Thünen-Series of Applied Economic Theory

Thünen-Reihe Angewandter Volkswirtschaftstheorie

Working Paper No. 6

Environmental Policy, Firm Location, and Product Differentiation:

The Role of "Green" Preferences and Inter-firm Pollution

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1997

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Abstract

Endogenous firm location is analyzed in a discrete two-region-two-firm model of product differentiation. In a non-cooperative game, two regional governments first decide on the imposition (or lifting) of domestic production standards; firms then choose technology (clean or polluting), location and price. Equilibrium quality and location structure are determined analytically. The existence of consumers willing to pay a premium on clean production methods, and the possibility of inter-firm pollution alleviate the tendency of firms to delocate into the region with the weaker regulation; then, a deregulatory „race to the bottom" is less likely.

JEL classification: H73, L13, Q28

Keywords: environmental policy, product differentiation, firm location, institutional competition, green preferences

1. Introduction

The problem of business delocation in reaction to a unilateral tightening of environmental regulation has become a top priority on the agenda of policy makers, executives, and economists. A related issue is the fear of a "race to the bottom" type of deregulation, in which Governments undercut each other's environmental standards or taxes in order to attract firms, thereby increasing environmental damage in all regions. Markusen et al. (1993) and Mot-

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ta/Thisse (1994) consider the location choices of duopolistic firms. Both studies conclude that, in order to avoid an increase in costs, firms tend to delocate in reaction to a unilateral tightening of environmental regulation. Motta/Thisse show that the existence of sunk costs or barriers to trade reduces the tendency of delocation. However, the loss of competitiveness for a producer not being able to delocate may force him out of business. Markusen et al. (1995) and Rauscher (1995) consider a monopolist whose location choice is dependent on the pollution tax rates, which are set by the welfare maximizing countries in a non-cooperative game. A race to the bottom is the outcome unless governments have a second instrument at their disposal, say a subsidy, to influence firms´ location choices (Rauscher) or unless disutility of pollution is sufficiently high (Markusen et al. and Rauscher).[1]

However, to my knowledge, all location models disregard a firm´s option to use the installation of a - usually more costly - clean production technology as a selling argument. Suppose some consumers have a preference for goods that are produced by means of a clean technology. Even without environmental regulation, a firm may then introduce a clean technology, because it gains a monopolistic profit by differentiating its product from those produced in a polluting manner. Now, consider a producer who has not installed a clean technology, because the monopolistic rent to be gained from product differentiation does not compensate the higher cost. Yet, if faced by more stringent environmental regulation, he might install the clean technology rather than delocate if the overall decrease in profit for selling a "green" good is smaller than a given cost of delocation. The producer of a *homogeneous* good in Motta/Thisse loses competitiveness if he cannot avoid the switch to a costly clean technology, by means of delocation. Yet, the producer of a *differentiated* "green" product may get around the loss of competitiveness without having to delocate. Hence, there are two forces counterbalancing the incentives for delocation: (1) the cost of delocation, being a necessary condition, and (2) the option of product differentiation, adding sufficiency to (1) for delocation not to take place. To see this, consider a zero cost of delocation. Even under product differentiation the locational structure is arbitrary, and delocation cannot be excluded. On the other hand, for a given cost of delocation, the option of selling a differentiated "green" product is the driving force behind the introducion of a clean technology. The reduced tendency of delocation implies that a country will not necessarily attract foreign firms by means of deregulation. Hence, the incentive for countries to engage in a race to the bottom is reduced. Policy makers should, therefore, consider the demand side, too, when evaluating the effects of environmental policies.

To provide a more rigorous foundation of the argument above, I extend a discrete partial equilibrium model of vertical product differentiation by Ecchia/Mariotti (1994). It belongs to the class of models that apply the concept of vertical product differentiation to environmental economics (see Ronnen 1991, Motta/Thisse 1993, Crampes/Hollander 1995, Boom 1995). Central to them is the existence of heterogeneous preferences with regard to product quality. With all other product characteristics being equal, it is straightforward to regard the environmentally friendly variant as the high quality one. However, we have to be careful about our conception of what constitutes "environmental friendliness". This characteristic may refer to

(1) a qualitative attribute of the product itself having (a) a direct impact on utility obtained through consumption - e.g. the degree to which food or other consumer products contain

[1] For a more detailed discussion of the theoretical and empirical literature on the delocation issue see Kuhn/Tivig (1996). In particular, their overview includes models assuming perfect competition in the product market besides the ones of imperfect competition mentioned in this paper, as well as a critical assessment of the misleading character of the term "environmental capital flight" being widely used in the public debate.

harmful chemicals, or the energy efficiency of cars or electrical appliances -, or (b), in the presence of the social dilemma character of pollution, an indirect moral impact on utility by determining the pollution generated by consumption of the product, e.g. catalytic converters vs. none, and

(2) the process of production, clean vs. pollution intensive, usually also having only a moral impact on utility.[2]

Whereas most of the literature explicitly or implicitly refers to case (1), it is case (2) which we are looking at. Avoiding an in-depth inquiry into the nature of "green" consumption behaviour, we will leave it with our above assumption of consumers´ preferences for products being produced with a clean technology.[3] Examples are organically grown food, textiles made of pesticide free raw material, recycled or chlorine free paper products, furniture produced without the use of tropical timber or harmful chemicals, etc. Often, environmentally friendly production implies a higher physical quality of the product itself. This strongly reinforces our assumption of green preferences, since we do not have to solely rely on the moral component.

Apart from the different notion of "environmental friendliness", the Eccia/Mariotti model departs from the related literature by focusing on the introduction of clean technologies rather than on the question how equilibrium levels of product qualities can be influenced by quality standards. The discrete character of the model captures the idea that technologies are usually not chosen from a continuous set of alternatives. It also provides for simple analytics, which is of some virtue, since I add a great deal of complexity, as will be seen below. For its discrete character the model is somewhat awkward compared to a continuous formulation. However, it allows for an analytical solution, where continuous duopoly models of location choice have to resort to numerical solutions even in a much simpler setting (e.g. Markuse et al. 1993, Motta/Thisse 1994).

The extensions are as follows. First, I allow for "location" as a third choice variable for firms besides "quality" and "price". Quality relates to the production technology, which may either be clean (green) or polluting (non-green). The clean technology incurs a higher fixed cost. Further, I introduce a game between two regions choosing their environmental policies prior to the subgame of firm competition, where firms take the regions´ policies as given. Finally, the pollution generated by the non-green producers is accounted for. However, unlike Markusen et. al. (1993,1995) and Rauscher (1995) I do not focus on consumers´ disutility of pollution as an argument of the welfare function, but rather consider a negative inter-firm externality giving rise to damage cost for the firm which is harmed by pollution. Thereby, both, green and non-green producers may be affected by another fim´s pollution. The inter-firm externality can be interpreted as a rather particular type of delocation cost: For a producer moving to a region where a polluting firm is located, it is a cost of delocation, whereas for a producer moving away from a region hosting a polluter it is a again to delocation. Other more common forms of delocation costs (e.g. sunk costs) are not considered. The notion of the inter-firm externality also captures the idea that "green" producers will in general have an in-

[2] A consumer cannot expect to change the aggregate pollution level by individually choosing a "green" product given the non-green consumption behaviour of the other consumers. This gives rise to the social dilemma situation in (1b) and (2).

[3] Since the method of production only constitutes an indirect quality component of the good, in the following we refer to "green" and "non-green" variants rather than to "high" and "low quality" ones.

centive to move away from polluting firms, and, in this model, will always do so. As we will see, the assumption of the externality is central, and results are highly sensitive to it.

In joining the issues of firm location and vertical product differentiation Cordella/Grilo (1995) have followed a similar idea in the context of social dumping. However, they consider product quality levels as exogeneously given, where I endogenize location *and* quality choice. Another related line of literature deals with the introduction of clean technology in reaction to environmental regulation. Recent examples for this type of work are Carrao/Topa (1994) and Ulph (1994). Whereas both analyze innovation towards clean technologies in a strategic competition context, neither incorporates the issue of product differentiation.

The paper is organized as follows. Section 2 introduces the model. Section 3 solves the subgame of firm competition contingent on environmental policy choices and discusses the delocation issue. Section 4 solves the regions´ game and comments on the "race to the bottom" issue. Section 5 concludes.

2. The model

Consider a setting of two identical regions (or contries) $j = A, B$ and two identical firms $i = 1,2$. Firms choose their location of production in one region exclusively. Let $\varphi_i \in \{A, B\}$ denote the location of firm *i.* There are no sunk costs serving as a barrier to leaving a location or switching qualities. Hence, firms are not restricted in moving. However, we assume that firms will only switch location or quality if this increases their profit.[4] As there are no transportation costs, the markets of region *A* and *B* are integrated, and there are no spatial price differences.

Firms can produce a green $(\theta = G)$ or a standard variant $(\theta = N)$ of a differentiated product. Variants are defined by technology: Technology *N* cause pollution as a local negative externality whereas *G* is a non-polluting technology. In principle, pollution affects consumers as well as other firms located in the same region. However, for expositional ease and in order to isolate the influence of product differentiation and inter-firm pollution on (strategic) environmental policies, we only consider the damage cost accruing to firms. In our conclusion we will argue that taking consumers´ disutility of pollution into consideration whould only reinforce our general findings. Each firm chooses one and only one of the two technologies. Let $\theta_i \in \{G, N\}$ denote the technology/quality choice of firm *i*.

Demand and consumer surplus

As in Eccia/Mariotti (1994) consumers are differentiated in their willingness to pay (wtp) for environmental friendliness in the production of the good. Of a total of *M* consumers, there is

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4 This assumption reflects the fact that usually there is a switching cost. For reasons of simplicity it is considered to be small relative to all other arguments of the profit function and is, thus, neglected in our case. However, a switch of quality or location must yield a minimum gain in profits to offset this cost.

a proportion $1-m$ of non-green (type N) and a proportion m of green (type Γ) consumers. Let p_k^θ denote the reservation price of a consumer of type $k=\Gamma,N$ for a variant θ.[5] All consumers have a common reservation price for the non-green variant, which we normalize to $p_k^N \equiv 1$, with $k=\Gamma,N$.[6] Non-green consumers have a wtp of zero for clean production of the good, and thus their reservation price is $p_N^\theta = 1$ regardless of the quality. They will always buy the cheaper variant but weakly prefer *G* if offered at the same price as *N*. Green consumers have a marginal wtp of *g* for clean production of the good. Hence, their reservation price for the green variant is given by $p_\Gamma^G = 1+g$ consisting of the reservation price for the standard version and the premium. Consumers are assumed to either buy one unit of their preferred variant or nothing at all. For an individual consumer of type $k=\Gamma,N$, we therefore have a demand of

$$q_k \in \{0,1\}.$$

Let

$$CS_k^\theta = p_k^\theta - p(\theta) \tag{2.1}$$

denote the distance between reservation price p_k^θ of a consumer of type *k* and market price $p(\theta)$ for one unit of a variant θ. Consumer *k's* individual demand for a variant θ then is

$$q_k^G = \begin{cases} 1 \text{ for } \mathrm{CS}_k^G \geq \mathrm{argmax}\ \{0, \mathrm{CS}_k^N\} \\ 0 \text{ for } \mathrm{CS}_k^G < \mathrm{argmax}\ \{0, \mathrm{CS}_k^N\} \end{cases} \tag{2.2a}$$

and

$$q_k^N = \begin{cases} 1 \text{ for } \mathrm{CS}_k^N \geq 0 \wedge \mathrm{CS}_k^N > \mathrm{CS}_k^G \\ 0 \text{ for } \mathrm{CS}_k^N < 0 \vee \mathrm{CS}_k^N \leq \mathrm{CS}_k^G \end{cases} \tag{2.2b}$$

Thus, a consumer demands one unit of a given variant θ if and only if the distance function takes on a nonnegative value *and* exceeds the value of the distance function for the other variant, while weak preference for *G* is observed. The price of a variant θ not being offered is assumed to be $p(\theta)=\infty$.

Using the weights m and $1-m$, respectively, we can derive the aggregate demand function for each variant $\theta = G,N$

$$q^\theta(p(G), p(N)) = mq_\Gamma^\theta + (1-m)q_\mathbf{N}^\theta \tag{2.3}$$

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[5] In the following, we use an upper index to denote qualities/variants $(\theta = G,N)$, and the lower index either to denote consumer types $(k=\Gamma,N)$, firms $(i=1,2)$, or regions $(j=A,B)$

[6] Consult the discussion of a type 1 decision vector in section 3.1 to see how this assumption, also to be found in Ecchia/Mariotti (1994), bears an important influence on the existence of equilibria with homogeneous products.

Note that by (2.3) all quantities and hence all expressions containing quantities (consumer surplus, profit, welfare) are given in per capita terms, where "per-capita" always refers to *total population M in both regions.*

Demand q_i for each firm´s output depends on the qualities θ_i offered by the two firms and the respective prices p_i, with $i = 1,2$:

$$q_i = q_i(\theta_1, \theta_2, p_1, p_2) \qquad (2.4).^{7,8}$$

Using (2.1), (2.2a), (2.2b), (2.3) and (2.4), we can calculate the demand faced by firms for all possible combinations of qualities and prices. Thereby, for the symmetric case $\theta = \theta_1 = \theta_2$ and $p = p_1 = p_2$, we assume that aggregate demand for variant θ is split evenly between firms, and thus

$$q_1^\theta = q_2^\theta = q^\theta(p)/2.$$

Since firms are symmetric, this assumption is well founded.

Aggregate consumer surplus is given by

$$CS(\theta_1, \theta_2, p_1, p_2) = mCS_\Gamma(\theta_1, \theta_2, p_1, p_2) + (1-m)\,CS_\mathrm{N}(\theta_1, \theta_2, p_1, p_2) \qquad (2.5),$$

where

$$CS_k = \begin{cases} CS_k^G\, q_k^G & \text{for } q_k^G > 0 \\ CS_k^N\, q_k^N & \text{for } q_k^N > 0 \\ 0 & \text{for } q_k^G = q_k^N = 0 \end{cases}$$

denotes the surplus of a consumer of type $k = \Gamma, N$. For a type k consumer and a variant θ, it is given by the product of the value of the distance function CS_k^θ, as given by (2.1), and individual demand for a variant q_k^θ, as given by (2.2a) and (2.2b). The structure of demand, given by the weights m and $1-m$, and the reservation prices p_Γ^θ and p_N^θ, is identical for both regions.

Firms

Production technology of each firm $i = 1,2$ is characterized by the following cost function:

$$C_i(\theta_1, \theta_2, \varphi_1, \varphi_2, q_1, q_2,) = q_i^2 + F(\theta_i) + X_i(\theta_{-i}, \varphi_1, \varphi_2, q_{-i}) \qquad (2.6),^9$$

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7 Because of the discrete quality choice between *G* and *N*, q_i is not a smooth but rather a step function in prices. Thereby, q_i is completely inelastic to price for certain intervals of price but may jump at certain threshold prices.

9 A "-" sign in front of an index indicates "the other".

where q_i^2 is a variable cost, assumed to be quadratic in quantity and independent of quality, and F is a quality dependent fixed cost. Thereby, we assume $F(G) = \alpha$, with $\alpha > 0$, for production of G and $F(N) = 0$ for production of N. As all the quantities are given in per capita terms, we normalize the fixed cost α to be given as a per capita expression, too.

The final term in (2.6)

$$X_i(\theta_{-i},\varphi_1,\varphi_2,q_{-i}) = x(\theta_{-i},\varphi_1,\varphi_2)q_{-i}^2 \qquad (2.7)$$

is the damage cost accruing to firm $i = 1,2$. It is determined by a damage coefficient x and the quantity q_{-i} produced by the other firm, where we assume a quadratic dependency. The damage coefficient is dependent on the quality choice of the other firm, θ_{-i}, and the location decisions φ_1 and φ_2 of the two firms such that

$$x(\theta_{-i},\varphi_1,\varphi_2) = \begin{cases} x > 0 & \text{if } \theta_{-i} = N \wedge \varphi_1 = \varphi_2 \\ 0 & \text{otherwise} \end{cases}.$$

Hence, an external damage cost is imposed on firm i if and only if the other firm $-i$ produces with the polluting technology *and* is located in the same region. Remember that we assume no transboundary spillovers. For simplicity, it is assumed that x is invariant to the quality produced by the negatively affected firm.

For demand and cost, given by (2.4) and (2.6), respectively, the profit of a firm $i = 1,2$ is

$$\pi_i = p_i q_i(\theta_1,\theta_2,p_1,p_2) - C_i(\theta_1,\theta_2,\varphi_1,\varphi_2,q_1,q_2) \;;\theta \in \{G,N\}; j \in \{A,B\} \qquad (2.8)$$

A firm´s profit is thus dependent on its own and its competitor´s choice of quality, location, and price.[10] Each firm i is assumed to maximize profits by choosing a strategy $f_i = \{\theta_i,\varphi_i,p_i\}$, given its rival´s strategy f_{-i}

$$\max_{f_i} \pi_i(f_1,f_2) \text{ for } i = 1,2 \qquad (2.9).$$

The structure of the game that determines the character of the strategies will be discussed below.

Regions

Welfare for each region $j = A,B$ is given by

$$W_j = \sum_{i=1}^{2} \pi_i(f_1,f_2)\Big|_{\varphi_i = j} + (1/2)CS(f_1,f_2) \qquad (2.10),$$

10 Note that through the discrete nature of θ, φ and q the profit function is a step function in these variables.

consisting of the aggregate profit of firms located in region *j*, and, according to symmetry, one half of the aggregate consumer surplus, given by (2.5).

Local governments in *A* and *B* have the jurisdictional power to impose environmental standards on production activity, e.g. emission standards. The policy implemented in region *j* is captured in the variable $s_j \in \{0,1\}$, which takes on a value of $s_j = 1$ if an environmental standards exists and $s_j = 0$ in the unregulated state. It is assumed that the polluting technology *N* can under no circumstances meet the standard. The existence of a standard effectively means a prohibition of technology *N* in the respective region. Hence, environmental policies affect firms` strategies and thus welfare in each region.

The government of each region *j* is assumed to maximize local welfare by taking an environmental policy decision s_j, given the environmental policy s_{-j} of the other region,

$$\max_{s_j} W_j(s_A, s_B) \text{ for } j = A, B \qquad (2.11).$$

Structure of the game

Consider the following non-cooperative game under complete information and common knowledge.

The outset of the game, assumed as given by history, is defined as follows:

- There is one firm located in each region. Be $\varphi_1^0 = A$ and $\varphi_2^0 = B$.
- Both regions have imposed the same environmental policies, i.e. $(s_A^0 = s_B^0)$.
- Each firm has chosen a strategy $f_i^0 = \{\theta_i^0, \varphi_i^0, p_i^0\}$ of quality, location and price such that the vector (f_1^0, f_2^0) forms a market equilibrium which is feasible for the given state of environmental regulation.[11]

Stage 1:

Governments in *A* and *B* play a simultaneous one-shot game, maximizing local welfare according to (2.11).

Thereby, we can distinguish the two following cases: If $(s_A^0 = s_B^0 = 0)$, i.e. neither region has a standard imposed at the outset, we can interpret $s_j = 1$ as introduction of a standard into an unregulated market by a region *j*, while $s_j = 0$ implies maintenance of the unregulated state. If $(s_A^0 = s_B^0 = 1)$, i.e. both regions have a standard imposed at the outset, we can interpret $s_j = 0$ as deregulation by a region *j* and $s_j = 1$ as a maintenance of the standard.

[11] For discussion of these equilibria, see section 3. below.

Stage 2:

In reaction to the policy decisions of regions, firms play a one-shot subgame. Their payoffs are given by their profit functions, which they maximize according to (2.9). It is important to observe that the existence of a standard in a region implies that for both firms any strategy including a production of *N* in this region becomes unfeasible.

The firm subgame consists of two stages.

In stage 2.1 each firm takes a decision on quality *and* location, $d_i = \{\theta_i, \varphi_i\}$. Thereby, firms move according to the following rule:

- Firms move sequentially if one region decides unilaterally to revise its policy. The firm located in the region which has deviated always moves first. This may be grounded on an informational advantage, which it holds, with regards to domestic policy changes.
- Firms move simultaneously it both regions revise their policy.
- The subgame is not triggered such that $\left(f_1 = f_1^0, f_2 = f_2^0\right)$, if neither region revises its strategy.

By bundling the choice of quality and location into a single decision d_i we are able to eliminate one stage of the game, thereby simplifying our analysis significantly. We are allowed to do so if the equilibria (strategies and pay-offs) are unaffected by (I) the order of decisions on quality and location and (II) the order of firms´ moves. It is easily verified that for our model this condition is always fulfilled with respect to (I) as long as firms play subgame perfect (SPG). The result holds for both, simultaneous and sequential moves.[12] By definition, (II) is irrelevant in case of simultaneous moves. Within a sequential structure, it can be shown that a reversal of the order in which firms decide in the two stages does not have an influence on the equilibria obtained. Equilibrium structure depends solely on which firm takes the very first decision on no matter what variable.[13] However, this dependency is accommodated for in a bundled decision, while which firm moves first is uniquely determined by the outcome of the regions´ game. Hence, bundling will have no influence on equilibrium structure and is therefore a legitimate simplification.

In stage 2.2 firms engage in Bertrand competition. Each firm chooses a price p_i, taking as given the other firm´s price p_{-i} as well as its own and its competitor´s choice $\left(d_1, d_2\right)$ of quality and location.

We cannot exclude a priori cases in which one or both firms realize a non-positive profit in the price equilibrium for given qualities and location. In most cases, we can expect these equilibria not to occur, since firms would avoid them by making appropriate quality and location choices. However, there may exist constellations of parameters that yield non-positive

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[12] Simultaneous moves may give rise to a coordination problem affecting uniqueness and structure of pay-offs; sequential moves (and asymmetric pay-offs) gives rise to issues of leadership and commitment. We can show for both cases that the order of decisions with regard to variables is irrelevant for these issues.

[13] Note that, in our model, the first decision determines profit leadership in the case of product differentiation. The first-mover assures leadership either directly by choice of quality or indirectly by choice of location, serving as a commitment.

profits for any strategy. In fact, in our model there exists one such constellation. In this case, we would have at least one firm exit the market. Since this would complicate things further, we exclude this case. This is possible by imposing a mild restriction on the externality parameter *x*, which we will refer to in more detail when we derive the equilibria below (see proof of Proposition 1.1). Hence, we only look at equilibria with both firms being in the market. This not withstanding, our model allows for the possibility of the market not being covered, in the sense that in equilibrium there may exist some consumers who do not buy the commodity at all.

The game is solved by applying the SGP criterion and working by backward induction. First the firm subgame is solved in two steps. Step 1 gives the price equilibria (p_1*, p_2*) for the feasible sets (d_1, d_2) of quality and location. Then, firms profits can be determined contingent on (d_1, d_2). Step 2 gives the SGP equilibrium decisions (d_1*, d_2*) in quality and location contingent on regions′ strategies (s_A, s_B). Hence, $\left(f_1* = \{\theta_1*, \varphi_1*, p_1*\}, f_2* = \{\theta_2*, \varphi_2*, p_2*\}\right)$ are the SGP equilibria of the firm subgame, where $\left(f_1*(s_A, s_B), f_2*(s_A, s_B)\right)$. Using the equilibrium values $\theta_i*, \varphi_i*, p_i*$ for $i = 1,2$ and (2.5), we can determine consumer surplus *CS**. Inserting *CS** and equilibrium profits π_1* and π_2* into (2.10), we can calculate regional welfare levels, which are contingent on regions′ strategies (s_A, s_B). We can now determine the SGP strategies (s_A*, s_B*) Hence, $\left((s_A*, s_B*), (f_1**, f_2**)\right)$ defines a SGP equilibrium of the game being contingent on the parameters α, *m, g* and *x*, where f_i** denotes a firm *i*′s subgame perfect strategy given (s_A*, s_B*).[14]

3. The firm subgame

In this section we derive the equilibrium outcomes of the firm subgame. Proceeding in three steps, we first identify four types of decision vectors (d_1, d_2) that may obtain in equilibrium (section 3.1). For each of them we determine a Bertrand-Nash price equilibrium. In the second step (section 3.2) we derive the conditions under which each one of the four decision vectors constitutes a unique equilibrium in quality and price. Using these conditions, we finally obtain the equilibria of the firm sub game contingent on the outcome of the regions′ game (section 3.3). Thereby, we concentrate on the case in which both firms produce the polluting good if the unregulated state obtains.

3.1 The price equilibria

In the following, we can restrict our attention to four types of decision vectors as candidates for equilibrium. For each of them a price equilibrium will be determined. We will discuss them in turn, while also showing that any decision vector differing from the ones discussed, cannot be element of an equilibrium strategy.

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14 An overview of the game in extensive form can be obtained form the author upon request.

First, suppose both firms produce *G*. Then, the decision vector will necessarily be of

Type 1: $(d_1 = \{G, A\}, d_2 = \{G, B\})$.

If both firms produce *G* they will always stick to their original location, i.e. $\varphi_1 = \varphi_1^0 = A, \varphi_2 = \varphi_2^0 = B$. This can be explained as follows: By assumption, a firm only delocates if there are gains to it. Delocation may be motivated either by avoidance of external damage cost or by evasion of environmental regulation in order to produce the possibly more profitable variant *N*. However, since both firms produce *G*, they are not restricted in their location by environmental regulation, and, by virtue of (2.7), damage cost is zero for both firms. Thus, neither of the two causes applies and delocation does not occur.

Given a type 1 decision vector, we find the following (equilibrium) prices in a pay-off dominant Bertrand-Nash equilibrium:

$$p_1{*} = p_2{*} = p{*} = \begin{cases} 3m/2 \text{if } m \geq \sqrt{1/2} \\ 1 \quad \text{if } m < \sqrt{1/2} \end{cases} .$$

We assume $3m/2 \leq 1 + g$, and thus avoid that the reservation price for the green variant, $1 + g$, becomes a third candidate equilibrium price. Inserting $p*$ into (2.8), we obtain firm demand for each firm $i = 1,2$ and profits as follows:

For $p{*} = 3m/2$

$q_i = m/2$,

$$\pi^{GG} = m^2/2 - \alpha \qquad (3.1),^{15}$$

and for $p{*} = 1$

$q_i = 1/2$,

$$\pi^{GG}{'} = 1/4 - \alpha \qquad (3.1').$$

The extensive proof can be found in Ecchia/Mariotti (1994: 6-8); here, we will restrain our attention to an intuitive explanation, part of which is not given in Ecchia/Mariotti. To begin with, we have to distinguish between two potential equilibria, one with a covered the other with an uncovered market. For any price $p \leq 1$ charged by either of the two firms, the market is covered, and aggregate demand is $q^G = 1$. However, for any *p*, with $1 + \varepsilon \leq p \leq 1 + g$ and $\varepsilon \to 0$, aggregate demand discretely switches to $q^G = m$, where only green consumers buy the good. Equilibria are feasible for both, a covered and an uncovered market. For both cases analysis proceeds as follows. For a type 1 decision vector, firms produce the homogeneous product *G,* and we should expect some Bertrand undercutting. Equilibrium is then given at a price for which undercutting becomes unprofitable. It is easily established that for any price $p \geq p*$ neither firm has an incentive to undercut. Facing a continuum of equilibria , the con-

[15] With the upper index on profits we denote the corresponding quality choices of firms, where the first letter denotes the choice of the producer whose profit we look at and the second denotes the choice of his competitor.

cept of pay-off dominance (Harsanyi/Selten, 1998) is used as a selection criterion to determine p^* as the unique equilibrium price.[16] Note that

$$\pi^{GG} \geq \pi^{GG'} \Leftrightarrow m \geq \sqrt{1/2} \qquad \text{(C3.1).}$$

allows for unambiguous selection of a unique equilibrium price $p^*(m) \in \{1, 3m/2\}$. For a sufficiently large share of green consumers, serving only the green market segment at a high price becomes more profitable than serving the whole market at a low price.

Even though firms produce a homogeneous good and compete in Bertrand fashion, they gain positive operating profits, the explanation being as follows: For decreasing returns to scale, which are implied by a quadatic cost function, undercutting becomes unprofitable for some price greater than marginal cost, which in itself exceeds variable unit cost. For the uncovered market, undercutting only takes place for $p > 3m/2 > C'$, with $C' = m$ for $q_i = m/2$. Since we assume $1 + g \geq 3m/2$, competition inhibits firms from appropriating all of the consumer surplus. As easily shown, in the covered market firms undercut not even for the maximum price attainable, $p^* = p_N^G \equiv 1$, and thus capture the consumer surplus totally. Obviously, this result is owing to the normalization of the reservation price p_N^G to one and will not necessarily hold for a more general specification. The fact that Bertrand competition does not erode profits completely has an important implication: As opposed to the standard models of vertical differentiation, in our case, firms will not always have an incentive to differentiate products in order to gain some monopolistic rent.

Now, suppose firms differentiate products. Then, the decision vector will necessarily be of

<u>Type 2</u>: $\left(d_i = \{G, j\}, d_{-i} = \{N, -j\}\right)$.

If firms differentiate products they will always differentiate location. Suppose both firms are located in the same region *–j*. Then the producer of *G* will always increase his profit by delocating to the other region *j* and, thereby, avoiding the pollution damage. At this stage, we cannot assign specific firms to the qualities yet. Neither can location be unambiguously assigned, because a type 2 decision vector does not necessarily imply that firms are located in their initial host region.

For a type 2 decision vector, we obtain the Bertrand-Nash equilibrium prices

$$p_i^* = 1 + g; p_{-i}^* = 1,$$

where *i* and *–i* are producers of *G* and *N*, respectively. Firm demand and profits are given by

$$q_i = m,$$

$$\pi^{GN} = (1 + g)m - m^2 - \alpha \qquad \text{(3.2.1)}$$

for the producer of *G*, and

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[16] Multiple equilibria are due to the price elasticity of demand being zero at all points of the demand function except the discontinuities.

$$q_{-i} = 1 - m,$$

$$\pi^{NG} = m - m^2 \quad (3.2.2)$$

for the producer of *N*.

For an explicit derivation, consult Eccia/Mariotti (1994: 9-11). For an intuitive explanation, we note that product differentiation gives each firm a monopolistic margin in its market segment, where the green and non-green producer serve only green and non-green consumers, respectively. Undercutting by "large" amounts in order to attract the other firm´s consumers can be shown to be unprofitable. Hence, each firm sets a monopolistic price equal to the reservation price of its respective customers, thereby capturing consumer surplus completely.

Finally, consider both firms producing *N*. In this case, there are two types of decision. Which one obtains depends on the state of environmental regulation. Note that production of *N* is unfeasible if both regions have imposed a standard. If neither region regulates the decision vector will be of

<u>Type 3</u>: $(d_1 = \{N, A\}, d_2 = \{N, B\})$.

Both firms produce *N* in the region that hosts them at the outset. Obviously, there is no incentive to delocate since firms are neither restricted in their production of *N* or harmed by pollution. Equilibrium prices are

$$p_1{*} = p_2{*} = p{*} = 1.$$

Each firm $i = 1,2$ faces a demand of

$$q_i = 1/2$$

and realizes a profit of

$$\pi^{NN} = 1/4 \quad (3.3).$$

The explicit derivation can be found in Ecchia/Mariotti (1994: 9). Again, for reasons of decreasing returns to scale, firms are able to charge an equilibrium price exceeding their average variable cost. Owing to their monopolistic margin, they appropriate consumer surplus completely.

Now suppose that region *–j* has imposed a standard unilaterally. For both firms producing *N*, the decision vector must then be of

<u>Type 4</u>: $(d_1 = \{N, j\}, d_2 = \{N, j\})$.

Both firms produce *N* in the same location, thereby imposing an external damage on each other, which is given by (2.7). Even though each firm $i = 1,2$ has an incentive to delocate in order to evade the damage cost, this is not feasible if region *–j* has set a standard. Equilibrium prices are

$$p_1* = p_2* = p* = 1 \qquad (3.4).$$

Each firm $i = 1,2$ faces a demand of

$$q_i = 1/2$$

and realizes a profit of

$$\pi^{NNx} = (1-x)/4 \qquad (3.5).$$

Since Ecchia/Mariotti (1994) do not consider the negative inter-firm externality, becoming relevant in this case, we will provide the proof that for a type 4 decision vector, equilibrium prices are given by (3.4).

Proof Since $\theta_1 = \theta_2 = N$ and $\varphi_1 = \varphi_2 = j$, both firms will only have a positive profit for $p_1 = p_2 = p \in [(1-x)/2,1]$. Thereby, $(1-x)/2$ is the zero-profit price for *N* in the presence of external damage, which is determined by solving $\pi_1(p)\big|_{\theta_1=\theta_2=N\wedge\varphi_1=\varphi_2=j} = \pi_2(p)\big|_{\theta_1=\theta_2=N\wedge\varphi_1=\varphi_2=j} = 0$ for *p* under use of (2.7) and (2.8). Suppose both firms choose a price $p \in [(1-x)/2,1]$. In this case, all consumers buy *N*, i.e. $q_\Gamma = q_N = 1$, $q^N = 1$ and $q_i = 1/2$. Each firm realizes a profit $\pi_i = p/2 - (1+x)/4$. If an undercutting firm *i* sets $p_i' = p - \varepsilon$, while $p_{-i} = p$, it captures the whole market and realizes a profit $\pi_U = p - \varepsilon - 1$. Note that, by driving its competitor from the market, firm *i* has also eliminated the externality. For $\varepsilon \to 0$ we have $\pi_U \geq \pi_i$ if $p \geq (3-x)/2$. Hence, the value of the externality parameter *x* determines the upper bound for candidate equilibrium prices. Given that firms will not charge prices higher than the reservation price, i.e. $p \leq p_k^N = 1$, undercutting would never occur if $x \leq 1$. For reasons not directly related to the undercutting problem, we assume $x \leq 1$ later on (see Appendix, proof of Proposition 1.1). Hence, undercutting is always unprofitable in the range of relevant prices, and $p_1* = p_2* = p* \in [(1-x)/2,1]$ defines a continuum of Nash equilibria. To resolve the problem of multiplicity, we assume firms to coordinate on the profit-maximizing price $p* = 1$. QED.

Firms thus charge the same equilibrium price as for a type 3 decision vector but realize a lower profit because of the damage they impose on each other.

3.2 Characterization of the SGP equilibria

We now derive the Nash equilibrium decision vectors (d_1*, d_2*) of quality and location. Together with the corresponding price equilibria, derived in section 3.1, they form candidate SGP equilibria (f_1*, f_2*) of the firm subgame. In deriving (d_1*, d_2*) we will have to apply the following conditions, which are obtained under use of equations (3.1)-(3.3) and (3.5):

$$\pi^{GG} \geq \pi^{NG} \quad \text{if} \quad m \geq \overline{m}_1 := (1/3)\left(1+\sqrt{1+6\alpha}\right) \qquad (C3.1),$$

$$\pi^{GG}{'} \geq \pi^{NG} \quad \text{if} \quad m \geq \overline{m}_2 := 1/2 + \sqrt{a} \vee m \leq \underline{m} := 1/2 - \sqrt{a} \qquad (C3.2),$$

$$\pi^{GN} \geq \pi^{NN} \text{ if } \quad g \geq \bar{g} := \left(1/4 + m^2 - m + a\right)/m \qquad \text{(C3.3)},$$

$$\pi^{GN} \geq \pi^{NNx} \quad \text{if} \quad g \geq \bar{g}^x = \left((1-x)/4 + m^2 - m + \alpha\right)/m \qquad \text{(C3.4)}.$$

For the moment, consider the unregulated state $(s_A = s_B = 0)$, where firms´ strategy sets are unrestricted. In this case we can distinguish three types of equilibria corresponding to the type 1 through 3 decision vectors.

<u>Green equilibrium:</u> (type 1) $\left(f_1{*} = \{G, A, p{*}\}, f_2{*} = \{G, B, p{*}\}\right)$

is a SGP equilibrium if

$$m < \underline{m} \vee \overline{m} < m, \text{ with } \overline{m} = \text{argmin } \{\overline{m}_1, \overline{m}_2\} \qquad \text{(C3.5)}.$$

Thereby,

$$p{*} = \begin{cases} 3m/2 & \text{if } \left[m > \underline{m} \wedge \alpha \geq 0{,}043\right] \vee m \geq \sqrt{1/2} \qquad \text{(C3.6a)} \\ 1 & \text{if } m < \underline{m} \vee \left[\alpha < 0{,}043 \wedge m < \sqrt{1/2}\right] \qquad \text{(C3.6b)} \end{cases}.$$

The equilibrium is unique if

$$g > \bar{g}.$$

Again, we will only give a brief outline of the proof, which is extensively established in Ecchia/Mariotti (1994: 12-15).[17] Consider a type 1 decision vector. If (C3.5) is fulfilled at least one of the conditions (C3.1) and (C3.2) holds. Hence, argmax $\{\pi^{GG}, \pi^{GG}{'}\} > \pi^{NG}$ and neither firm has an incentive to differentiate products by switching production from *G* to *N*. Satisfaction of (C3.3) guarantees uniqueness of the equilibrium, since, in this case, $\pi^{GN} > \pi^{NN}$, which excludes an equilibrium with both firms producing *N*. The green equilibrium is SGP, since there is a price equilibrium attached to it. Which equilibrium price *p** will obtain is determined by (C3.6). Noting that $\overline{m}_2 \underset{\geq}{\overset{<}{}} \overline{m}_1 \underset{\geq}{\overset{<}{}} \sqrt{1/2}$ for $\alpha \underset{\geq}{\overset{<}{}} 0{,}043$ and using (C3.1), (C3.2), (C3.3) and (C3.5), it is straightforward to derive (C3.6a) and (C3.6b).

Inserting equilibrium profits, given by (3.1) and (3.1'), respectively, and consumer surplus, given by (2.5), into (2.10), we can calculate regional welfare. Welfare in each region $j = A, B$ is given conditional on *p**. For $p{*} = 3m/2$

$$W^{GG} = (1+g)m/2 - m^2/4 - \alpha \qquad \text{(3.6)},$$

and for $p{*} = 1$

$$W^{GG}{'} = gm/2 + 1/4 - \alpha \qquad \text{(3.6')}.$$

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[17] With respect to the conditions captured in (C3.6a) and (C3.6b) Ecchia/Mariotti (1994: 14-15) obtain a different, to my view erroneous, result.

<u>Product differentiation equilibrium</u>: (type 2) $\left(f_i^* = \{G, j, 1+g\}, f_{-i}^* = \{N, -j, 1\}\right)$

is a SGP equilibrium if

$$\underline{m} < m < \overline{m},\ \text{with}\ \overline{m} = \text{argmin}\ \{\overline{m}_1, \overline{m}_2\} \qquad \text{(C3.7)}$$

and

$$g > \overline{g}\,.$$

In brief, the proof goes as follows (Ecchia/Mariotti (1994: 11-14). Consider a type 2 decision vector. Satisfaction of (C3.7) guarantees that both conditions (C3.1) and (C3.2) do not hold, and thus argmax $\{\pi^{GG}, \pi^{GG'}\} < \pi^{NG}$. Satisfaction of (C3.3) guarantees that $\pi^{GN} > \pi^{NN}$. Hence, neither producer has an incentive to give up product differentiation. Since there always is the price equilibrium $p_i^* = 1+g,\ p_{-i}^* = 1$ attached to the equilibrium decision, it is also SGP.

For an equilibrium with product differentiation, profits are given by (3.2.1) and (3.2.2), respectively. Welfare for the region hosting the green producer then amounts to

$$W^{GN} = (1+g)m - m^2 - \alpha \qquad \text{(3.7.1)},$$

and for the region hosting the non-green producer to

$$W^{NG} = m - m^2 \qquad \text{(3.7.2)}.$$

Non-green equilibrium without externalities: (type 3) $\left(f_1^* = \{N, A, 1\}, f_2^* = \{N, B, 1\}\right)$ is a SGP equilibrium if

$$g < \overline{g}\,.$$

It is unique if

$$\underline{m} < m < \overline{m},\ \text{with}\ \overline{m} = \text{argmin}\ \{\overline{m}_1, \overline{m}_2\}.$$

The explicit proof is presented in Ecchia/Mariotti (1994: 13-16). Given a type 3 decision vector, non-satisfaction of (C3.3) ensures that in a non-green equilibrium neither producer has an incentive to switch to the clean technology *G*. Since (C3.7) holds, a green equilibrium is also excluded. The equilibrium decision is SGP, because the price equilibrium with $p^* = 1$ is attached. Profitability of a monopolistic supply of *G* is the lower relative to competitive production of *N*, and thus realization of a non-green equilibrium is the more likely, the higher the fixed cost of clean production, α, and the lower the wtp for environmental friendliness, *g*. Surprisingly, the influence of the share of green consumers *m* is ambiguous. This can be explained as follows: The coexistence of a quadratic variable cost and a fixed cost in the production of *G* gives rise to a U-shaped average cost curve, where scale economies are realized for quantities below some optimum size, while decreasing returns to scale dominate for quantities in excess of optimum size. As easily shown, the profit π^{GN} of a monopolistic producer of *G* is thus a strictly concave function in *m* with a maximum at $m^* = (1+g)/2$. Hence, if wtp for environmental friendliness is not too high such that $1+g<2$ and $m^*<1, \pi^{GN}$ will first increase and then decrease in *m*. Profits in the non-green equilibrium are given by a constant. Consequently, profitability of competitive production of *N* relative to monopolistic production of *G* decreases with the size of the green market segment as long as $m<m^*$, but increases in *m* for $m^*<m<1$.

For profits, given by (3.3), welfare in each region $j=A,B$ is

$$W^{NN}=1/4 \tag{3.8}$$

For the unregulated state, i.e. $(s_A=s_B=0)$, all three equilibria described so far may obtain, for unilateral regulation, i.e. $(s_j=0, s_{-j}=1)$ the non-green or product differentiation may obtain, and for bilateral regulation i.e. $(s_A=s_B=1)$, only the green equilibrium is feasible. However, there is a fourth equilibrium corresponding to the type 4 decision vector, which may obtain only in the case of unilateral regulation.

<u>Non-green equilibrium with externalities</u>: (type 4) $(f_1^*=\{N,j,1\}, f_2^*=\{N,j,1\})$

is a SGP equilibrium if

$$(s_j=0, s_{-j}=1)$$

and

$$g<\bar{g}^x.$$

It is unique if

$$\underline{m}<m<\overline{m}, \text{ with } \overline{m}= \text{argmin } \{\overline{m}_1,\overline{m}_2\}.$$

Since Ecchia/Mariotti (1994) do not consider this equilibrium, we will provide the complete proof.

Proof Consider the type 4 decision $(d_1=\{N,j\}, d_2=\{N,j\})$. For the unilateral existence of a standard in region $-j$, i.e. $(s_j=0, s_{-j}=1)$, the otherwise dominating decision $(d_1=\{N,A\}, d_2=\{N,B\})$ becomes unfeasible. Since (C3.4) is not satisfied, we have $\pi^{GN}<\pi^{NNx}$, and neither firm *i* has an incentive to deviate to $d_i=\{G,\varphi_i\}$ for a given $d_{-i}=\{N,j_{-i}\}$. Hence, $(d_1^*=\{N,A\}, d_2^*=\{N,B\})$ is a SGP equilibrium in quality and location, with a price equilibrium with $p_1^*=p_2^*=1$ being attached to it.

Now consider $(d_1=\{G,A\}, d_2=\{G,B\})$. Satisfaction of (C3.7) guarantees that both conditions (C3.1) and (C3.2) do not hold. Hence, argmax $\{\pi^{GG},\pi^{GG'}\}<\pi^{NG}$, and each firm *i* has an incentive to deviate to $d_i=\{N,\varphi_i\}$ for a given $d_{-i}=\{G,j_{-i}\}$. (C3.4) not being fulfilled completes for uniqueness. QED.

Note that $\overline{g} > \overline{g}^x$ for $x > 0$. Realization of non-green equilibrium is less likely in the presence of externalities, since the reduction of profits due to damage cost will make competitive supply of *N* less attractive relative to product differentiation.

For profits given by (3.5), the region hosting the two polluting firms attains a welfare level

$$W^{NNx} = (1-x)/2 \qquad (3.9.1).$$

Welfare of the region not hosting a firm amounts to

$$W^0 = 0 \qquad (3.9.2).$$

3.3 Equilibria of the firm subgame

In the preceding section we have characterized the candidate SGP equilbria. However, to determine the equilibria actually obtained in the firm subgame we have to consider the environmental policy vector (s_A, s_B). As the outcome of the regions´ game it is taken as given by the firms. Moreover, we have to consider the state of environmental policies (s_A^0, s_B^0) at the outset, since it may influence the sequence of moves in the firm subgame.

In order to obtain any clear-cut outcomes of the firm subgame we have to establish a point of reference. Since the focus of our analysis lies on the conditions under which a firm reacts to environmental regulation with installation of a clean technology rather than delocation, we assume that market conditions, captured in the parameters α, *m* and *g*, are such that in the unregulated case both firms produce the non-green variant *N*. Labelling it a non-green regime (NR), we assume

$$g < \overline{g} \qquad (A3.1)$$

and

$$\underline{m} < m < \overline{m}, \text{ with } \overline{m} = \text{argmin } \{\overline{m}_1, \overline{m}_2\} \qquad (A3.2)$$

to be satisfied ex-ante. Obviously, this determines firm´s first best strategies

$$\left(f_1^{fb} = \{N, A, 1\}, f_2^{fb} = \{N, B, 1\}\right)$$

for the unregulated state. However, due to regulation a first-best equilibrium may be unfeasible. For this cases we have to determine a vector of feasible strategies yielding a second-best equilibrium.[18]

We distinguish two cases.

[18] Using the same framework it is straightforward to analyse the remaining two cases of a green regime and a product differentiation regime, respectively. The results my be obtained from the author upon request.

Case 1: $\left(s_A^0 = s_B^0 = 0\right)$

With no regulation at the outset firms can play their first-best strategies $\left(f_1^0 = f_1^{fb}, f_2^0 = f_2^{fb}\right)$. By determining the SGP equilibria of the firm subgame conditional on the outcome of the regions game we establish

Proposition 1.1 *For the non-green regime, the two firms′ location and technology choices depend on the introduction of production standards such that*

a) *each firm produces G in its original location if both regions introduce a standard.*

b) *for one region introducing a standard unilaterally,*

ba) *both firms produce N in the region without a standard if* $g < \overline{g}^x$ *,*

bb) *the firms differentiate products and location if* $\overline{g} > g > \overline{g}^x$*. G is produced in the region setting a standard. Which firm produces G and N, respectively, is determined by* $g \underset{<}{\geq} \alpha/m$ *.*

c) *both firms produce N in their original location if neither region introduces a standard.*

Proof see Appendix

Cases a) and c) are trivial, and we can thus concentrate our discussion on the case of unilateral regulation (case b). Even if his first-best strategy involves production of *N*, a producer will not always delocate in reaction to unilateral introduction of an environmental standard, but may rather switch to clean production of *G*. In particular, he will not delocate, if wtp for environmental friendliness exceeds a certain boundary value, $g > \overline{g}^x$. As easily verified, this condition captures the trade-off between the loss of profit $\Delta\pi_1 = \pi^{NNx} - \pi^{NN} = -x/4 < 0$

incurred through the damage suffered at the new location, and the loss of profit

$$\Delta\pi_2 = \pi^{GN} - \pi^{NN} = (1+g)m - m^2 - \alpha - 1/4 < 0$$

incurred for non-optimal production of *G* instead of *N*, where

$$\left|\Delta\pi_1\right| \underset{<}{\geq} \left|\Delta\pi_2\right| \text{ for } g \underset{<}{\geq} \overline{g}^x .$$

Obviously, the outcome of this trade-off will be the less favourable for delocation the stronger the externality, where $\partial(\Delta\pi_1)/\partial x < 0$. A stronger externality raises the cost of delocation. Increasing wtp for environmental friendliness also reduces the incentive to delocate, where $\partial(\Delta\pi_2)/\partial g > 0$. The higher *g*, the higher is the profit of a monopolistic supplier of *G* and, correspondingly, the lower is the relative loss due to product differentiation. The fixes cost of clean technology α reduces the profitability of *G* and thus reinforces the relative loss, $\partial(\Delta\pi_2)/\partial g < 0$. Clearly, the incentive to delocate increases in α. The influence of *m* is ambiguous: $\partial(\Delta\pi_2)/\partial m \underset{<}{\geq}$ for $m \underset{<}{\geq} (1+g)/2$. Thus, a large share of green consumers will be favourable for a switch to a clean technology only if green consumers have a sufficiently high reservation price for *G*. The reason for this ambiguity has been given in our discussion of the non-green equilibrium above.

To gain some further insight, we isolate the two main determinants of this result - wtp for environmental friendliness as a demand factor and the externality as a supply factor - , and ask whether our result holds if we look at each determinant in isolation.

If there is no externality, i.e. $x = 0$, a firm will not delocate if

$$g > \underset{x \to 0}{\bar{g}^x} = \left(1/4 + m^2 - m + \alpha\right)/m = \bar{g}\ .$$

However, by (A3.1), this condition never holds for the NR. Unless producers of *N* impose a negative externality on each other when located in the same region, they will delocate in reaction to unilateral environmental regulation.[19] Hence, existence of the externality is a necessary, albeit not always sufficient, condition for delocation not to occur. We should keep in mind that existence of a more general cost of delocation would also satisfy this condition.

If demand structure is such that green consumers are not willing to pay a significant premium for environmental friendliness, i.e. $g = 0$, a firm will not delocate if

$$g = 0 > \bar{g}^x.$$ [20]

As easily shown, this condition is satisfied for $(1/2)\left(1 - \sqrt{x - 4\alpha}\right) < m < (1/2)\left(1 + \sqrt{x - 4\alpha}\right)$ and $x > 4\alpha$. It is readily verified that satisfaction of this condition is not excluded by our assumption (A3.2). If the externality is strong enough relative to fixed cost of clean production, a firm will avoid delocation and switch to production of *G* in reaction to a standard even if no consumer is willing to pay a higher price for *G*. However, for $x < 4\alpha$ a producer will always delocate. For low levels of the externality, only the existence of a sufficient wtp for "greenness" of products will keep firms from delocating. Hence demand factors play an important role in driving the "non delocation" result. Coexistence of an externality together with a sufficient wtp for green products are thus necessary and sufficient for delocation not to occur. Finally, consider $g \to \bar{g}$: Even though both producers $i = 1,2$ have chosen production of *N* as their first-best strategies $\left(f_i^0 = f_i^{fb} = \{N, \varphi_i^0, 1\}\right)$ each producer is almost indifferent between f_i^{fb} and $f_i = \{G, \varphi_i^0, \gamma\}$ for a given strategy f_{-i}^{fb} of her competitor. If a standard is introduced in region *j*, the producer in this region will switch to a clean technology rather than delocate even for $x \to 0$ if there is a positive, however small cost of delocation. This has an important policy implication. In this case, the introduction of environmental friendly prod-

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[19] The assumption of a global externality would also debase our findings. If firms are harmed by transboundary spillovers, the damage suffered becomes independent of locational decisions, and the payoff structure is as if there were no externality.

[20] This implies that $p(G)$=1 and $p(N)$=1−ε, where $\varepsilon \to 0$, such that demand for the green producer is q^G=*m* and for the non-green producer q^N=1−*m*. Stability of this equilibrium is easily verified.

uct variants into an existing but hitherto unserved green market segment can be "pushed" by environmental regulation without the risk of delocation.

Finally, let us briefly remark on the question as to which firm produces *G* and *N*, respectively. For unilateral regulation firms always play a sequential game, in which the firm in the country introducing a standard has a first mover advantage. It will always choose the more profitable variant, thereby also determining its location. Since

$$\pi^{GN} \underset{<}{\overset{\geq}{}} \pi^{NG} \text{ for } g \underset{<}{\overset{\geq}{}} \alpha / m$$

the first-moving firm will produce variant $\left.\begin{matrix} G \\ N \end{matrix}\right\}$ for $g \underset{<}{\overset{\geq}{}} \alpha / m$. For choice of *G*, the firm always locates in the standard setting region in order to avoid pollution damage; for choice of *N*, it is forced to locate in the region without regulation.

<u>Case 2:</u> $\left(s_A^0 = s_B^0 = 1\right)$

In this case first best strategies are unfeasible at the outset, and firms play $\left(f_1^0 = \{G, A, p^*\}, f_2^0 = \{G, B, p^*\}\right)$, with p^* determined by (C3.6a) and (C3.6b). Having solved for the SGP equilibria of the subgame we arrive at

Proposition 1.2 *For the non-green regime, the two firms′ location and technology choices depend on deregulation such that*

a) each firm produces G in its original location if both regions maintain their standard.

b) for one region deregulating unilaterally,

ba) both firms produce N in the region without a standard if $g < \overline{g}^x$,

bb) the firms differentiate products and location if $\overline{g} > g > \overline{g}^x$. *N is produced in the region deregulating. Which firm produces G and N, respectively, is determined by* $g \underset{<}{\overset{\geq}{}} \alpha/m$.

c) both firms produce N in their original location if neither region introduces a standard.

Proof see Appendix

For the NR, as defined by (A3.1) and (A3.2), we establish after some algebra:

$$2\pi^{NN} > \pi^{GN} + \pi^{NG} > \text{argmax } \{\pi^{GG}, \pi^{GG'}\}.$$

Hence, regulation by both regions yields a distortion of market structure, in the sense that profits are smaller than in the optimum. Only multilateral deregulation will remove this distortion completely. For unilateral deregulation, the market distortion given by a suboptimal production structure is substituted by another distortion. If both firms produce *N* in the deregulating region, optimal production structure is achieved but under generation of an externality. If firms differentiate products profits increase but remain suboptimal.

For the reasons outlined above, unilateral deregulation will not necessarily work as a means of attracting firms from other regions. Firms will not react to an undercutting of standards if the external damage cost is sufficiently strong while preferences and the fixed cost of the clean technology are such that monopolistic production of *G* does not yield too large a loss relative to production of the polluting good.

4. The regions´ game

The regional welfare levels, given by (3.5)-(3.9), which correspond to the SGP equilibria of the firm subgame, constitute the payoffs of the regions´ game. We can now determine the equilibria in regional strategies, and thus the equilibria of the game. Thereby, we maintain our assumption of a NR, as captured in (A3.1) and (A3.2).[21]

We easily derive the payoff matrix of the regions´ game depicted in Table 1.

region *A* region *B*	$s_A = 1$	$s_A = 0$

$s_B = 1$	$W_A = W_B = W^{GG}$
	if (C3.7a)
	
	$W_A = W_B = W^{GG'}$
	if (C3.7b)
		a) $g < \bar{g}^x$:
		$W_A = W^{NNx}$
		$W_B = W^0$
		
		b) $g > \bar{g}^x$:
		$W_A = W^{NG}$
		$W_B = W^{GN}$

$s_B = 0$	a) $g < \bar{g}^x$: $W_A = W^0$ $W_B = W^{NNx}$ b) $g > \bar{g}^x$: $W_A = W^{GN}$ $W_B = W^{NG}$	$W_A = W_B = W^{NN}$

Table 1

21 Again, analysis is easily extended to the cases of a green or product differentiation regime. The results may be obtained from the author upon request.

Notice that the payoffs for the strategy vectors $(s_j = 0, s_{-j} = 1)$ are determined by $g \gtrless \overline{g}^x$.

In order to determine the equilibria, we will have to compare welfare levels. After some tedious algebra we obtain:

- $W^{GG} \geq W^{NNx}$ if $g \geq \tilde{g}^x := \left(1 - x + m^2/2 - m + 2\alpha\right)/m$ (C4.1).

  where satisfaction requires under (A3.1)

  $\tilde{g}^x < \overline{g}^x$ if $m > \tilde{m}_1^x := \sqrt{3/2(1-x) + 2\alpha}$,

  where satisfaction requires under (A3.2)

  $\tilde{m}_1^x < \overline{m}_1$ if $x > \underline{x} := (1/27)\left(23 + 24a - 4\sqrt{1+6\alpha}\right)$,

  where satisfaction requires

  $\underline{x} \leq 1$ if $\alpha \leq 1/2$.

Notice that only (C4.1) is necessary *and* sufficient for $W^{GG} \geq W^{NNx}$. The "follow-up" conditions are only necessary but not sufficient in the following sense. They guarantee that there exists an interval $\left[\tilde{g}^x, \overline{g}^x\right[$ of values g satisfying (C4.1). If any one of the follow-up conditions with respect to m, x, and α is not fulfilled the interval $\left[\tilde{g}^x, \overline{g}^x\right[$ does not exist, and (C4.1) never holds. On the other hand, fulfilment of the follow-up conditions does not necessarily yield satisfaction of (C4.1). The same argument applies to the following conditions.

- $W^{GG}{}' \geq W^{NNx}$ if $g \geq \tilde{g}^x{}' := \left(1/2 - x + 2\alpha\right)/m$ (C4.2),

  where satisfaction requires under (A3.1)

  $\tilde{g}^x{}' < \overline{g}^x$ if

  (I) $m > \tilde{m}_2^x := 1/2 + 1/2\sqrt{\Delta} \vee m < \tilde{m}_L^x := 1/2 - 1/2\sqrt{\Delta}$,

  where for $\Delta := 2 - 3x + 4\alpha \geq 0$

  satisfaction requires under (A3.2)

  $\underline{m} < \tilde{m}_L^x < \tilde{m}_2^x < \overline{m}_2$ if $x > 2/3$,

  or

  (II) $\Delta < 0 \Leftrightarrow x > \underline{x}' := (2/3)(1 + 2\alpha)$,

  where satisfaction requires

  $\underline{x}' \leq 1$ if $\alpha \leq 1/4$.

- $W^{GG} \geq W^{NG}$ if $m \geq \tilde{m}_1 := (1/3)\left(1 - g + \sqrt{(g-1)^2 + 12\alpha}\right)$ (C4.3),

  where satisfaction requires under (A3.2)

  $\tilde{m}_1 < \overline{m}_1$ if $g > \tilde{g} = (1/2)\left(\sqrt{1+6\alpha} - 1\right)$,

  where $\tilde{g} < \overline{g}$ holds.

- $W^{GG}{}' \geq W^{NG}$ if

  (I) $m \leq (1/4)\left(2 - g - \sqrt{\rho}\right) =: \tilde{m}_L \vee m \geq \tilde{m}_2 := (1/4)\left(2 - g + \sqrt{\rho}\right)$ (C4.4a),

  where for $\rho := (g-2)^2 - 4(1-4\alpha) \geq 0$

  satisfaction requires under (A3.2)

  $\tilde{m}_2 < \overline{m}_2$, which holds or

  $\tilde{m}_L > \overline{m}_2$ if $\left(4g - g^2\right)/16 \leq \alpha < 1/4$ and $g < 2$,

  or

  (II) $\rho < 0 \Leftrightarrow 2\left(1 - \sqrt{1-4\alpha}\right) =: \tilde{g}_L{}' < g < \tilde{g}' := 2\left(1 + \sqrt{1-4\alpha}\right)$ and $\alpha < 1/4$ (C4.4b),

  where satisfaction requires under (A3.1)

  $\tilde{g}_L{}' < \overline{g}$ if $m < \underline{\underline{m}} := 3/2 - \sqrt{1-4\alpha} - \sqrt{3\left(1-\sqrt{1-4\alpha}\right) - 5\alpha}$,

  where $\underline{\underline{m}} > \underline{m}$ holds for $\alpha < 1/4$.

- $W^{NN} > W^0$, trivially.
- $W^{NN} > W^{GN}$, by assumption (A3.1).

Under application the above conditions to the pay-off matrix (Tab. 1) it is straightforward to derive the SGP equilibria.

a) $(s_A{}^* = s_B{}^* = 1)$ if $(s_A^0 = s_B^0 = 1)$ and

aa) case of $\overline{g}^x > g$:

I) if (C4.1) is satisfied, when (C3.6a) holds, or

II) if (C4.2) is satisfied, when (C3.6b) holds.

ab) case of $\overline{g}^x < g$:

I) if (C4.3) is satisfied, when (C3.6a) holds, or

II) if (C4.4a) or (C4.4b) is satisfied, when (C3.6b) holds.

b) $(s_A{*} = s_B{*} = 0)$ if

ba) $(s_A^0 = s_B^0 = 0)$, or

bb) $(s_A^0 = s_B^0 = 1)$ and the respective conditions above do *not* hold.[22]

Observing results a) and b), we obtain

Proposition 2 In the non-green regime regional environmental policies will be such that

a) neither region introduces a standard into an unregulated market.

b) both regions deregulate

ba) for $\bar{g}^x > g$, *if* $g < \tilde{g}^x$ *when (C3.6a) holds, or if* $g < \tilde{g}^{x}{'}$ *when (C3.6b) holds.*

bb) for $\bar{g}^x > g$, *if* $m < \tilde{m}_1$ *when (C3.6a) holds, or if* $\tilde{m}_L < m < \tilde{m}_2$ *and* $g < \tilde{g}_L{'} \vee \tilde{g}{'} < g$ *when (C3.6b) holds.*

c) neither region deregulates

ca) for $\bar{g}^x > g$, *if* $g > \tilde{g}^x$ *when (C3.6a) holds, and if* $g > \tilde{g}^{x}{'}$ *when (C3.6b) holds.*

cb) for $\bar{g}^x < g$, *if* $m > \tilde{m}_1$ *when (C3.6a) holds, or if* $m < \tilde{m}_L \vee m > \tilde{m}_2$ *or* $\tilde{g}_L{'} < g < \tilde{g}{'}$ *when (C3.6b) holds.*

For a sufficiently high level of the externality (at the least $x > 2/3$), regions may prefer not to engage in mutual deregulation even if firms would actually delocate to a region having unilaterally abandoned its standard (case ca.)).[23] The necessary and sufficient condition implies that wtp for environmental friendliness has to exceed a certain boundary value, $g > \tilde{g}^x$ or $g > \tilde{g}^{x}{'}$, respectively. Thereby, everything else equal, wtp has to be the higher the higher α and the lower *x*. The influence of the green market segment´s size, *m*, is ambiguous. The result that regions may not deregulate extends to the weaker case (cb)) for which firms would not delocate in reaction to unilateral standards. Regions do not engage in deregulation if the share of green consumers *m* exceeds a certain minimum. Thereby, the minimum size of the green market *m* increases with the level of fixes cost α. A higher cost technology requires a greater volume of production for realization of sufficient economies of scale (in the uncovered market case), or from a social point of view, a higher fixed cost has to be matched by a greater share of consumers wiling to pay a given amount *g* for environmental friendliness. On the other hand, an increasing *g* implies that deregulation will not occur even for relatively lower values of *m*. In reversal of the argument above, for a rising wtp, a relatively lower share of green consumers suffices to match aggregate consumer surplus with a given fix cost. Surprisingly, standards may also be maintained if the green market segment is relatively small. In

22 Note that for ab)II) it must be (C4.4a) *and* (C4.4b) not being satisfied.

23 Where $x > 2/3$ is a necessary condition for $W^{GG} > W^{NNx}$.

this case, both firm supply the whole market with *G* at a low price, which gives rise to a consumer surplus large enough to overcompensate the relatively lower profits. For some values of *g* the condition for non-deregulation is satisfied irrespective of market size or fixed cost. Summarizing case c), a "race to the bottom" in environmental standards cannot always be expected if technology gives rise to negative inter-firm externalities and some share of consumers has preferences for green products.

However, maintenance of standards is not welfare optimal for a region. It is easily shown that

$$\left.\begin{matrix} W^{GG} \\ W^{GG'} \end{matrix}\right\} < W^{NN} \text{ for (A3.1) and (A3.2).}$$

For the NR, consumer surplus, being positive in the case of a green-equilibrium, does not suffice to compensate for the lower profits relative to a non-green equilibrium. Or from a social point of view: Wtp for environmental friendliness is not sufficient to finance the fixed cost of clean production.[24] Hence, deregulation is welfare improving not only form the firms´, but also from a welfare point of view.[25] In this sense, maintenance of standards may be viewed as a prisoner´s dilemma calling for a cooperative solution. However, if (A3.2) is not satisfied the non-green equilibrium is not unique. A green-equilibrium exists also, which may yield a higher or lower welfare level than the non-green equilibrium. Cleary, in this case, maintenance of standard may be welfare optimal. Moreover, we should keep in mind that we have (deliberately) excluded from our welfare function the environmental damage suffered by households. Hence, the very narrow perspective of welfare and efficiency involved here greatly qualifies this result.

If the conditions for maintenance of regulation is not fulfilled, regions engage in mutual deregulation (case b)). They will do so even if, for reasons of the externality, they cannot expect to attract their "competitor´s" firm (case bb)). From the, albeit narrow, welfare point of view case b) describes the efficient outcome.

Surprisingly, a situation of unilateral regulation is not stable. In the NR, hosting a competitive producer of *N* always yields higher welfare for a region than hosting a monopolistic producer of *G*. While consumer surplus equals zero in both cases, profits are unambiguously higher for competitive supply of *N* relative to monopolistic supply of *G*. Thus, a region always prefers to host a non-green producer, and there never exists an incentive for a region to unilaterally impose a standard. On the other hand, while, by assumption (A3.2), the profit of a competitive supplier of *G* will always be lower than the profit of a monopolistic supplier of *N*, consumer surplus is positive in a green-equilibrium. If regiona-lized consumer surplus overcompensates the lower profit of the competitive green producer, both regions have an incentive to maintain regulation.

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24 The symmetry of the green and non-green equilibrium, respectively, allows for an interpretation of the welfare expression as net economic benefit, defined as aggregate consumer surplus less aggregate cost of production, where all expression refer to a regional level.

25 Due to the symmetry of the green and non-green equilibria, we obtain the same result not only for regional but also for aggregate welfare.

As long as regions do not take the damage incurred by consumers into their consideration, environmental standards will not be introduced into an unregulated market (case a)). This allows for an interesting interpretation. If not for purely environmental reasons, the introduction of environmental standards may be motivated by the increase in consumer surplus that comes with the existence of green products. We have argued above that such a policy is welfare enhancing only if the increase in consumer surplus at the least compensates the higher fixed cost. However, if this were the case there would be an incentive for at least one of the firms to introduce a green variant voluntarily: Owing to its monopolistic margin, the firm could appropriate part or all of the increase in consumer surplus and thereby finance the fixed cost of the clean technology. Hence, if under free market conditions the green variant is not introduced we should not expect an introduction of standards to increase welfare net of disutility of pollution. Naturally, all of the caveats mentioned above apply to this case, too.

5. Conclusions

In general, we conclude that the answer to the question as to whether firm delocation and the "race to the bottom" are serious stepping stones in the way towards effective environmental policies can only be given in the light of supply and demand conditions. Specifically, we find that the existence of local negative inter-firm externalities alleviates the tendency of firms to delocate in reaction to unilateral environmental regulation. Thereby, the existence of this type of externality is a necessary condition for the non-delocation result. Examples are abundant:[26] two fisheries sharing a lake or estuary, where the externality is avoided by introduction of sustainalble methods of fishing; two firms, such as the "renowned" paper-mills or breweries, sharing a body of standing water as a source of (fresh) water and a sink for waste water; or two suppliers of food, who have integrated the cultivation of crops and food processing on a limited stretch of land. Thereby, not only does the agricultural run-off of one producer negatively affect the processing plant of the other, but also does pollution generated in food processing negatively affect the cultivation of crops. Note that, for all of the examples given, differentiation into green and standard variants is also a relevant phenomenon.

The non-delocation result is much strengthened if the existence of green preferences allows a firm to recover the higher cost of a clean technology by selling the green product at a monopolistic price. For high levels of willingness to pay for environmental friendliness, there is an incentive for at least one firm to introduce a green technology even if there is no regulation. Delocation will never be a problem then.[27] For some intermediate levels of green willingness to pay both firms may produce the non-green variant at the outset. However, confronted with local environmental standards, a firm may introduce a green technology rather than delocate even for very low levels of the externality. For low levels of willingness to pay the externality will have to be correspondingly higher, to guarantee the non-delocation result. In general, existence of an externality is a necessary condition for non-delocation, while exis-

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[26] For a more detailed discussion of the symmetric common property dilemma we deal with, see Dasgupta/Heal (1977), Baumol/Oates (1988).

[27] This result, which obtains for the product differantiation regime, has not been explicitly derived in this version of the paper but will be supplied by the author upon request.

tence of some sufficient willingness to pay for green product versions adds sufficiency. The size of the green market segment also matters. However, its influence is ambiguous and dependent on the specification of the cost function. A policy recommendation is that paying some attention to the demand side of the product market is important for environmental policy making and may even lead to some more optimistic results about the introduction of environmental regulation.

The alleviation of the delocation problem is paralleled by the finding that governments will not engage in a race to the bottom if preferences for green products are sufficiently strong in an economy. This results is mainly driven by the willingness to pay for environmental friendliness, where, clearly, maintenance of standards is the more likely the higher the willingness to pay. If firms delocate in reaction to unilateral standards the externality has to exceed some minimum level as a necessary condition for non-deregulation. The size of the green market segment only has an unambiguously positive influence if firms would not delocate from regions setting standards unilaterally. A different finding is that regions will not introduce environmental regulation into a non-green market equilibrium for other than environmental considerations. Let me briefly report two results not derived in this version of the paper: If the structure of the economy is such that product differentiation obtains in the unregulated state a single region may set a standard unilaterally to give the domestic firm a competitive advantage. Thereby, the standard servers as a commitment to produce the more profitable green variant. For sufficiently high levels of willingness to pay for greenness, regions may even engage in a "race to the top", trading off a higher consumer surplus against a loss in profits.[28]

For an economic structure favouring production of the non-green variant only, deregulation is always welfare enhancing. However, let me stress again that I have not considered consumers´ disutility of pollution in the regions´ welfare functions in order to isolate the influence of product differentiation and inter-firm externalities on regional environmental policies. Hence, the results obtained may be considered the least favourable for the environment. It is easily verified that accounting for consumer disutility in the welfare function would shift the balance in favour of "more regulation" for all findings.

The main weakness of the approach chosen lies in the specific functional forms and structure of the game. Obviously, there is some potential for generalizations. Lines of extension lie in the modelling of a more general form of switching cost with respect to location and/or quality and in the inclusion of incomplete information giving rise to issues of signalling and reputation. I hope to address these issues in forthcoming work.

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[28] Derivation of these results may also be obtained from the author upon request.

Acknowledgements

A very preliminary version of this paper has been presented at the Workshop "Environmental Capital Flight" held at Ede, 13-15 September 1995, which was organized by the Agricultural University of Wageningen and the Dutch Science Foundation. An earlier version has been held at the Environmental Economics Forum, 29-31st August 1996, Ambleside, Cumbria. I thank Thusnelda Tivig and participants of the above meetings for useful comments. The usual disclaimer applies.

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Appendix

Proof of Proposition 1.1

a) Consider $(s_A = s_B = 1)$: For either firm *i* any strategy $f_i = \{N, \varphi_i, p_i\}$ involving production of N is unfeasible. Trivially, $(f_1{*} = \{G, A, p{*}\}, f_2{*} = \{G, B, p{*}\})$ is the equilibrium, where $p{*}$ is determined by (C3.6a) and (C3.6b).

b) case I: Consider $(s_A = 1, s_B = 0)$. $(s_A \neq s_A^0, s_B = s_B^0)$ triggers a sequential game with firm 1 moving first. Thereby, for either firm *i* a strategy $f_i = \{N, A, p_i\}$ is unfeasible. Solving for a SGP equilibrium under observance of (A3.1), (A3.2) and (C3.4), yields three possible outcomes:

ba) By (C3.5), $g < \bar{g}^x$ implies $\pi^{GN} < \pi^{NNx}$, and $(f_1{*} = \{N, B, 1\}, f_2{*} = \{N, B, 1\})$ is a unique equilibrium.

bb) By (C3.5), $\bar{g} > g > \bar{g}^x$ implies $\pi^{GN} > \pi^{NNx}$. Hence, firms wish to differentiate products and location. For $\bar{g} > g$, $\pi^{GN} > \pi^{NG}$ only holds for $g > \alpha/m$. Observing that firm 1 moves first, we obtain an SGP equilibrium with

$$(f_1{*} = \{G, A, 1+g\}, f_2{*} = \{N, B, 1\}) \text{ if } g > \alpha/m$$

and

$$(f_1{*} = \{N, B, 1\}, f_2{*} = \{G, A, 1+g\}) \text{ if } g < \alpha/m .$$

case II: Consider $(s_A = 0, s_B = 1)$. Proof in analogy to the one presented for case I yields the following equilibria:

ba) for $g < \bar{g}^x$: $(f_1{*} = \{N, A, 1\}, f_2{*} = \{N, A, 1\})$

bb) $\bar{g} > g > \bar{g}^x$:

- $(f_1{*} = \{N, A, 1\}, f_2{*} = \{G, B, 1+g\})$ if $g > \alpha/m$
- $(f_1{*} = \{G, B, 1+g\}, f_2{*} = \{N, A, 1\})$ if $g < \alpha/m$.

Notice that, by (3.2.1), $\pi^{GN} < 0$ for $\alpha > (1+g)m - m^2$, and by (3.5), $\pi^{NNx} < 0$ for $x > 1$. Observe that for $\pi^{GN}, \pi^{NNx} < 0$ (C3.5) still works as a selection criterion, yielding a unique equilibrium. However, the firm suffers a loss, no matter which equilibrium obtains. In this case, the equilibrium cannot be stable and the firm leaves the market. As indicated in section 2 we wish to exclude the case of a monopoly. By assuming $x \leq 1$ we assure that $\pi^{NNx} \geq 0$ is always satisfied and, hence, profits are always non-negative in equilibrium. Comparing damage cost, as given by (2.7), with variable cost in (2.6) we find that both functions are quadratic in quantity, where the weight is $0 \leq x \leq 1$ for damage cost and one for variable cost. Hence, we implicitly assume a technology where the external cost inflicted on others is not greater than private variable cost. While this seems reasonable for a lot of cases, counter-examples could certainly be found.

c) Consider $(s_A = s_B = 0)$: Since $(s_A = s_A^0, s_B = s_B^0)$, we have $(f_1{*} = f_1^0, f_2{*} = f_2^0)$. QED.

Proof of Proposition 1.2

a) Consider $(s_A = s_B = 1)$: Since $(s_A = s_A^0, s_B = s_B^0)$ the subgame is not triggered, and the equilibrium $(f_1{*} = f_1^0, f_2{*} = f_2^0)$ remains unchanged.

b) Proof in analogy to the one for Proposition 1.1 b) yields the following equilibria:

case I: $(s_A = 1, s_B = 0)$

ba) for $g < \bar{g}^x$: $(f_1{*} = \{N, B, 1\}, f_2{*} = \{N, B, 1\})$.

bb) $\bar{g} > g > \bar{g}^x$:

- $(f_1{*} = \{N, B, 1\}, f_2{*} = \{G, A, 1+g\})$ if $g > \alpha/m$.
- $(f_1{*} = \{G, A, 1+g\}, f_2{*} = \{N, B, 1\})$ if $g < \alpha/m$.

case II: $(s_A = 0, s_B = 1)$

ba) for $g < \bar{g}^x$ **:** $(f_1{*} = \{N, A, 1\}, f_2{*} = \{N, A, 1\})$.

bb) $\bar{g} > g > \bar{g}^x$ **:**

- $(f_1{*} = \{G, B, 1+g\}, f_2{*} = \{N, A, 1\})$ if $g > \alpha/m$.
- $(f_1{*} = \{N, A, 1\}, f_2{*} = \{G, B, 1+g\})$ if $g < \alpha/m$.

c) Consider $(s_A = s_B = 0)$: Since $(s_A \neq s_A^0, s_B \neq s_B^0)$, firms play a simultaneous game. First best strategies are feasible now, and thus $(f_1{*} = f_1^{fb}, f_2{*} = f_2^{fb})$ is the unique equilibrium. QED.

Notation

α	fixed cost for variant *G*
C	(total) cost
C'	marginal cost
CS	aggregate consumer surplus
CS_k	surplus of a consumer of type *k*
CS_k^θ	distance function in p_k^θ and $p(\theta)$
$d_i = \{\theta_i, \varphi_i\}$	decision of firm *i* on quality and location
ε	amount by which a price is undercut
$F(\theta)$	quality dependent fixed cost
$f_i = \{\theta_i, \varphi_i, p_i\}$	strategy of firm *i* in quality, location and price
fb	index denoting first-best strategies
G	green technology, green variant
g	willingness to pay for environmental friendliness; premium for environmental friendliness
$i = 1,2$	index of firms, where "-*i*" denotes "the other firms"
$j = A, B$	index of regions, where "-*j*" denotes "the other regions" location of firm *i*
$k = \Gamma, N$	type of consumer: green (Γ)or non-green *(N)*
M	aggregate number of consumers in both region
m	share of green consumers
N	non-green, i.e. polluting, technology, non-green variant price (for quality θ)
p_k^0	reservation price of a consumer of type *k* for a variant θ
π_i	profit (of a firm *i*)
q_i	demand faced by firm *i*
q_i^θ	demand for variant θ faced by firm *i*
q^θ	aggregate demand for variant θ
q_k	aggregate demand of a consumer of type *k*
q_k^θ	individual demand of a type *k* consumer for a variant θ

$\theta = G, N$	technology/quality/variant
$\theta_i \in \{G, N\}$	technology/quality chosen by firm *i*
$s_j \in \{0,1\}$	environmental policy of region *j*, where "one" means standard and "zero" means unregulated state
W_j	welfare (in a region *j*)
X	damage cost
$x(\theta_{-i}, \varphi_1, \varphi_2)$	damage coefficient for a firm *i*
*	equilibrium value
$\overline{v}, \widetilde{v}$	upper bounds for any parameter *v*
$\underline{v}, \underline{\underline{v}}, \widetilde{v}_L$	lower bounds for any parameter *v*
v'	any parameter/variable *v* in a green equilibrium with $p^* = 1$
v^x	any variable/bound relating to the externality
$\pi^{\theta_i \theta_{-i}}$	profit of firm *i*, where *i* produces the variant $\theta_i \in \{G, N\}$ and –*i* and produces $\theta_{-i} \in \{G, N\}$
$W^{\theta_j \theta_{-j}}$	welfare of region *j*, where the firm located in *j* produces $\theta_j \in \{G, N\}$ and the firm in –*j* produces $\theta_{-i} \in \{G, N\}$
W^{NNx}	welfare in region *j*, where both firms are located in *j* and produce *N*