's [0, 1] line. When environmental awareness is

[3] See Bernheim (1994).

sufficiently important relative to intrinsic utility, many individuals conform to a single homogeneous standard of behavior, despite heterogeneous underlying preferences. Social groups often penalize individuals who deviate from accepted norms, even when deviations are relatively minor.[4] We incorporate environmental concern directly into individual preferences. There are at least three separate justifications for doing this. First, the assumption that individuals care about the environment is consistent with evidence. Second, evolutionary pressures could well produce preferences of this form. Third, deviations from social environmental awareness are punished by loss of social "reputation" (not being "in").[5] The utility of consumer θ when buying from i is then defined by

(2) $$U\left(q_i,\theta\right)=r-t\left(q_i-\theta\right)^2-d\left(1-q_i\right)-p_i$$

where p_i is the price of firm i (i = 1, 2). The utility (2) captures different types of product differentiation together with a social externality.[6] The consumer feels he should consider to buy "green" but his preferences are different. Social pressure as an externality compels him to incorporate environmental aspects into his preferences.

The market is modeled as a two-stage game, the solution of which is given by a subgame perfect Nash equilibrium in pure strategies. In the first stage, firms select their characteristics. In the second one, given any pair of characteristics, the firms choose their prices. By backwards induction we want to determine for a given pair of characteristics $\left(q_1,q_2\right)$ all the price pairs for which both firms have a strictly positive demand. We therefore are interested in finding a consumer $\hat{\theta}\in\left(0,1\right)$ who is indifferent between the two suppliers, given their prices $\left(p_1,p_2\right)$. For that, $\hat{\theta}$ must satisfy the following equation:

(3) $$U\left(q_1,\hat{\theta}\right)=U\left(q_2,\hat{\theta}\right).$$

Using (2) and solving (3) for $\hat{\theta}$ yields:

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[4] See Bernheim (1994) for a model of social interaction in which individuals care about status as well as "intrinsic" utility.

[5] In the status model by Akerlof (1997), the individual chooses a status-producing variable x to maximize an utility function $U=u(x)-d\cdot\left(\tilde{x}-x\right)$ where the person loses utility in amount $d\left(\tilde{x}-x\right)$ insofar as she falls behind everyone else in her choice of x where $\tilde{x}$ is the choice of everyone else.

[6] See Grilo, Shy and Thisse (2001).

(4) $$\hat{\theta} = \frac{p_2 - p_1 + t(q_2 - q_1)\left[q_1 + q_2 - d^*\right]}{2\,t(q_2 - q_1)}$$

where $d^* = d/t$. Under horizontal product differentiation consumers split their purchase between the two firms when they offer their product at the same price. Setting $p_1 = p_2$ in (4) implies $0 < q_1 + q_2 - d^* < 2$ as a condition for horizontal product differentiation. For consumers with $\theta < \hat{\theta}$, it is $v(q_1,\theta) - p_1 > v(q_2,\theta) - p_2$; i.e. they buy the product of firm 1. Consumers with $\theta > \hat{\theta}$ buy the product of firm 2 as for them $v(q_1,\theta) - p_1 < v(q_2,\theta) - p_2$. The firm specific demand functions are therefore

(5) $$D_1(p_1, p_2) = \hat{\theta} \quad , \qquad D_2(p_1, p_2) = 1 - \hat{\theta}$$

for firm 1 and firm 2, respectively.

In producing the two characteristics we assume that costs increase in q. Environmentally friendly products incur higher costs to produce them. Profits are then defined as follows:

(6) $$\pi_1 = \left[p_1 - c\,q_1\right] D_1(p_1, p_2), \quad \pi_2 = \left[p_2 - c\,q_2\right] D_2(p_1, p_2)$$

where c in $C_i = c \cdot q_i \cdot D_i$ is a constant. From the FOCs for a profit-maximizing price strategy we obtain the following reaction functions:

(7) $$p_1 = p_1^R(p_2) = \frac{1}{2}\left\{p_2 + t(q_2 - q_1)\left[q_1 + q_2 - d^*\right] + c\,q_1\right\}$$

(8) $$p_2 = p_2^R(p_1) = \frac{1}{2}\left\{p_1 + t(q_2 - q_1)\left[2 - q_1 - q_2 + d^*\right] + c\,q_2\right\}.$$

Firm *i*'s best response on the price of its competitor depends on the characteristics chosen by the firms at the first stage of the game. Solving the reaction functions for p_1 and p_2 yields the unique equilibrium prices:

(9) $$p_1^* = \frac{1}{3}\Big[t\left(q_2 - q_1\right)\left[2 + q_1 + q_2 - d^*\right] + c\left(q_2 + 2\,q_1\right)\Big]$$

(10) $$p_2^* = \frac{1}{3}\Big[t\left(q_2 - q_1\right)\left[4 - q_1 - q_2 + d^*\right] + c\left(q_1 + 2\,q_2\right)\Big].$$

Since for horizontal product differentiation $0 < q_1 + q_2 - d^* < 2$, prices are positive. Evaluating the marginal consumer (4) at the price equilibrium, we have

(11) $$\theta^* = d_1\left(q_1, q_2\right) = \frac{t\left[2 + q_1 + q_2 - d^*\right] + c}{6\,t}$$

(12) $$1 - \theta^* = d_2\left(q_1, q_2\right) = \frac{t\left[4 - q_1 - q_2 + d^*\right] - c}{6\,t}.$$

Proposition

Consumer awareness of the environment, *d*, lowers the price p_1^* and raises the price p_2^*. The market share of firm 1 will decline and the one of firm 2 will increase, i.e.

$$\frac{\partial\, p_1^*}{\partial\, d^*} < 0, \quad \frac{\partial\, p_2^*}{\partial\, d^*} > 0, \quad \frac{\partial\, \theta^*}{\partial\, d^*} < 0, \quad \frac{\partial\left(1 - \theta^*\right)}{\partial\, d^*} > 0\,.$$

Second, higher costs of production, *c*, reduces the market share of the environmentally concerned firm 2. Both firms raise their prices but the price increase of firm 2 is higher than the one of firm 1. The spread of their prices increase and depends on the difference in product differentiation

$$\left(\frac{\partial\left(1 - \theta^*\right)}{\partial\, c} < 0, \quad \frac{\partial\, p_1^*}{\partial\, c} < \frac{\partial\, p_2^*}{\partial\, c}, \quad \frac{\partial\left(p_2^* - p_1^*\right)}{\partial\, c} = \frac{1}{3}\left(q_2 - q_1\right)\right).$$

These conclusions only hold if q_1 and q_2 are fixed. When choosing the characteristics at the first stage of the game, firms take into account the effect of their quality decisions on the price, set at the second stage. Profit of firm *i* is $\pi_i(q_1,q_2)=\left[p_i^*(q_1,q_2)-c\,q_i\right]\cdot d_i(q_1,q_2)$ and depends on the characteristics (q_1,q_2). We consider first the case of an interior solution $0\le q_i\le 1$ and solve the FOCs $\frac{\partial\,\pi_i}{\partial\,q_i}=0$ in terms of two reaction functions. The result is

(13) $$q_1=q_1^R(q_2)=\frac{1}{3}\left[-2+d^*+q_2-c^*\right]$$

(14) $$q_2=q_2^R(q_1)=\frac{1}{3}\left[4+d^*+q_1-c^*\right]$$

where $d^*=d/t$ and $c^*=c/t$. It is well known that in the conventional case $(d=c=0)$ there exists no interior solution. Both firms choose maximal product differentiation by producing $\tilde{q}_1=0$ and $\tilde{q}_2=1$. Solving the simultaneous system (13) and (14) yields

(15) $$\tilde{q}_1=-\frac{1}{4}+\frac{1}{2}\left(d^*-c^*\right)$$

(16) $$\tilde{q}_2=\frac{5}{4}+\frac{1}{2}\left(d^*-c^*\right).$$

An interior solution for $\tilde{q}_1\ge 0$ would require $d^*-c^*\ge\frac{1}{2}$, and for $\tilde{q}_2\le 1$ the inequality $d^*-c^*\le -\frac{1}{2}$. We conclude that there exists no interior Nash equilibrium in characteristics.

We next characterize three equilibria of (q_1,q_2), depending on the difference d^*-c^*.

Case (*i*): $d^*-c^*\ge\frac{1}{2}$

It is $\tilde{q}_1\ge 0$ from (15) and $\tilde{q}_2=1$ as q_2 must not exceed one. According to (13), the best response of firm 1 on $\tilde{q}_2=1$ is $q_1^R(1)=\frac{1}{3}\left[-1+d^*-c^*\right]$ which implies $q_1\ge 0$ if $d^*-c^*\ge 1$.

The best response of firm 2 on $q_1^R(1)$ follows from (14). It is $q_2 = q_2^R\left(q_1^R(1)\right) = \frac{11}{9} + \frac{4}{9}\left(d^* - c^*\right) > 1$ that is, firm 2 sticks to $\tilde{q}_2 = 1$. We conclude:

Proposition 2:

If $\quad d^* - c^* \geq 1 \quad (i.e.\ d - c \geq t),\quad$ then

(17) $$\begin{aligned} q_1^* &= \frac{1}{3}\left[-1 + d^* - c^*\right] \geq 0 \\ q_2^* &= 1 \end{aligned}$$

is a Nash equilibrium in the characteristics q_1 and q_2.

Case (*ii*): $\quad d^* - c^* \leq -\frac{1}{2}$

It is $\tilde{q}_2 \leq 1$ from (16) and $\tilde{q}_1 = 0$ as q_1 can not become negative. The best response (14) of firm 2 on $\tilde{q}_1 = 0$ is $q_2^R(0) = \frac{1}{3}\left[4 + d^* - c^*\right]$ with $q_2^R(0) \leq 1$ if $d^* - c^* \leq -1$. The best response of firm 1 on $q_2^R(0)$ is in turn $q_1^R\left(q_2^R(0)\right) = \frac{1}{9}\left[-2 + 4\left(d^* - c^*\right)\right] < 0$ with $d^* - c^* \leq -1$; that is $\tilde{q}_1 = 0$. We conclude:

Proposition 3:

If $\quad d^* - c^* \leq -1 \quad (i.e.\ \ d - c \leq -t),\quad$ then

(18) $$\begin{aligned} q_1^* &= 0 \\ q_2^* &= \frac{1}{3}\left[4 + d^* - c^*\right] \leq 1 \end{aligned}$$

is a Nash equilibrium in $\left(q_1, q_2\right)$.

Case (*iii*): $\quad -\frac{1}{2} \leq d^* - c^* \leq \frac{1}{2}$

It is $\tilde{q}_1 = 0,\ \tilde{q}_2 = 1$. The best response of firm 2 on $\tilde{q}_1 = 0$ is $q_2^R(0) = \frac{1}{3}\left[4 + d^* - c^*\right]$ with $q_2^R(0) > 1$ if $d^* - c^* > -1$. In that case it is $q_2^R = 1$. The best response of firm 1 on $q_2^R = 1$ is $q_1^R(1) = \frac{1}{3}\left[-1 + d^* - c^*\right]$ with $q_1^R(1) < 0$ if $d^* - c^* < 1$. We conclude:

Proposition 4:

If $\quad -1 < d^* - c^* < 1 \quad (i.e.\ \ -t < d - c < t)$, then

(19) $\quad q_1^* = 0 \qquad q_2^* = 1$

is a Nash equilibrium in (q_1, q_2).

The market shares in our three cases can be determined by inserting q_1^*, q_2^* in (11) and (12):

$$\text{(20)}\qquad \begin{array}{llll} 1) & 4 \ge d^* - c^* \ge 1 & : \ \theta^* = \frac{4}{9} - \frac{1}{9}\left(d^* - c^*\right), & 1 - \theta^* = \frac{5}{9} + \frac{1}{9}\left(d^* - c^*\right) \\ 2) & -4 \le d^* - c^* \le -1 & : \ \theta^* = \frac{5}{9} - \frac{1}{9}\left(d^* - c^*\right), & 1 - \theta^* = \frac{4}{9} + \frac{1}{9}\left(d^* - c^*\right) \\ 3) & -1 < d^* - c^* < 1 & : \ \theta^* = \frac{1}{2} - \frac{1}{6}\left(d^* - c^*\right), & 1 - \theta^* = \frac{1}{2} + \frac{1}{6}\left(d^* - c^*\right). \end{array}$$

As expected, environmental awareness reduces the market share of firm 1 and increases the market share of good 2. The same effect has a lower unit cost *c*. In Table 1 we present the characteristics, prices, market shares and profit for our three Nash-equilibria. As values for $d^* - c^*$ we choose an upper bound, a lower bound and an intermediate value (we set $t = 1$ for simplification).

Table 1: Market structure and performance in the three Nash equilibria (t = 1)

$d-c$	q_1^*	q_2^*	p_1^*	p_2^*	θ^*	π_1^*	π_2^*
1. Nash eq.							
$d-c=4t$ $(d=c+4)$	1	1	c	c	0	0	0
$d-c=2t$ $(d=c+2)$	1/3	1	$c/3+8/27$	$c+28/27$	2/9	0.066	0.806
$d-c=t$ $(d=c+1)$	0	1	2/3	$c+4/3$	1/3	2/9	8/9
2. Nash eq.							
$d-c=-t$ $(d=c-1)$	0	1	4/3	$c+2/3$	2/3	8/9	2/9
$d-c=-2t$ $(d=c-2)$	0	2/3	28/27	$2/3\,c+8/27$	7/9	0.806	0.065
$d-c=-4t$ $(d=c-4)$	0	0	0	0	1	0	0
3. Nash eq.							
$d-c=t/2$ $(d=c+1/2)$	0	1	5/6	$c+7/6$	11/24	0.382	0.632
$d-c=0$ $(d=c)$	0	1	1	$c+1$	1/3	1/3	2/3
$d-c=-t/2$ $(d=c-1/2)$	0	1	7/6	$c+5/6$	13/24	0.632	0.382

3. Social welfare maximizing characteristics

The next step is to check for market failure in the sense that the private choice of the characteristics might differ from the social optimal one preferred by an environmental authority. For that purpose we define social welfare as a function of q_1 and q_2. It is equal to the aggregate willingness to pay minus cost of production. Therefore

$$(21)\quad W(q_1,q_2)=\int_0^{\breve{\theta}}\left[r-t(q_1-\theta)^2-d(1-q_1)-cq_1\right]d\theta+\int_{\breve{\theta}}^{1}\left[r-t(q_2-\theta)^2-d(1-q_2)-cq_2\right]d\theta$$

The market share $\breve{\theta}$ separates the consumers with higher welfare from q_1 from those wilt higher welfare from q_2. It is determined by the consumer being indifferent between welfare from q_1 and welfare from q_2:

$$r-t(q_1-\breve{\theta})^2-d(1-q_1)-cq_1=r-t(q_2-\breve{\theta})^2-d(1-q_2)-cq_2$$

This condition yields

$$\breve{\theta}=\frac{1}{2}(q_1+q_2-d^*+c^*)$$

For maximizing welfare in (21) with respect to q_1 and q_2, we first integrate W with respect to θ, and then we set the partial derivatives $\frac{\partial W}{\partial q_1}$ and $\frac{\partial W}{\partial q_2}$ equal to zero. Solving the two FOCs for q_1 and q_2 yields the characteristics which maximize social welfare[7]:

$$(22)\qquad \hat{q}_1=\frac{d^*-c^*}{2}+\frac{1}{4},\qquad \hat{q}_2=\frac{d^*-c^*}{2}+\frac{3}{4}.$$

Inserting these values in $\breve{\theta}$, given above, yields $\breve{\theta}=\frac{1}{2}$. In the conventional case $(d=c=0)$, it is $\hat{q}_1=\frac{1}{4}$, $\hat{q}_2=\frac{3}{4}$ and $\theta=\frac{1}{2}$. Each firm should produce the optimal quality of that consumer who is located in the middle of the corresponding market segment of the firm[8]. Compared with the private choice in that case, i.e. $q_1^*=0,\ q_2^*=1,$ private competition leads to an extreme product differentiation relative to the social optimum. In our case $(d>0,\ c>0)$, we have to compare the three Nash equilibria (q_1^*,q_2^*) with the corresponding social pair $(\hat{q}_1,\hat{q}_2)$ to find out whether private and social characteristics differ.

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[7] See the Appendix for mathematical details.

[8] See Bester, p. 116 for the conventional case.

Let us consider the first Nash equilibrium in (17). Since $d^* - c^* \geq 1$, it is $q_2^* = \hat{q}_2 = 1$, but $q_1^* \neq \hat{q}_1$. In order to achieve that q_1^* is equal to $\hat{q}_1$, we have to introduce a policy parameter as an incentive for firm 1 to produce $\hat{q}_1$. One possibility is to set $c = c_0 - s$ where *s* could be a subsidy $(s > 0)$ or a tax $(s < 0)$ on the unit cost of production. Private calculations are now based on $c = c_0 - s$, social welfare calculations on $c = c_0$. We are interested in finding a value of *s* such that $q_1^*(s) = \hat{q}_1$, i.e.

$$(23) \qquad q_1^*(s) = \frac{1}{3}\left[-1 + d^* - \frac{c_0 - s}{t}\right] = \frac{d^* - c_0^*}{2} + \frac{1}{4} = \hat{q}_1 .$$

This condition is satisfied for

$$(24) \qquad s = \frac{7}{4}t + \frac{d - c_0}{2} .$$

In order to check whether *s* is a subsidy or a tax, we substitute *s* from (24) into the parameter condition for case (i), i.e. into $4 \geq \frac{d - (c_0 - s)}{t} \geq 1$ and obtain $\frac{3}{2}t \geq d - c_0 \geq -\frac{t}{2}$. Therefore *s* is positive and a subsidy on the cost of production. Since $q_1^* < \hat{q}_1$ without a subsidy, $s > 0$ is an incentive for firm 1 to raise the environmental characteristics of its product. Firm 2 benefits from this policy because it gets also the subsidy but produces already the highest environmental characteristic $q_2^* = 1 (= \hat{q}_1)$.

An alternative policy to raise q_1^* could be to launch a campaign to raise environmental awareness (d) of the consumers by δ (advertising, TV sports, etc.). The equivalent condition to (23) is

$$q_1^*(\delta) = \frac{1}{3}\left[-1 + \frac{d + \delta - c}{t}\right] = \frac{d^* - c^*}{2} + \frac{1}{4} = \hat{q}_1 .$$

The required impact on environmental awareness is then

$$\delta = \frac{7}{4}t + \frac{d^* - c^*}{2} > 0$$

which is positive since $d^* - c^* \geq 1$.

Let us next consider the second Nash equilibrium in (18). Since $d^* - c^* \leq -1$, it is $q_1^* = \hat{q}_1$ but $q_2^* \neq \hat{q}_2$. Similarly as before we have to find a *s* such that

(25) $$q_2^*(s) = \frac{1}{3}\left[4 + d^* - \frac{c_0 - s}{t}\right] = \frac{d^* - c_0}{2} + \frac{3}{4} = \hat{q}_2 .$$

Since without an incentive *s*, $q_2^* > \hat{q}_2$, we expect a tax $(s < 0)$. Solving (25) for s yields

(26) $$s^* = \frac{d^* - c^*}{2} - \frac{9}{4}$$

where $s^* = s/t$. If we substitute s^* into the parameter conditions for case (*iii*), i.e. $-4 \leq d^* - (c_0^* - s^*) \leq -1$, we obtain $-\frac{7}{6} \leq d^* - c_0^* \leq \frac{5}{6}$, that is, $s^* < 0$, a tax on production. We could think of two firms, one produces electricity with a coal-fired power plant, the other one with wind energy. From the social point of view there might be too much wind energy because its installation ruins the landscape $(q_2^* > \hat{q}_2)$. A tax on electricity would correct this private outcome. Since firm 1 produces $q_1^* = 0$, it has no costs $\left((c_0 - s) \cdot q_1^* = 0\right)$ and is therefore not affected by the tax.

We could also think of affecting d by $d + \delta$. If we replace d in (25) by $d + \delta$ and solve for δ, we obtain a negative δ[9]. The government announces that global warming is not caused by carbon dioxide emissions (coal-fired power plants) and that there is no reason to disfigure the landscape by economic inefficient wind mills.

Finally, if the third Nash equilibrium occurs $(q_1^* = 0, q_2^* = 1)$, there is no way to influence the firms to produce the social optimal environmental qualities $\hat{q}_1$ and $\hat{q}_2$ in (22). The only possibility is to affect d or c in the corresponding interval $-1 < d^* - c^* < 1$ such that the private outcome is one of the other two Nash equilibria. Since one policy parameter is needed to end up in another equilibrium and another policy parameter to adjust private environmental qualities to the social ones, a campaign has to be launched as well as a tax or subsidy to be paid to achieve the social outcome.

[9] It is $\delta = \frac{d^* - c^*}{2} - \frac{7}{4}$ and negative because of $d^* - c^* \leq -1$.

4. Summary and conclusion

Increasing environmental awareness may affect the pleasure of consuming a good for which an environmental friendly substitute is available. When deciding to buy differentiated products, a compromise is sometimes made between preferred characteristics of the good and its environmental properties. In this paper we have investigated the market implication of product differentiation when customers are concerned about environmental aspects of the good. We have used the spacial duopoly model to determine how environmental concern affects prices, product characteristics and market shares of the competing firms.

We first have solved the second stage of the game, that is, price competition when differences in quality exists. The unique equilibrium prices and market shares are affected by consumer awareness of the environment and by the higher costs for producing those goods. We next determined the characteristics at the first stage of the game when firms take into account the effect of their quality decisions on profit, price and hence on market shares. We found no interior Nash equilibrium $\tilde{q}_1 > 0$, $\tilde{q}_2 < 1$ but three Nash equilibria of the type $\left(q_1^* > 0, q_2^* = 1\right)$, $\left(q_1^* = 0, q_2^* < 1\right)$ and $\left(q_1^* = 0, q_2^* = 1\right)$, depending on the parameter constellations. The market share of the environmental good increases in each type with environmental concern and it declines if costs are higher to produce those goods.

In order to find out whether the market functions in an optimal way we have to compare the private decisions on quality with the choice of quality by a welfare maximizing authority. We found that the social welfare maximizing characteristics are not the same than the quality distribution by private firms in the three Nash equilibria. It is, however, possible to choose environmental policy instruments to stimulate private firms to produce the social optimal quality distribution. Depending on the type of the Nash equilibrium, the government can either choose a subsidy on costs or can launch a campaign in favor of environmental awareness, or it can raise the cost of a product by a tax or can announce its environmental irrelevance if producers care more for the environment than is socially justified.

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Appendix

Proof of (22):

$$\frac{W}{t}=\int_{0}^{\breve{\theta}}\left(r^{*}-\left(q_{1}-\theta\right)^{2}-d^{*}\left(1-q_{1}\right)\right)d\,\theta$$

$$-c^{*}\,q_{1}\int_{0}^{\breve{\theta}}d\,\theta+\int_{0}^{1}\left(r^{*}-\left(q_{2}-\theta\right)^{2}-d^{*}\left(1-q_{2}\right)\right)d\,\theta-c^{*}\,q_{2}\int_{\breve{\theta}}^{1}d\,\theta$$

where $r^{*}=\frac{r}{t},\quad d^{*}=\frac{d}{t},\quad c^{*}=\frac{c}{t}$.

Integrated:

$$W^{*}=\left[r^{*}\,\theta+\frac{1}{3}\left(q_{1}-\theta\right)^{3}-d^{*}\left(1-q_{1}\right)\theta-c^{*}\,q_{1}\,\theta\right]_{0}^{\breve{\theta}}$$

$$+\left[r^{*}\,\theta+\frac{1}{3}\left(q_{2}-\theta\right)^{3}-d^{*}\left(1-q_{2}\right)\theta-c^{*}\,q_{2}\,\theta\right]_{\breve{\theta}}^{1}$$

$$\Rightarrow W^{*}=r^{*}\,\breve{\theta}+\frac{1}{3}\left(q_{1}-\theta\right)^{3}-d^{*}\left(1-q_{1}\right)\breve{\theta}-c^{*}\,q_{1}\,\breve{\theta}-\frac{1}{3}\,q_{1}^{3}$$

$$+r^{*}+\frac{1}{3}\left(q_{2}-1\right)^{3}-d^{*}\left(1-q_{2}\right)-c^{*}\,q_{2}-r^{*}\,\breve{\theta}-\frac{1}{3}\left(q_{2}-\breve{\theta}\right)^{3}+d^{*}\left(1-q_{2}\right)\breve{\theta}+c\,q_{2}\,\breve{\theta}.$$

FOC with respect to q_1:

$$\frac{\partial W^{*}}{\partial q_{1}}=\left(q_{1}-\breve{\theta}\right)^{2}\left(1-\frac{1}{2}\right)+d^{*}\,\breve{\theta}-d^{*}\left(1-q_{1}\right)\frac{1}{2}-c^{*}\,\breve{\theta}$$

$$-c^{*}\,q_{1}\,\frac{1}{2}-q_{1}^{2}-\left(q_{2}-\breve{\theta}\right)^{2}\left(-\frac{1}{2}\right)+d^{*}\left(1-q_{2}\right)\frac{1}{2}+c^{*}\,q_{2}\,\frac{1}{2}=0$$

$$\Rightarrow\left(\frac{q_1-q_2+d^*-c^*}{2}\right)^2\frac{1}{2}+d^*\,\breve{\theta}-\frac{d^*}{2}\left(1-q_2\right)-c^*\,\breve{\theta}$$

$$-\frac{c^*}{2}\left(q_1-q_2\right)-q_1^2+\frac{1}{2}\left(\frac{q_2-q_1+d^*-c^*}{2}\right)^2+\frac{d^*}{2}\left(1-q_2\right)=0$$

$$\Rightarrow\frac{1}{4}\left(q_1-q_2+d^*-c^*\right)\left(q_1-q_2+d^*-c^*\right)+2\,d^*\,\breve{\theta}+d\,q_1$$

$$-2\,c^*\,\breve{\theta}-c^*\left(q_1-q_2\right)-2\,q_1^2+\frac{1}{4}\left(q_2-q_1+d^*-c^*\right)\left(q_2-q_1+d^*-c^*\right)-d^*\,q_2=0$$

$$\Rightarrow\frac{1}{4}\Big[q_1^2-q_1\,q_2+d^*q_1-c^*\,q_1-q_1\,q_2+q_2^2-d^*q_2+c^*q_2+d^*q_1-d^*\,q_2+d^{*2}-d\,c^*-c^*\,q_1$$

$$+c^*\,q_2-d^*\,c^*+c^{*2}\Big]+d^*q_1+d^*\,q_2-d^{*2}+d^*\,c^*+d^*\,q_1-c^*\,q_1-c^*q_2+c^*\,d^*-c^{*2}-c^*\,q_1$$

$$+c^*\,q_2-2\,q_1^2+\frac{1}{4}\Big[q_2^2-q_1\,q_2+d^*q_2-c^*\,q_2-q_1\,q_2+q_1^2-d^*\,q_1+c^*\,q_1+d^*q_2-d^*\,q_1$$

$$+d^{*2}-c^*\,d^*-q_2\,c^*+q_1\,c^*-d^*\,c^*+c^{*2}\Big]-d^*\,q_2=0$$

$$\Rightarrow\frac{1}{4}\Big[2\,q_1^2-4\,q_1\,q_2+2\,q_2^2+2\,d^{*2}-4\,d^*\,c^*+2\,c^{*2}\Big]$$

$$+2\,d^*\,q_1-d^{*2}+2\,d^*\,c^*-2\,c^*\,q_1-c^{*2}-2\,q_1^2=0$$

$$\Rightarrow\frac{1}{2}\;q_1^2-q_1\,q_2+\frac{1}{2}q_2^2+\frac{1}{2}d^{*2}-d^*\,c^*+\frac{1}{2}c^{*2}+2\,d^*\,q_1$$

$$-d^{*2}+2\,d^*\,c^*-2\,c^*\,q_1-c^{*2}-2\,q_1^2=0$$

$$\Rightarrow\quad\boxed{-\frac{3}{2}q_1^2-q_1\,q_2+\frac{q_2^2}{2}-\frac{d^{*2}}{2}+d^*\,c^*-\frac{c^{*2}}{2}+2\,d^*\,q_1-2\,c^*\,q_1=0\qquad(\mathrm{A})}$$

FOC with respect to q_2:

$$\frac{\partial W^*}{\partial q_2} = -\left(q_1-\breve{\theta}\right)^2 \frac{1}{2} - d^*\left(1-q_2\right)\frac{1}{2} - c^*\, q_1 \frac{1}{2} + \left(q_2-1\right)^2 + d^* - c^*$$

$$-\left(q_2-\breve{\theta}\right)^2 \frac{1}{2} - d^*\,\breve{\theta} + d^*\left(1-q_2\right)\frac{1}{2} + c^*\,\breve{\theta} + \frac{c^* q_2}{2} = 0$$

$$\Rightarrow -\frac{1}{2}\left(\frac{q_1-q_2+d^*-c^*}{2}\right)^2 + \frac{d^*\, q_1}{2} - \frac{c^*\, q_1}{2} + q_2^2 - 2\, q_2 + 1 + d^*$$

$$-c^* - \frac{1}{2}\left(\frac{q_2-q_1+d^*-c^*}{2}\right)^2 - \frac{d^*\, q_1}{2} - \frac{d^*\, q_2}{2} + \frac{d^{*2}}{2} - \frac{d^*\, c^*}{2}$$

$$-\frac{d^*\, q_2}{2} + \frac{c^*\, q_1}{2} + \frac{c^*\, q_2}{2} - \frac{c^*\, d^*}{2} + \frac{c^{*2}}{2} + \frac{c^*\, q_2}{2} = 0$$

$$\Rightarrow -\frac{1}{4}\left(q_1-q_2+d^*-c^*\right)^2 + 2\, q_2^2 - 4\, q_2 + 2 + 2\, d^* - 2\, c^*$$

$$-\frac{1}{4}\left(q_2-q_1+d^*-c^*\right)\left(q_2-q_1+d^*-c^*\right) - 2\, d^*\, q_2 + d^{*2} - 2\, d^* c^* + 2\, c^*\, q_2 + c^{*2} = 0$$

$$\Rightarrow -\frac{1}{4}\left[2\, q_1^2 - 4\, q_1\, q_2 + 2\, q_2^2 + 2\, d^{*2} - 4\, d^* c^* + 2\, c^{*2}\right] + 2\, q_2^2 - 4\, q_2 + 2\left(1+d^*-c^*\right)$$

$$-2\, d^*\, q_2 + d^{*2} - 2\, d^* c^* + 2\, c^*\, q_2 + c^{*2} = 0$$

$$\Rightarrow \quad \boxed{\begin{aligned} &-\frac{q_1^2}{2}+q_1\,q_2+\frac{3}{2}q_2^2+\frac{d^{*2}}{2}-d^*\,c^*+\frac{c^{*2}}{2}-4\,q_2 \\ &+2\left(1+d^*-c^*\right)-2\,d^*\,q_2+2\,c^*\,q_2=0 \qquad\qquad (\mathrm{B}) \end{aligned}}$$

Next we add (A) + (B):

$$q_1^2-q_1(d^*-c^*)-\left[q_2^2-2q_2+(1-d^*-c^*)-d^*q_2+c^*q_2\right]=0$$

$$\Rightarrow \qquad q_1=\frac{d^*-c^*}{2}\pm\sqrt{\frac{(d^*-c^*)^2}{4}+\left[q_2^2-2q_2+(1+d^*-c^*)-d^*q_2+c^*q_2\right]}$$

$$\Rightarrow \qquad q_1=\frac{d^*-c^*}{2}\pm\left(\frac{d^*}{2}-q_2+1-\frac{c^*}{2}\right)$$

$$\Rightarrow \qquad (\mathrm{C}) \quad \boxed{q_1^1=d^*-c^*-q_2+1} \qquad\qquad q_1^2=-1+q_2\le 0$$

q_1^1 inserted into (A) yields:

$$-\frac{3}{2}\left[d^*-c^*-q_2+1\right]^2-\left[d^*-c^*-q_2+1\right]q_2+\frac{q_2^2}{2}-\frac{d^{*2}}{2}+d^*c^*-\frac{c^{*2}}{2}+$$

$$2d^*(d^*-c^*-q_2+1)-2c^*(d^*-c^*-q_2+1)=0$$

$$\Rightarrow \qquad q_2=\frac{d^*-c^*}{2}+\frac{3}{4}$$

$$\overset{(\mathrm{C})}{\Rightarrow} \qquad q_1=\frac{d^*-c^*}{2}+\frac{1}{4}$$

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