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Environmental policy in a differentiated market with a green network effect

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Abstract

We examine the impact of a "green network effect" in a market characterized by consumers' environmental awareness and competition between firms in both environmental quality and product prices. The unique aspect of this model comes from the assumption that an increase in the number of consumers of the green product increases the satisfaction of each green consumer. We show that this externality raises the consumption of the green product, reduces the environmental quality of products and improves welfare, even if it doesn't affect the overall level of pollution. The externality correction requires using three optimal fiscal policies: an *ad valorem* tax on products, an emission tax, and a subsidy of the green purchase. A second-best optimum can also be reached through the green taxation.

Keywords : consumer behavior, environmental quality, , network effect, vertical differentiation, taxation

JEL classification : D11, D62, H21, L13, Q58

1. Introduction

Green products make up an increasingly greater proportion of household expenditure. According to the most recent surveys by the European Commission (2008, 2009), 83% of Europeans pay great attention to the impact of products on the environment when buying. 75% are "ready to buy environmentally friendly products even if they cost a little bit more", compared to 31% in 2005. However, in 2008, only 17% had recently bought "products marked with an environmental label". In the United-States, a recent survey shows that 82% of consumers continue to buy green, despite the battered economy, even if it costs more.[1]

Green purchasing is primarily motivated by a certain degree of consumer ecological consciousness. This consciousness finds expression in concern about environmental problems and an intention to work for the improvement of the environment. Frey and Stutzer (2006) identify a number reasons behind "environmental motivation": intrinsic motivations, altruism, internalized norms and social norms. Intrinsic motivations are based on individual tastes and ethical values. Altruism, the opposite of egoism, implies that the consumers of green products take into account the benefit that their consumption brings to other present and future members of the society, through the preservation or improvement of environmental quality. Internalized norms refers to individual morals: the culpability felt when polluting the planet by consuming polluting products and the warm glow felt due to green purchase. Social norms lead individuals to take into consideration the opinions of the other members of society when choosing a green product over another: if they think that their acquaintances approve of green product purchase and disapprove of standard product purchase, there are encouraged to buy green products. One American consumer out of five claims that word of mouth is a key factor in green purchase decisions.

There is a link to the idea developed by Veblen (1899) and Leibenstein (1950), who emphasize that consumers are aware of the consumption choices of others. This awareness may be explained, for certain products, by consumer vanity or the *snob effect,* which is mainly characterized by the purchase of luxury goods and stems from the satisfaction arising from having an rare product, owned by few consumers. In the case of green products, consumers are more characterized by a certain conformity or *bandwagon effect*. The latter is defined by Leibenstein (1950) as follows: "By the bandwagon effect, we refer to the extent to which the demand for a commodity is increased due to the fact that others are also consuming the same commodity. It represents the desire of people to purchase a commodity in order to get into "the swim of things"; in order to conform with the people they wish to be associated with; in order to be fashionable or stylish; or, in order to appear to be "one of the boys."" In this situation, consumers are all the more satisfied with their purchases as many others are buying the same product. In this paper, we adopt the assumption of a spillover effect of the consumption of green products: the pleasure of consuming a green product increases with the number of consumer doing the same thing.

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[1] Survey conducted in January 2009 by Green Seal and EnviroMedia and carried out on 1 000 consumers (www.greenseal.org/resources/green_buying_research.cfm (accessed 21/10/2009)).

Some constraints can however limit the purchase of green products, including economic reasons (high prices, budget constraints) and cognitive reasons (lack of information about environmental problems, product features). The feeling that individual action can only play a minor role in the improvement of the environment leads some consumers to turn away from green products. Indeed, among the 85% of Europeans who claim to make an effort to protect the environment, more than half do not believe that their efforts have an impact as long as others and the major polluters (corporations and industry) do not do the same (European Commission, 2005). These two reasons go a long way to explaining why 15% of Europeans rarely or never make effort for the environment. Once again, we encounter the idea that the lower the number of green consumers, the lower the individual motivation for such consumption.

A number of consumer surveys show a further feature of green products: most consumers perceive them as having a higher (environmental) quality than their competitors. Indeed, European Commission (2008, 2005) and the OECD (2002) studies emphasize that if they were sold at the same price as their more polluting counterparts, a large majority of consumers would turn towards green products. This assumption has been commonly assumed in the literature since Cremer and Thisse's 1999 article.[2] In the present paper, we also adopt this assumption of a market which is vertically differentiated for environmental reasons.

The uniqueness of our model principally stems from the assumption of a network effect in a green market. This assumption is related to that adopted by Grilo *et al.* (2001). They formalize the effects of both consumer vanity and consumer conformity on product differentiation and competition between firms. Their analysis differs from that in the present paper in that it draws upon a horizontally differentiated model and does not deal with product environmental quality. Furthermore, conformity and vanity affect all the products in the market. They show two interesting results in the case of conformity: "when bandwagon effects are present but not too strong, both firms remain in business but price competition is fiercer and results in lower equilibrium price" and "when bandwagon effects are strong enough, different price equilibria may coexist in which either firm captures the whole market." Lambertini and Orsini (2005) transcribe the vanity assumption into a market where products are vertically differentiated. They suppose that a positional product, whose quality is high, is in competition with a standard one, whose quality is lower. This study is comparable to the present one since the green product, with a higher quality, benefits from the externality in our model. We will see how our results differ to those of Lambertini and Orsini (2005), who show that product quality tends to decrease with the externality while welfare improves. Our analysis differs from these two models since it focuses on a green market and aims at providing insight for environmental policies. To our knowledge no previous analysis has been carried out on the network effect in green markets.

In this paper, we study the impact of the network effect not only on the price and quality strategy of firms, but also on the social optimum. We emphasize that the externality tends to lower the environmental quality of both products, but has no effect on product differentiation. It also encourages the consumption of green products. With

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[2] See Amacher *et al.* (2004), Eriksson (2004), Conrad (2005), Lombardini-Riipinen (2005), Motta and Thisse (1999), Brécard (2008), Arora and Gangopadhyay (1995), Moraga-González and Padrón-Fumero (2002), Poyago-Theotoky and Teerasuwannajac (2002) and Bansal and Gangopadhyay (2003).

regard to the first-best optimum, a green market equilibrium leads to an excess of differentiation, a too low standard quality, a too low (high) green quality when the marginal environmental damage is high (low) and insufficient consumption of the green product. Nevertheless, using taxation, the regulator is able to move the market equilibrium towards the optimum. We show that the association of an *ad valorem* tax, a pollution tax and a subsidy for the green purchase can reconcile equilibrium and optimum. Our analysis of the second-best optimum shows that only green taxation achieves an improvement in social welfare.

The remainder of the paper is organized as follows. In section 2, we introduce the model. In section 3, we study the unregulated equilibrium and the impact of the network effect on equilibrium qualities and prices. In section 4, we examine the first-best optimum. In section 5, we introduce taxation and investigate the regulated equilibrium. Section 6 deals with optimal taxation. Section 7 is a conclusion.

2. The model

We assume that the environmental characteristics of a product do not affect the other characteristics of the product. A green product is thus viewed as of better quality than the standard product and is therefore more expensive. We further assume that the consumer of a green product is aware of the number of people purchasing the product. As in the models of vertical product differentiation developed by Mussa and Rosen (1978) and Cremer and Thisse (1999), each firm produces one variant of a product and decides on its price. Each consumer only gains satisfaction from the consumption of the first unit of the product and buys one unit of the product or none.

Consumer preferences are represented by the following utility function $u_i(\theta)$:

$$u_i(\theta) = \theta q_i - p_i + \alpha_i n_i \quad i = l,h \tag{1}$$

with θ an ecological consciousness parameter which is uniformly distributed over $\left[\underline{\theta},\overline{\theta}\right]$ with a unit density function ($\underline{\theta} = \overline{\theta} - 1$), θq_i willingness-to-pay for quality q_i , p_i the price of product *i,* and n_i the number of consumers buying the product *i*. We assume that the network effect only works for the green product with quality q_h ($q_h \geq q_l$), so that $\alpha_h \geq 0$ and $\alpha_l = 0$. In order to simplify notations, we define $\alpha \equiv \alpha_h$.

Faced with a "green" quality q_h and a "brown" quality q_l ($q_h > q_l$), only consumers with a parameter $\theta \geq \tilde{\theta} = p_l / q_l$ purchase. The consumer $\hat{\theta} = \left(p_h - p_l - \alpha\overline{\theta}\right) / \left(q_h - q_l - \alpha\right)$ is indifferent between buying the brown product q_l at price p_l or the green product q_h at price p_h. Through concern for simplicity, we assume that the market is covered and thus that $\tilde{\theta} \leq \underline{\theta}$.[3] Accordingly, the demand functions are defined by: $d_h = \overline{\theta} - \hat{\theta}$ and $d_l = \hat{\theta} - \underline{\theta}$, with $n_h \equiv d_h$.

The firms' marginal production cost are assumed, in line with Cremer and Thisse (1994, 1999), to be independent of quantity, strictly increasing and convex in quality, with the quadratic form $c(q_i) = \frac{1}{2} c q_i^2$. The ecological quality of the product *i* is defined

[3] The analytical results of this model are hugely more difficult to provide and to analyse when we assume that the market is not covered. Without tax and with a cost parameter *c* equal to one, Motta (1993) only succeeds in giving a numerical solution of the game.

by abatement $q_i = \bar{e} - e_i$, where $\bar{e}$ is the maximal pollution by each firm and e_i pollution by firm i. Quality is defined over the interval $[0,\bar{e}]$. We also assume, following Cremer and Thisse (1999), Amacher *et al.* (2004), Eriksson (2004), Conrad (2005) and Lombardini-Riipinen (2005), that abatement is achieved through a variable production cost, so that firms' profits are defined by:

$$\pi_i = \left(p_i - c(q_i)\right)d_i \quad i = h,l \tag{2}$$

The competition between firms takes place in a two-stage game. In the first stage, the environmental quality, q_i, to produce is decided on. In the second stage, prices, p_i, are chosen

The economy is here characterized by three market failures: imperfect competition, a network effect and pollution. The issue of behavior optimality is thus particularly relevant. In order to analyze this question, we define welfare as the sum of the consumers' surpluses and the firms' profits less the environmental damage:

$$W = CS_h(q_h,q_l) + CS_l(q_h,q_l) + \pi_h(q_h,q_l) + \pi_l(q_h,q_l) - D(E) \tag{3}$$

The surplus of consumers of a product i is defined, as usual, by $CS_i(q_h,q_l) = \int_{\hat{\theta}_i}^{\bar{\theta}_i}(\theta q_i - p_i)df(\theta)$, with $\hat{\theta}_l = \bar{\theta} - 1$, $\bar{\theta}_l = \hat{\theta}_h = \hat{\theta}$ and $\bar{\theta}_h = \bar{\theta}$. The environmental damage is the monetary equivalent of the consequences of polluting emissions for the whole of society. It is defined in a linear function of overall emissions E: $D(E) = \delta E$, with $\delta \geq 0$ and $E \equiv e_h d_h + e_l d_l$. The regulator role consists in guiding the economic actors towards optimal behavior, i.e. behavior which maximizes the social welfare. The introduction of corrective fiscal policies in the fifth section of the paper will lead us to add State revenue to the welfare components.

In the following section, we examine the game equilibrium in the case of *laissez-faire*.

3. The unregulated equilibrium

The game is solved using backward induction in order to provide the sub-game perfect equilibrium. [4]

In the second stage, firms compete on price knowing the product qualities decided on in the first stage. Maximization of profit (2) with respect to price induces the following reaction functions:

$$\begin{aligned} p_h &= \frac{1}{2}p_l + 2(q_h - q_l)\bar{\theta} + \frac{cq_h^2}{4} \\ p_l &= \frac{1}{2}p_h + 2(q_h - q_l)\left(1 - \bar{\theta}\right) + \frac{cq_l^2}{4} - \frac{\alpha}{2} \end{aligned} \tag{4}$$

We find here the standard property of increasing reaction functions.

We deduce from (4) the equilibrium prices of the sub-game:

[4] The demonstrations are given in appendix A1.

$$p_h = \frac{1}{3}(q_h - q_l)(\overline{\theta} + 1) - \frac{\alpha}{3} + \frac{1}{3}cq_h^2 + \frac{1}{6}cq_l^2$$
$$p_l = \frac{1}{3}(q_h - q_l)(2 - \overline{\theta}) - \frac{2\alpha}{3} + \frac{1}{3}cq_l^2 + \frac{1}{6}cq_h^2 \qquad (5)$$

In the first stage, firms decide on quality levels by maximizing their profits (2) and anticipating prices (5) of the second stage. We show in appendix A1 that, when condition (C1), $c\alpha \leq 9/16$, is fulfilled, the only equilibrium of the quality sub-game is the following:

$$q_h^* = \frac{12\overline{\theta} + 3 - 8c\alpha(2\overline{\theta} + 1)}{4c(3 - 4c\alpha)}$$
$$q_l^* = \frac{12\overline{\theta} - 15 - 16c\alpha(\overline{\theta} - 1)}{4c(3 - 4c\alpha)} \qquad (6)$$

The associated equilibrium prices are then:

$$p_h^* = \frac{16\overline{\theta}^2 + 8\overline{\theta} + 25}{32c} - \alpha\frac{64c^2\alpha^2 - 6c\alpha(8\overline{\theta} + 15) + 9(4\overline{\theta} + 3)}{12(3 - 4c\alpha)^2}$$
$$p_l^* = \frac{16\overline{\theta}^2 - 40\overline{\theta} + 49}{32c} - \alpha\frac{128c^2\alpha^2 - 6c\alpha(8\overline{\theta} + 27) + 9(4\overline{\theta} + 5)}{12(3 - 4c\alpha)^2} \qquad (7)$$

The demand for the green product is defined by:

$$n_h^* = 1/2 + (2c\alpha)/(9 - 12c\alpha) \qquad (8)$$

The firms' profits are then:

$$\pi_h(q_h^*, q_l^*) = (3/2c - \alpha)n_h^{*2}$$
$$\pi_l(q_h^*, q_l^*) = (3/2c - \alpha)(1 - n_h^*)^2 \qquad (9)$$

The size of the network effect, α, tends to deteriorate the quality of both products in the same degree.[5] The product differentiation is hence not affected by this externality ($q_h^* - q_l^* = 3/2c$). The intensity of price competition remains the same, but prices decrease because of the lower product quality.[6] Finally, without a network effect, firms share the demand equitably. The network effect favors the green product firm, which sees its market share increase with α ($\partial n_h^*/\partial\alpha = 2c/(4c\alpha - 3)^2$) and corners the whole market when $\alpha = 9/16c$.[7] As a result, the network effect acts favorably on the profit of

[5] $\partial q_i^*/\partial\alpha = -3/(3 - 4c\alpha)^2$

[6] We deduce, from equation (5), the following equalities: $\frac{\partial p_l}{\partial\alpha} = -\frac{2}{3} + \frac{c}{3}q_h\frac{\partial q_h}{\partial\alpha} + \frac{2c}{3}q_l\frac{\partial q_l}{\partial\alpha} \leq 0$ and $\frac{\partial p_h}{\partial\alpha} = -\frac{1}{3} + \frac{2c}{3}q_h\frac{\partial q_h}{\partial\alpha} + \frac{c}{3}q_l\frac{\partial q_l}{\partial\alpha} \leq 0$

[7] We show in the appendix that, whatever the extent of the network effect may be ($0 \leq \alpha \leq 9/16c$), the market is fully covered if $\overline{\theta} \geq 9/4$.

the green firm.[8] By contrast, the brown product firm is penalized by the externality, which reduces the number of its customers.[9]

When the products are sold at price (7) with equilibrium qualities (6), welfare, defined by the equation (3), is written:

$$W^* = \frac{\overline{\theta}\left(\overline{\theta}-1\right)}{2c} + \frac{9}{32c\left(3-4c\alpha\right)^2} + \alpha\frac{9-8c\alpha}{18\left(3-4c\alpha\right)} + \frac{\delta\left(2\overline{\theta}-1\right)}{2c} - \delta\overline{e} \tag{10}$$

Welfare rises with the green network effect.[10] In the following section, we compare the unregulated equilibrium with the first-best optimum.

4. The first-best optimum

The first-best optimum is reached when, for each product, the marginal benefit of consumption is equal to the marginal social cost of production, and also when the allocation of consumers between both qualities is optimal (see Cremer and Thisse, 1999, Lombardini-Riipinen,, 2005 and Lambertini et Orsini, 2005). The three green market failures (imperfect competition, a network effect and pollution) lead us to give new definitions for the product prices and for the environmental consciousness parameter for the consumer indifferent between both products, compared to those used for the equilibrium.

The optimal product prices correspond here to the marginal production cost minus the marginal environmental damage, plus, for the green product, the marginal benefit of the network effect. Hence, the "fair prices" are the following (see appendix A2):

$$\begin{aligned} p_h^o &= \frac{c}{2}q_h^{o2} + \delta\left(\overline{e} - q_h^o\right) - \alpha\, n_h^o \\ p_l^o &= \frac{c}{2}q_l^{o2} + \delta\left(\overline{e} - q_l^o\right) \end{aligned} \tag{11}$$

The welfare function is then defined by:

$$W = \int_{\overline{\theta}-1}^{\hat{\theta}^\circ}\left[\theta q_l - p_l^o\right]d\theta + \int_{\hat{\theta}^\circ}^{\overline{\theta}}\left[\theta q_h - p_h^o\right]d\theta \tag{12}$$

$$\text{with } \hat{\theta}^\circ = \frac{p_h^o - p_l^o - \alpha\overline{\theta}}{q_h - q_l - \alpha} \tag{13}$$

The optimal qualities of the green and brown products are solutions of both first order conditions $\partial W/\partial q_h = 0$ and $\partial W/\partial q_l = 0$ detailed in appendix A2. The only solution for this system of equations that satisfies the second order conditions and the stability condition is the following:

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[8] $\partial\pi_h/\partial\alpha = \left(9-8c\alpha\right)\left(-32c^2\alpha^2+36c\alpha+9\right)\Big/\left(3-4c\alpha\right)^3 \geq 0$ for $c\alpha \in \left[0,9/16\right]$

[9] $\partial\pi_l/\partial\alpha = \left(9-8c\alpha\right)\left(-64c^2\alpha^2+108c\alpha-63\right)\Big/\left(3-4c\alpha\right)^3 \leq 0$ for $c\alpha \in \left[0,9/16\right]$

[10] We verify that, when condition (C1) is fulfilled, $\dfrac{\partial W^*}{\partial\alpha} = \dfrac{243-504c\alpha+576c^2\alpha^2-256c^3\alpha^3}{36\left(3-4c\alpha\right)^3} \geq 0$

$$q_h^O = \frac{4\overline{\theta} + 4\delta - 1 - 32c\alpha\left(\overline{\theta} + \delta\right)}{4c\left(1 - 8c\alpha\right)}$$
$$q_l^O = \frac{4\overline{\theta} + 4\delta - 3 - 32c\alpha\left(\overline{\theta} + \delta - 1/2\right)}{4c\left(1 - 8c\alpha\right)} \quad (14)$$

This solution is valid when the green network effect is relatively low: the condition, denoted (C2), $c\alpha \leq 1/16$, which is more restrictive than condition (C1).

At the optimum, the differentiation is lower than at the unregulated equilibrium ($q_h^o - q_l^o = 1/2c$). This is explained by the behavior of the firms that want to raise product differentiation in order to relax price competition. Differentiation remains at the optimum independent of the extent of the network effect. The equilibrium green quality is too low (high) when the marginal damage, δ, is higher (lower) than a given threshold[11], whereas the standard quality is always too low. In addition, the optimal allocation of consumers corresponds to a demand for the green product higher than that at equilibrium:

$$\hat{\theta}^o = \overline{\theta} - \frac{1}{2} - \frac{4c\alpha}{1 - 8c\alpha} \leq \hat{\theta} = \overline{\theta} - \frac{1}{2} - \frac{2c\alpha}{3\left(3 - 4c\alpha\right)} \quad (15)$$

This difference in demand arises from the network effect alone. Thus the network effect benefits the green firm, to the expense of the brown firm, at the equilibrium.

Welfare at the first-best optimum is therefore defined by:

$$W^o = \frac{16\overline{\theta}\left(\overline{\theta} - 1\right) - 32c\alpha\left(2\overline{\theta} - 1\right)^2 + 5}{32c\left(1 - 8c\alpha\right)} + \frac{\delta\left(2\overline{\theta} - 1 + \delta\right)}{2c} - \delta\overline{e} \quad (16)$$

Welfare tends to grow with the network effect.[12] The following equation shows that, unsurprisingly, first-best optimal welfare is higher than welfare at the equilibrium:

$$W^* - W^o = -\frac{1 + 4d^2}{8c} - \frac{c\alpha^2\left(256c^2\alpha^2 - 512c\alpha + 285\right)}{18\left(3 - 4c\alpha\right)^2\left(1 - 8c\alpha\right)} \leq 0 \quad (17)$$

The unregulated equilibrium is suboptimal whatever the extent of the network effect may be.[13] This difference is due, in particular, to an overall optimal pollution higher than that at the game equilibrium:

$$E^o = \overline{e} - \frac{2\overline{\theta} - 1}{2c} - \frac{\delta}{c} \leq E^* = \overline{e} - \frac{2\overline{\theta} - 1}{2c} \quad (18)$$

The three market failures lead firms to non-optimal behavior. Only corrective policies are able to motivate them to change their supply strategy in the desired direction. Accordingly, in the following section, we introduce policies likely to play this role.

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[11] This threshold is defined by: $\tilde{\delta} = \frac{1}{2} + \frac{10c\alpha}{2\left(3 - 4c\alpha\right)\left(1 - 8c\alpha\right)}$

[12] $\frac{\partial W^o}{\partial \alpha} = \frac{1}{4\left(1 - 8c\alpha\right)^2} \geq 0$

[13] The polynomial function of degree two of equation (16) has no real root and remains positive whatever the values of c and α .

5. The regulated equilibrium

We envisage three fiscal policies: a pollution tax in order to limit excessive environmental damage, an *ad valorem* tax in order to reduce product differentiation, and a subsidy for the green product in order to favor the network externality. Doing this, we draw on a framework close to the one proposed by Lombardini-Riipinen (2005). However, the introduction of the green network effect means a corrective policy including three instruments rather than two.

With consumers of the green product benefiting from the subsidy, s, the utility function is modified in the following way:

$$u_i(\theta) = \theta q_i - p_i + \alpha_i n_i + s_i \quad i = l,h \tag{19}$$

with $\alpha_v \equiv \alpha \geq 0$, $s_v \equiv s \geq 0$ and $\alpha_l = s_l = 0$. The subsidy[14] tends to increase *ex ante* the demand for the green product, by moving consumer who is indifferent between the green and standard product towards the left, over the interval $\left[\overline{\theta} - 1, \overline{\theta}\right]$. This is characterized by the parameter $\hat{\theta} = \left(p_h - p_l - \alpha\overline{\theta} - s\right) / \left(q_h - q_l - \alpha\right)$.

The firms are subject to an emission tax and a product tax. Their profits are thus rewritten as follows:

$$\begin{aligned} \pi_i &= \left((1 - t_v)p_i - c(q_i) - \tau_e(\overline{e} - q_i)\right)d_i \\ &= \frac{1}{\tau_v}\left(p_i - \tau_v\, c(q_i) - \tau_v \tau_e(\overline{e} - q_i)\right)d_i \quad i = h,l \end{aligned} \tag{20}$$

with t_v the *ad valorem* tax defined over $[0,1]$, $\tau_v = 1/(1 - t_v)$ an index of the *ad valorem* tax defined over $[1,+\infty)$, and τ_e the pollution tax defined over $[0,+\infty)$.

The second game stage, price competition, consists of firms maximizing their profits (20), knowing the chosen qualities at the first stage of the game $\left(q_h^{**}, q_l^{**}\right)$. We show in appendix A3 that the equilibrium prices of the subgame are here characterized by:

$$\begin{aligned} p_h^{**} &= \frac{1}{3}\left(q_h^{**} - q_l^{**}\right)\left(\overline{\theta} + 1\right) + \frac{\tau_e \tau_v}{3}\left(3\overline{e} - 2q_h^{**} - q_l^{**}\right) + \frac{s - \alpha}{3} + \frac{1}{3}\tau_v c q_h^{**2} + \frac{1}{6}\tau_v c q_l^{**2} \\ p_l^{**} &= \frac{1}{3}\left(q_h^{**} - q_l^{**}\right)\left(2 - \overline{\theta}\right) + \frac{\tau_e \tau_v}{3}\left(3\overline{e} - q_h^{**} - 2q_l^{**}\right) - \frac{s + 2\alpha}{3} + \frac{1}{3}\tau_v c q_l^{**2} + \frac{1}{6}\tau_v c q_h^{**2} \end{aligned} \tag{21}$$

The first game stage, quality competition, leads firms to maximize their profits (20) knowing the prices (21). As in the unregulated game, there exists a unique quality equilibrium. The equilibrium qualities are the following:

$$\begin{aligned} q_h^{**} &= \frac{12\overline{\theta} + 3 - 8\tau_v c\alpha\left(2\overline{\theta} + 1\right)}{4\tau_v c\left(3 - 4\tau_v c\alpha\right)} - \frac{2s}{3 - 4\tau_v c\alpha} + \frac{\tau_e}{c} \\ q_l^{**} &= \frac{12\overline{\theta} - 15 - 16\tau_v c\alpha\left(\overline{\theta} - 1\right)}{4\tau_v c\left(3 - 4\tau_v c\alpha\right)} - \frac{2s}{3 - 4\tau_v c\alpha} + \frac{\tau_e}{c} \end{aligned} \tag{22}$$

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[14] The subsidy s is here different from the one assumed by Lombardini-Riipinen (2005), who weights the subsidy by the gap between both qualities $(q_h - q_l)$.

The environmental tax motivates firms to enhance the quality of their products, whereas the subsidy encourages them to reduce quality. Notwithstanding this, neither of them affects product differentiation ($q_h^{**} - q_l^{**} = 3/(2\tau_v c)$). This is only influenced by the *ad valorem* tax, which, as noted it Cremer and Thisse (1994), tends to decrease differentiation. This effect brings about a reduction of the ecological quality and a lower deterioration, or an improvement, of the standard quality.[15]

The demand for the green product is given as:

$$n_h^{**} = \frac{1}{2} + \frac{\tau_v c(2s+\alpha)}{3(3-4\tau_v c\alpha)} \quad (23)$$

It is stimulated by the subsidy for green purchases and the *ad valorem* tax[16] but is not affected by the environmental tax. The standard firm enjoys a positive demand since the condition, $\tau_v c(s+2\alpha) \le 9/8$, denoted (C3), is fulfilled.

The firms' profits are defined by:

$$\begin{aligned} \pi_h(q_h^{**}, q_l^{*}) &= \left(3/2\tau_v^2 c - \alpha/\tau_v\right) n_h^{**2} \\ \pi_l(q_h^{**}, q_l^{**}) &= \left(3/2\tau_v^2 c - \alpha/\tau_v\right)\left(1-n_h^{**}\right)^2 \end{aligned} \quad (24)$$

The profits at the regulated equilibrium are independent of the level of the pollution tax, which affect qualities and prices of both firms in the same way. The *ad valorem* tax reduces the profits.[17] The subsidy increases the profits of the green firm to the detriment of its competitor.

How can the taxes and subsidy induce an optimal behavior in firms? We deal, in the following section, with the possibilities of reaching the first best optimum using appropriate taxation and with the existence of an environmental taxation able to attain a second best optimum.

6. Optimal taxation

Only implementation of the three fiscal instruments can motivate firms to supply the optimal qualities at "fair prices" to consumers while stimulating demand for the green product to its optimal level. When the regulator is only responsible for environmental policies, he cannot guide the economy towards the first best optimum. Therefore, we investigate how an environmental tax and/or a subsidy for green purchase can lead to a second best optimum. We ignore the *ad valorem* tax because it has the propensity to increase pollution and, hence, is not suitable for an environmental policy (see Lombardini-Riipinen, 2005 and Brécard, 2008).

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15 $\partial q_h^{**}/\partial\tau_v = -\bar{\theta}/c\tau_v^2 - \left[9+8c\tau_v\left(3-4c\tau_v(\alpha+s)\right)\right] / \left[4c\tau_v^2(3-4c\tau_v\alpha)^2\right] \le 0$ and
$\partial q_l^{**}/\partial\tau_v = \partial q_h^{**}/\partial\tau_v + 3/\left(2c\tau_v^2\right) \ge \partial q_h^{**}/\partial\tau_v$

16 $\partial n_h^{**}/\partial\tau_v = 2c(2s+\alpha)/(4c\alpha-3)^2$

17 $\frac{\partial\pi_h}{\partial\tau_v} = -\frac{3-\tau_v c\alpha}{c\tau_v^3} n_h^2 - \frac{4c(3-2\tau_v c\alpha)(2s+\alpha)}{3c\tau_v^2(3-4\tau_v c\alpha)} n_h \le 0$, and

$$\frac{\partial\pi_l}{\partial\tau_v} = -\left(\frac{3-\tau_v c\alpha}{2c\tau_v^2} + \frac{2c\alpha(9-4\tau_v c\alpha)(2s+\alpha)}{3\tau_v(3-4\tau_v c\alpha)^2}\right)(1-n_h) \le 0$$

The first best optimal taxation has to equalize the equilibrium values of qualities, prices and demand, and their optimal values. Consequently, we attempt to find one or more solutions $(\tau_v^o, \tau_e^o, s^o)$ to the system of three equations $q_h^{**} = q_h^o$, $q_l^{**} = q_l^o$ and $n_h^{**} = n_h^o$. The single optimal taxation is defined in the following way:

$$(\tau_v^o, \tau_e^o, s^o) = \left(3,\ \delta + \frac{2}{3}\left(\bar{\theta} - \frac{1}{2}\right), \frac{\alpha(5 - 16c\alpha)}{2(1 - 8c\alpha)}\right) \tag{25}$$

The *ad valorem* tax and the environmental tax are the same as those given by Lombardini-Riipinen (2005). This result is not surprising insofar as the network effect of the consumption of the green product affects neither the product differentiation nor the pollution at the equilibrium. The *ad valorem* tax is equal to 2/3 while the environmental tax is higher than the marginal damage, δ, in order to correct the harmful effect of the product tax on pollution levels. The optimal subsidy is null if the spillover doesn't come into play and positive when (C2) is fulfilled; the greater the spillover effect, the greater the optimal subsidy[18] in order to stimulate the demand for the green product.

If the regulator only has one or two tax instruments, he aims to achieve a second best optimum characterized by maximal welfare when prices and qualities are those chosen by the firms at the regulated equilibrium. The welfare is thus defined by:

$$W^{**} = CS_h^{**} + CS_l^{**} + \pi_h^{**} + \pi_l^{**} + GR^{**} - \delta E^{**} \tag{26}$$

with $GR^{**} = \tau_e E^{**} - s n_h^{**}$ the government revenue coming from the environmental tax paid by the firms (redistributed to consumers as a lump sum) from which the subsidy paid to consumers of green product is deducted (financed by a lump sum tax paid by the whole consumer base)

At the regulated game equilibrium, the pollution tax has no impact on product differentiation, firms' market share or profits. Nevertheless, it raises the prices of the products and increases the qualities firms supply to consumers. Without other corrective policies, the welfare is defined by:

$$W_{\tau_e}^{**} = W^* + \tau_e \frac{2\delta - \tau_e}{2c} \tag{27}$$

We deduce from equation (27) that the second order environmental tax $\hat{\tau}_e$ is here equal to the pigouvian tax δ. This result is the same as that of Lombardini-Riipinen (2005) because the network effect has no effect on pollution and thus on the policy that aims at reducing it. Furthermore, because of the assumption of full market coverage, the tax does not induce any reduction in the firms' supply.

The green purchase subsidy favors the green firm to the detriment of the brown firm. The monetary transfer from the whole of the consumer base, through an individual lump-sum tax $s n_h^{**}$, to the consumers of the green product (who are each given a subsidy of s) allows the following welfare to be achieved:

$$W_s^{**} = W^* + 2c\, s \frac{\alpha(21 - 16c\alpha) + s(3 + 8c\alpha)}{9(2 - 4c\alpha)^2} \tag{28}$$

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[18] $\partial s^o / \partial \alpha = (128c^2\alpha^2 - 32c\alpha + 5) / 2(1 - 8c\alpha)^2 \geq 0$

Under condition (C1), the subsidy tends to improve welfare beyond that achieved without the environmental policy. Consequently, the green purchase aid must be maximal. The highest optimal subsidy is the one that leads to the disappearance of the brown product. It arises from the equality $n_h^{**} = 1$ and is defined by $\hat{s} = (9 - 16c\alpha)/8c$.

The joint use of the two fiscal instruments achieves an increase in welfare to the threshold $W_{s+\tau_e}^{**} = (2\overline{\theta} + 2\delta - 1)^2 / (8c) + \alpha - \delta\overline{e}$. When the network effect fulfills condition (C2), welfare remains lower than that reached at the first best optimum. We indeed show that $W_{s+\tau_e}^{**} = W^o - (1-16c\alpha)^2 / (32c(1-8c\alpha))$. In a monopoly situation, the green firm[19] supplies the quality $\hat{q}_h = (2\overline{\theta} + 2\delta - 1)/2c$ at price $\hat{p}_h = (4\overline{\theta}^2 - 4\overline{\theta} + 13 - 4\delta^2)/(8c) - \alpha + \delta\overline{e}$ and earns a profit $\hat{\pi}_h = 3/2c - \alpha$.

The combination of the pollution tax and the green purchase subsidy is however likely to be subject to budget constraints. In this case, the subsidy arises from the following equality $\hat{\hat{s}}\, n_h = \tau_e E = \delta(\overline{e} - q_h n_h - q_l(1-n_h))$ in which the qualities and the demand depend on the subsidy level. It is defined by $\hat{\hat{s}} = \left(-9 + 8c\alpha + \sqrt{(9-8c\alpha)^2 + 96\delta(3-4c\alpha)(1 + 2c\overline{e} - 2\delta - 2\overline{\theta})}\right) / (16c)$. This subsidy is lower than the maximal one, $\hat{s}$, when the network effect is not too high ($\alpha \leq \left[9 + 4\delta(2\overline{\theta} + 2\delta - 2c\overline{e} - 1)\right] / (16c)$). The equilibrium qualities are therefore lower and the green consumers are fewer. Welfare is also lower than with the maximal subsidy.

The combination of the Pigouvian tax and the maximal subsidy of green purchase allows an improvement in welfare and moves the economy towards an second best optimum.

7. Conclusion

The taking into account the effect that the number of consumers of a green product has on their satisfaction on consuming that product has given new results about the working of a green market.

Firm behavior is not only influenced by consumer willingness to pay for ecological quality, as shown by Lombardini-Riipinen (2005), but also by the green network effect. This effect pushes firms to decrease both the quality of their products and their prices, although the product differentiation is not impacted by the externality. It benefits the green firm, which sees its market share and its profit rise to the detriment of its competitor. Moreover, it results in an improvement in welfare, although it doesn't affect total pollution.

The network externality cannot however alone compensate for the effects of pollution and imperfect competition on welfare. It doesn't change the tendency of firms to over-differentiate their products and to over-pollute in comparison with the first-best optimum. Nevertheless, the spillover effect is at the origin of an inefficiency in the

[19] The green firm is here in a situation of a monopoly threatened by the entry of the brown firm and can't apply its monopoly strategy.

green product demand. The implementation of an appropriate taxation system allows the reconciliation of the equilibrium to the optimum. We have shown that the optimal combination of an *ad valorem* tax, a pollution tax and a subsidy for green purchase can achieve this. When the regulator only has environmental policy tools, the optimal policy consists in imposing a pigouvian tax, equal to the marginal damage, and a subsidy for the green purchase that eventually removes the standard product firm from the market.

This paper completes the analysis initiated by Cremer and Thisse (1999) and drawn out by Lombardini-Riipinen (2005). It takes advantage of recent literature dealing with the effects of the number of consumers of a product on the satisfaction arising from its consumption (Grilo et al., 2001, Lambertini and Orsini, 2005). Even if our model has the merit of being relatively simple, it would undoubtedly gain from being generalized to the case of partially covered market. The network effect could then play on the total production and, in this way, on the total pollution. This would certainly modify the optimal taxation, in particular the pollution tax.

Appendix

A1. Unregulated equilibrium

Price competition results in the maximization of profits (2), when the varieties chosen in the previous stage are known. The following are the resulting reaction functions :

$$\begin{cases} p_h^*(p_l) = \frac{1}{2} p_l + 2(q_h - q_l)\bar{\theta} + \frac{cq_h^2}{4} \\ p_l^*(p_h) = \frac{1}{2} p_h + 2(q_h - q_l)(1-\bar{\theta}) + \frac{cq_l^2}{4} - \frac{\alpha}{2} \end{cases} \tag{A1}$$

The only candidate for the equilibrium of this subgame, $p_h^* = p_h^*(p_l^*)$ and $p_l^* = p_l^*(p_h^*)$ is written:

$$\begin{aligned} p_h^* &= \frac{1}{3}(q_h - q_l)(\bar{\theta}+1) - \frac{\alpha}{3} + \frac{1}{3}cq_h^2 + \frac{1}{6}cq_l^2 \\ p_l^* &= \frac{1}{3}(q_h - q_l)(2-\bar{\theta}) - \frac{2\alpha}{3} + \frac{1}{3}cq_l^2 + \frac{1}{6}cq_h^2 \end{aligned} \tag{A2}$$

We deduce from (A2) the demand for both firms:

$$\begin{aligned} n_h &= \frac{2(q_h - q_l)(1+\bar{\theta}) - 2\alpha - cq_h^2 + cq_l^2}{6(q_h - q_l - \alpha)} \\ n_l &= 1 - n_h \end{aligned} \tag{A3}$$

The profits (2) are then rewritten:

$$\begin{aligned} \pi_h(q_h, q_l) &= (q_h - q_l - \alpha)n_h^2 \\ \pi_l(q_h, q_l) &= (q_h - q_l - \alpha)(1 - n_h)^2 \end{aligned} \tag{A4}$$

Quality competition finds expression in the qualities maximizing (A4). The first order conditions (FOC) are written:

$$\begin{aligned} \frac{\partial \pi_h(q_h, q_l)}{\partial q_h} &= \frac{n_h}{6(q_h - q_l - \alpha)}\left[4cq_h(q_l + \alpha) + 2(q_h - q_l)(\bar{\theta}+1) - cq_l^2 - 3cq_h^2 - 2\alpha(1+2\bar{\theta})\right] = 0 \\ \frac{\partial \pi_l(q_h, q_l)}{\partial q_l} &= \frac{(1-n_h)}{6(q_h - q_l - \alpha)}\left[4cq_l(-q_h + \alpha) + 2(q_h - q_l)(\bar{\theta} - 2) + cq_h^2 + 3cq_l^2 - 4\alpha(\bar{\theta} - 1)\right] = 0 \end{aligned} \tag{A5}$$

Both firms remain in the market since $0 < n_h < 1$. The FOC thus reduces to the following two-equation system:

$$\begin{cases} 4cq_h\left(q_l+\alpha\right)+2\left(q_h-q_l\right)\left(\overline{\theta}+1\right)-cq_l^2-3cq_h^2-2\alpha\left(1+2\overline{\theta}\right)=0 \\ 4cq_l\left(-q_h+\alpha\right)+2\left(q_h-q_l\right)\left(\overline{\theta}-2\right)+cq_h^2+3cq_l^2-4\alpha\left(\overline{\theta}-1\right)=0 \end{cases} \quad \text{(A6)}$$

This system of two polynomial functions of degree two in q_h and q_l has five candidates for the equilibrium $\left(q_h^*,q_l^*\right)$:

$$\text{(i)} \left(\frac{2\left(\overline{\theta}+1\right)-\sqrt{9-8c\alpha}}{2c},\frac{2\overline{\theta}-1}{2c}\right) \qquad \text{(ii)} \left(\frac{2\overline{\theta}-1}{2c},\frac{2\left(\overline{\theta}-2\right)+\sqrt{9-16c\alpha}}{2c}\right)$$

$$\text{(iii)} \left(\frac{2\overline{\theta}-1}{2c},\frac{2\left(\overline{\theta}-2\right)-\sqrt{9-16c\alpha}}{2c}\right) \qquad \text{(iv)} \left(\frac{2\left(\overline{\theta}+1\right)+\sqrt{9-8c\alpha}}{2c},\frac{2\overline{\theta}-1}{2c}\right) \quad \text{(A7)}$$

$$\text{(v)} \left(\frac{3+12\overline{\theta}-8c\alpha\left(1+2\overline{\theta}\right)}{4c\left(3-4c\alpha\right)},\frac{-15+12\overline{\theta}-16c\alpha\left(\overline{\theta}-1\right)}{4c\left(3-4c\alpha\right)}\right)$$

Without the network effect, solution (i) and (ii) result in absence of differentiation. In this case, the profits of both firms are null and the second order conditions (SOC) are fulfilled ($\partial^2\pi_i/\partial q_i^2=-c/3$). These solutions can't be Nash equilibria insofar as solution (v) allows both firms to earn positive profits. Solutions (iii) and (iv) don't satisfy the SOC. Only solution (v) is a game equilibrium: profits are positive ($\pi_i=3/8c$) and the SOC are fulfilled ($\partial^2\pi_i/\partial q_i^2=-c/4$). With $\alpha\geq 0$, the SOC are written:

$$\left.\frac{\partial^2\pi_h\left(q_h,q_l\right)}{\partial q_h{}^2}\right|_{q_h^*,q_l^*}=\frac{c\left(9-8c\alpha\right)\left(-32c^2\alpha^2+64c\alpha-27\right)}{36\left(3-4c\alpha\right)^2\left(3-2c\alpha\right)}\leq 0 \quad \text{if} \quad c\alpha\leq 0.6047$$

$$\left.\frac{\partial^2\pi_l\left(q_h,q_l\right)}{\partial q_l{}^2}\right|_{q_h^*,q_l^*}=\frac{c\left(9-16c\alpha\right)\left(-32c^2\alpha^2+56c\alpha-27\right)}{36\left(3-4c\alpha\right)^2\left(3-2c\alpha\right)}\leq 0 \quad \text{if} \quad c\alpha\leq 9/16=0.5625 \quad \text{(A8)}$$

Finally, the condition for market coverage ($\tilde{\theta}\leq\overline{\theta}-1$) implies:

$$\frac{1024c^3\alpha^3+192c^2\alpha^2\left(4\overline{\theta}^2-8\overline{\theta}-11\right)-144c\alpha\left(8\overline{\theta}^2-16\overline{\theta}-9\right)-27\left(16\overline{\theta}^2-32\overline{\theta}-9\right)}{24\left(3-4c\alpha\right)\left(4\left(3-4c\alpha\right)\overline{\theta}+16c\alpha-15\right)}\geq 0 \quad \text{(A9)}$$

When the condition $0\leq c\alpha\leq 9/16$ is satisfied, the denominator is positive if $\theta\geq\dfrac{15-16c\alpha}{4\left(3-4c\alpha\right)}$. Without the network effect, the coverage condition is simply written $\left(4\overline{\theta}+1\right)\left(4\overline{\theta}-9\right)/\left(4\overline{\theta}-5\right)\geq 0$. It is fulfilled if $\overline{\theta}\geq 9/4$. In the case of a network effect, the graph below shows that the numerator is always positive under this last condition.

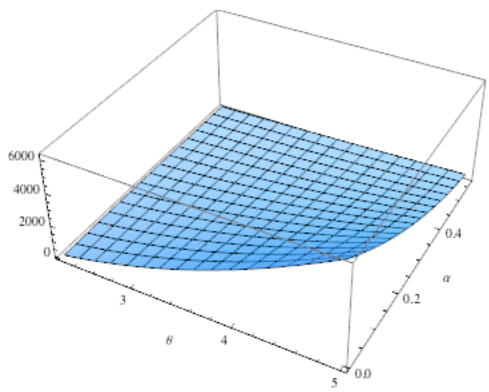

Fig.1. Numerator of the condition (A9)

A2. First-order optimum

We consider, as Cremer and Thisse (1999) and Lombardini-Riipinen (2005), that product prices correspond to the marginal social costs of these products. Equations (12) and (13) lead to the following expression for welfare at the first-best optimum:

$$W=\frac{\left(p_h-p_l-\bar{\theta}(q_h-q_l)\right)}{2(q_h-q_l-\alpha)^2}\Big[-2\delta(q_h-q_l)(q_h-q_l-\alpha)-(q_h-q_l-2\alpha)(p_h-p_l)+\left(cq_h^2+cq_l^2\right)\left(q_h+q_l-\alpha\right)-\bar{\theta}(q_h-q_l)(q_h-q_l)-q_l(q_h-q_l-\alpha)\Big]+\frac{(q_h-q_l-\alpha)}{2(q_h-q_l-\alpha)^2}\Big[\left((\bar{\theta}+1)q_l+cq_l^2-2\delta(\bar{e}-q_l)\right)(q_h-q_l-\alpha)-\alpha\bar{\theta}q_l+q_l(p_h-p_l)\Big] \quad \text{(A10)}$$

Let p_l^o be the optimal price of the standard product, the price of the green product maximizing the welfare defined by (A10) is the solution of:

$$p_h^o=p_l^o+\frac{c}{2}\left(q_h^2-q_l^2\right)-\delta\left(q_h-q_l\right)+\alpha\frac{\left(q_h-q_l\right)\left(c\left(q_h+q_l\right)-2\bar{\theta}-2\delta\right)}{2(q_h-q_l-2\alpha)} \quad \text{(A11)}$$

with $p_l^o=\frac{1}{2}cq_l^2+\delta\left(\bar{e}-q_l^o\right)$. We deduce that:

$$p_h^o=\frac{c}{2}q_h^2+\delta\left(\bar{e}-q_h\right)+\alpha\frac{\left(q_h-q_l\right)\left(c\left(q_h+q_l\right)-2\bar{\theta}-2\delta\right)}{2(q_h-q_l-2\alpha)} \quad \text{(A12)}$$

The number of consumers of green products is then defined by:

$$n_h^o=\frac{\left(q_h-q_l\right)\left(c\left(q_h+q_l\right)-2\bar{\theta}-2\delta\right)}{2(q_h-q_l-2\alpha)} \quad \text{(A13)}$$

The optimal price of the green product is thus simply defined by:

$$p_h^o=\frac{c}{2}q_h^2+\delta\left(\bar{e}-q_h\right)+\alpha\, n_h^o \quad \text{(A14)}$$

By substituting the optimal prices in the welfare function (A10), we obtain:

$$W=\frac{(q_h-q_l)^2\left[\left(c(q_h+q_l)-2\delta\right)\left(c(q_h+q_l)-2\delta-4\bar{\theta}\right)+4\bar{\theta}^2\right]}{8(q_h-q_l-2\alpha)}-\delta\,\bar{e}+\delta q_l-\frac{1}{2}q_l\left(cq_l-2\bar{\theta}+1\right) \quad \text{(A15)}$$

The maximization conditions for welfare are the following:

$$\frac{\partial W}{\partial q_h}=\frac{1}{8(q_h-q_l-2\alpha)^2}\Big[(q_h-q_l)\left(c(q_h+q_l)-2\bar{\theta}-2\delta\right)\left(-2\left(\delta+\bar{\theta}\right)(q_h-q_l-4\alpha)-c\left(3q_h^2+q_l^2-4q_hq_l-8\alpha q_h\right)\right)\Big]=0 \quad \text{(A16a)}$$

$$\frac{\partial W}{\partial q_l}=\frac{1}{8(q_h-q_l-2\alpha)^2}\Big[c^2(q_h-3q_l)(q_h+q_l)\left(q_h-q_l\right)^2+8c^2\alpha q_l(q_h+q_l)\left(q_h-q_l\right)+8cq_l\left(\bar{\theta}-1+\delta\right)\left(q_h-q_l\right)^2-8c\alpha(q_h+3q_l)(q_h-q_l)\left(\delta+\bar{\theta}\right)+32c\alpha q_l(q_h-q_l-\alpha)+16\alpha^2\left(2\bar{\theta}+2\delta-1\right)+16\alpha(q_h-q_l)\left(\bar{\theta}-1+\delta\right)^2-4\left(\bar{\theta}-1+\delta\right)^2\left(q_h-q_l\right)^2\Big]=0 \quad \text{(A16b)}$$

The system has only one solution satisfying the SOC and the stability condition. We can show that when the optimal qualities are defined by (14), the following second derivatives are definitely negative if $c\alpha<1/16$:

$$\left.\partial^2W/\partial q_h^2\right|_{q_h^o,q_l^o}=-c\left(3-48c\alpha+128c^2\alpha^2\right)\Big/8(1-8c\alpha)^2(1-4c\alpha)<0 \quad \text{(A17a)}$$

$$\partial^2 W/\partial q_l^2 = -c\left(1-16c\alpha\right)\left(3-32c\alpha+128c^2\alpha^2\right)/8\left(1-8c\alpha\right)^2\left(1-4c\alpha\right) < 0 \tag{A17b}$$

The cross second derivatives are positive:

$$\left.\partial^2 W/\partial q_h \partial q_l\right|_{q_h^o, q_l^o} = \left.\partial^2 W/\partial q_l \partial q_h\right|_{q_h^o, q_l^o} = c\left(1-16c\alpha\right)/8\left(1-8c\alpha\right)^2\left(1-4c\alpha\right) \tag{A18}$$

and the determinant of the hessian matrix H is positive:

$$\text{Det } H = c^2\left(1-16c\alpha\right)/8\left(1-8c\alpha\right)\left(1-4c\alpha\right) \tag{A19}$$

A3. Regulated equilibrium

At the price competition stage, the reaction functions resulting from maximization of profits (20) are written:

$$\begin{cases} p_h^*\left(p_l\right) = \dfrac{1}{2}\left[p_l + s + \left(q_h - q_l\right)\overline{\theta} + \tau_e\tau_v\left(\overline{e} - q_h\right)\right] + \dfrac{\tau_v}{4}cq_h^2 \\ p_l^*\left(p_h\right) = \dfrac{1}{2}\left[p_h - s + \left(q_h - q_l\right)\left(1-\overline{\theta}\right) + \tau_e\tau_v\left(\overline{e} - q_l\right) - \alpha\right]\dfrac{\tau_v}{4}cq_l^2 \end{cases} \tag{A20}$$

Only one candidate for the equilibrium, whose definition is given in the equation (21), results from (A20). The demand for products and the profits are then defined as functions of the qualities and parameters of the model:

$$n_h = \frac{2\left(q_h - q_l\right)\left(1+\tau_e\tau_v+\overline{\theta}\right) + 2s - 2\alpha - \tau_v cq_h^2 + \tau_v cq_l^2}{6\left(q_h - q_l - \alpha\right)} \tag{A21}$$

$$n_l = 1 - n_h$$

$$\begin{aligned} \pi_h\left(q_h, q_l\right) &= \frac{q_h - q_l - \alpha}{\tau_v} n_h^2 \\ \pi_l\left(q_h, q_l\right) &= \frac{q_h - q_l - \alpha}{\tau_v}\left(1-n_h\right)^2 \end{aligned} \tag{A22}$$

At the quality competition stage, maximization of the profits (A22) leads to the following first order conditions:

$$\begin{aligned} \frac{\partial \pi_h\left(q_h, q_l\right)}{\partial q_h} = \frac{n_h}{6\tau_v\left(q_h - q_l - \alpha\right)} &\left[4\tau_v cq_h\left(q_l + \alpha\right) + 2\left(q_h - q_l\right)\left(\overline{\theta} + 1 + \tau_v\tau_e\right)\right. \\ &\left.-\tau_v cq_l^2 - 3\tau_v cq_h^2 + 2\left(s + \alpha + 2\tau_v\tau_e\alpha + 2\alpha\overline{\theta}\right)\right] = 0 \end{aligned} \tag{A23a}$$

$$\begin{aligned} \frac{\partial \pi_l\left(q_h, q_l\right)}{\partial q_l} = \frac{\left(1-n_h\right)}{6\tau_v\left(q_h - q_l - \alpha\right)} &\left[4\tau_v cq_l\left(-q_h + \alpha\right) + 2\left(q_h - q_l\right)\left(\overline{\theta} - 2 + \tau_v\tau_e\right)\right. \\ &\left.+3\tau_v cq_l^2 + \tau_v cq_h^2 - 2s - 4\alpha\left(\overline{\theta} - 1 + \tau_v\tau_e\right)\right] = 0 \end{aligned} \tag{A23b}$$

As for the unregulated equilibrium, the equation system has five candidates for the equilibrium. We keep only the solution $\left(q_h^{**}, q_l^{**}\right)$, which, without a network effect or taxation, corresponds to the Nash equilibrium:

$$\left(\frac{\left(12\overline{\theta} + 3 + \tau_e\tau_v\right) - 8c\tau_v\left(2\alpha\overline{\theta} + s + \alpha\right)}{4c\tau_v\left(3 - 4c\tau_v\alpha\right)}, \frac{\left(12\overline{\theta} - 15 + \tau_e\tau_v\right) - 8c\tau_v\left(2\alpha\overline{\theta} + s - 2\alpha\right)}{4c\tau_v\left(3 - 4c\tau_v\alpha\right)}\right) \tag{A24}$$

The second derivatives of the profits are written:

$$\begin{aligned} \left.\frac{\partial^2 \pi_h\left(q_h, q_l\right)}{\partial q_h^2}\right|_{q_h^*, q_l^*} &= \frac{c\left(9 + 8c\tau_v\left(s - \alpha\right)\right)\left(-32c^2\tau_v^2\alpha^2 + 8c\tau_v\left(s + 8\alpha\right) - 27\right)}{36\left(3 - 4c\tau_v\alpha\right)^2\left(3 - 2c\tau_v\alpha\right)} \leq 0 \\ \left.\frac{\partial^2 \pi_l\left(q_h, q_l\right)}{\partial q_l^2}\right|_{q_h^*, q_l^*} &= \frac{c\left(9 - 8c\tau_v\left(s + 2\alpha\right)\right)\left(-32c^2\tau_v^2\alpha^2 - 8c\tau_v\left(s - 7\alpha\right) - 27\right)}{36\left(3 - 4c\alpha\right)^2\left(3 - 2c\alpha\right)} \leq 0 \end{aligned} \tag{A25}$$

The determinant of the hessian matrix is then defined by:

$$\text{Det}\, H = \frac{c\left(9+8\tau_v c(s-\alpha)\right)\left(9-8\tau_v c(s+2\alpha)\right)}{162(3-2\tau_v c\alpha)(3-4\tau_v c\alpha)} \quad \text{(A26)}$$

$$\text{with } \frac{\partial^2 \pi_h}{\partial q_h \partial q_l} = \frac{\partial^2 \pi_l}{\partial q_l \partial q_h} = \frac{c\left(9+8\tau_v c(s-\alpha)\right)\left(9-8\tau_v c(s+2\alpha)\right)}{36(3-2\tau_v c\alpha)(3-4\tau_v c\alpha)^2} \quad \text{(A26)}$$

The second derivatives are negative if, without taxation, $\alpha < 9/16c$ and, in the case of corrective taxation, $\tau_v \alpha < 9/16c$ and $\alpha \le \frac{8-\sqrt{10+8\tau_v cs}}{8\tau_v c}$. The determinant of the hessian matrix is positive under the previous conditions and the condition $s \le 9/(8\tau_v c) - 2\alpha$.

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