Stähler, Frank

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by Frank Stähler*

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Competitiveness and Environmental Policies in Strategic Environmental Policy Models

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Abstract: This paper discusses the issue of competitiveness and environmental regulation from the viewpoint of strategic environmental policy models. It demonstrates that the incentive for strategic policies is determined only by the reaction of the opponent. Furthermore, it shows that the conditions under which relatively strict environmental policies may lead to an increase in the profits of the domestic industry are rather artificial. The result depends in a rather complex way on the type of competition and several effects of research and development or environmental quality specification, and on the assumption that a unilateral policy is possible.

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* Frank Stähler, Institute for Economic Theory, University of Kiel, Wilhelm-Seelig-Platz 1, D-24098 Kiel, Germany, fstaehler@ifw.uni-kiel.de

Competitiveness and environmental policies in strategic environmental policy models

This paper is part of a research project on the effects of environmental policies on the international competitiveness. It discusses the so-called Porter Hypothesis which states that a comparably stricter environmental policy may lead to an increase in competitiveness. This paper constitutes a chapter of an intended monograph and covers the contribution of the theory of strategic environmental policies to this discussion. Other chapters on intersectoral effects in a general equilibrium framework and on a dynamic approach can be found in the Kiel Working Papers No. 857 and 859, respectively. We gratefully acknowledge financial support by the Fritz Thyssen Foundation.

1 Introduction

Scholz (1998) has demonstrated the intersectoral effects of unilateral environmental policies on the global scale of national economies. This paper will deal with the effects in a partial equilibrium framework. This partial equilibrium framework focuses on a specific sector and assumes that the general equilibrium effects of an environmental policy which affects this sector can be ignored. This assumption is made to be able to measure the welfare effects of environmental policies by changes of the producer rents of this sector and by changes of the environmental damages. Although this assumption is very constructive for the theoretical analysis, it raises a serious problem when the effects on competitiveness are to be discussed: if the effects on the rest of the economy can be ignored, the impact of environmental policies on this sector can be expected to be negligible as well. Hence, a more thorough investigation would require to explore the effects on the whole economy. If these effects were negligible, the effect on overall competitiveness should be negligible as well.

Despite this obvious inconsistency, a lot of papers have considered the effect of unilateral environmental policies on the basis of this assumption, for example Barrett (1994), Conrad and Wang (1993), Kennedy (1994), Rauscher (1994, 1995a, 1995b), Simpson and Bradford (1996) and Ulph (1994, 1996). The theoretical basis of these papers is the pathbreaking paper of Brander and Spencer (1985) on strategic trade policy. Brander and Spencer have shown that a single country has an incentive to subsidize a domestic firm in an international oligopolistic market under certain conditions. The reason is that subsidization - either by direct support causing cost reductions or by subsidization of research and development - is able to imply a behavior of the firm as if it were a Stackelberg leader. If the effects on the consumer rent can be ignored, it can be shown that it is profitable to pursue a policy for which the costs of subsidization do always fall short of the increased profits of the domestic firm. Based on this result, free trade agreements cannot be expected unless countries are able to bind themselves not to introduce trade policy instruments.

The discussion on strategic policies initiated by the results of Brander and Spencer was not restricted to trade policy instruments. The reason for an extension to other policy instruments is twofold. First, the use of trade policy instruments has been subject to severe restrictions by international trade agreements. Hence, their application is restricted although not excluded. Second, trade policy instruments are not the only option for pursuing strategic policies. The question was raised whether the design of other regulatory instruments could be affected by strategic considerations as well. Since environmental problems which are due to the public good property of an environmental asset require policy intervention, it is obviously a necessary exercise to investigate whether environmental policy may serve for other purposes in addition to increasing environmental net benefits. Hence, the issue of competitiveness can be covered by strategic policy models since the Porter Hypothesis claims such additional benefits of strict environmental policies. This paper will therefore discuss the impact of strict unilateral environmental policies on the competitiveness from this viewpoint of strategic policies. Since our attention is restricted to environmental regulation, we will refer to this policy as strategic environmental policy.

This paper is organized as follows. Section 2 will give a rather informal overview of the main results of strategic environmental policies. Section 3 will show why strategic aspects are so important. Sections 4 and 5 will explore the incentives for policy makers in more detail. Readers who are not interested in the mathematical exposition of this theory may skip over Sections 4 and 5. Section 4 will discuss a two-stage model; Section 5 will discuss a three-stage model which includes research and development or the specification of environmental quality. Section 6 will discuss how changing some crucial assumptions will alter the main results of the theory of strategic environmental policies. Section 7 will conclude.

2 Strategic environmental policies and competitiveness: the basic results

In order to capture the idea and to explain the main results of strategic environmental policy models, it is helpful to start with the basic assumptions. Strategic environmental policy models assume imperfect markets. A certain market will be served by a limited number of firms which are located in different countries. In order to simplify the analysis, it is helpful (and done in many papers) to assume two countries and two firms, one in each country. The assumed market structure is not endogenous such that firms enter the market as long as profits are positive and no further firm enters when profits are equal to zero (and the number of firms in the market is finite due to fixed costs). Instead, it is assumed that the market structure is given, for example because market entry of other firms is not possible.

Since only two firms are operating in a certain market, the behavior of one firm will have an impact not only on this firm's profits but on the profits of the other firm as well. For example, a firm which decreases its price in order to increase sales will obviously also imply decreased sales and decreased profits of the other firm. The profits and the change of profits implied by strategic environmental policies are at the heart of the analysis of strategic environmental policies. In order to arrive at clear-cut results, it is also assumed that effects on consumers can be ignored. This assumption is often justified by the consideration that both firms may produce for a market in a third country such that domestic consumers are not affected. Under this assumption, the welfare of a country is defined only by the profits of the domestic industry under consideration and the environmental damage caused by the industry.

The logic of strategic environmental policies can be demonstrated by considering policies which are not yet strategic. Non-strategic environmental policies reduce pollution such that the marginal profit decrease due to environmental regulation is equal to the marginal damage caused by pollution. Suppose that both countries pursue such an environmental policy. Taking this policy as a starting-point, one may then discuss whether a unilateral policy change in either the direction of more or of less regulation will benefit the country in terms of welfare. Hence, this paper will discuss strategic aspects of environmental policies by considering the strategic incentive for a policy which has not yet recognized strategic interactions.

The idea of strategic policies can be made clear by a simple example. Suppose that every firm has three options from which it may choose its market policy: option I mirrors a strategy which aims to realize the maximum profit given that the other firm chooses a less aggressive option, option II gives a medium aggressive strategy, and option III stands for a strategy which realizes a low but positive profit irrespective of the other firm's strategy. For the ease of exposition, we will assume specific numbers for the profits to be realized under the nine possible outcomes. These outcomes are summarized by Table 1.

Table 1: Profits under different market strategies

Firm 1 chooses rows Firm 2 chooses columns	I	II	III
I	(0,0)	(50,5)	(80,10)
II	(5,50)	(60,60)	(40,5)
III	(10,80)	(5,40)	(0,0)

The profits under all possible outcomes are given in parenthesis as (profit of firm 1, profit of firm 2). According to Table 1, the game is symmetric since a certain strategy pair turned around gives the original profits turned around as well. Table 1 mirrors the so-called strategic form of the market game since it summarizes the different outcomes but does not contain any information about the move structure, i.e. whether both firms are supposed to decide on their strategies simultaneously or whether a certain firm may decide first on its policy without any option for revision. The strategic form allows to determine all Nash equilibria, i.e. all outcomes which meet the condition that no firm can improve its profits by choosing a different strategy, given the strategy of its opponent. From Table 1, one finds that three Nash equilibria exist: (I,III), (II,II) and (III,I) which give profits of (80,10), (60,60) and (10,80), respectively.

The disadvantage of the presentation by the strategic form is that not all possible equilibria are credible under all possible mover structures. Suppose that firm 1 has to move first, and that after firm 1's move it is up to firm 2 to decide on its market strategy. Obviously, firm 1 realizes the highest profit if it chooses strategy I whereas firm 2 chooses strategy III. Hence, if firm 1 goes ahead, it will choose I because firm 2 cannot do better by another strategy than III given I by firm 1. In this case, firm 1 has a first-mover advantage since it is able to realize the Nash equilibrium which gives it the highest profits. It is not credible that firm 2 chooses II or I since it would be worse off.

If the move structure is turned around such that firm 2 moves first and firm 1 is to follow, the results are also turned around and only (III,I) giving (10,80) can qualify for a credible equilibrium. If both firms move simultaneously without being able to observe the behavior of the opponent, the traditional analysis of industrial markets implies the symmetric equilibrium (II,II) giving profits (60,60). Since a certain mover structure cannot be assumed without assuming an institutional arrangement which implies the mover structure, one may expect that (II,II) is the relevant equilibrium.

Strategic aspects may now enter the stage. At the heart of the strategic policy analysis is the question whether a unilateral policy change may imply that the relevant industry equilibrium changes such that social welfare is increased. Social welfare can be increased if the domestic firm is induced to behave as if it were in a leading position although it is not in fact. This behavior can be implied by changing the profits properly. Suppose that option I is a very "dirty" option because the high profits of I go along with excessive resource use due to a high production level. Hence, environmental regulation which does not take strategic aspects into account is stricter if a firm chooses I instead of II or III. Now suppose that country I relaxes environmental regulation such that it is not so strict if firm 1 chooses I. Assume that the profits are increased by 15 by a lax regulation for I, whereas the damage is increased by 20. Table 2 gives the revised payoffs.

Table 2: The influence of strategic subsidies on profits

Firm 1 chooses rows Firm 2 chooses columns	I	II	III
I	(15,0)	(65,5)	(95,10)
II	(5,50)	(60,60)	(40,5)
III	(10,80)	(5,40)	(0,0)

One may call such a policy strategic subsidization because a firm choosing option I does no longer take all environmental costs into account since regulation is too lax. As the increase in profits for I is 15 but the increase in damage is 20, one might find at first glance that this policy makes the country worse off. But the opposite is true since I was not the relevant equilibrium before but it is now. According to Table 2, the only equilibrium is (I,III) now because firm 1 will choose I in every case because strategy I gives the highest profits irrespective of the strategy of firm 2 when these subsidies are granted. Since the profits are increased by 35 (from 60 to 95) and the damage is increased by 20, social welfare is increased by 15. Hence, the lax environmental policy is able to increase social welfare.

This example demonstrates that a too lax environmental policy might increase social welfare and the profits of an industry. In this case, however, the profit increase goes along with more pollution. Hence, strategic policies do not necessarily imply less environmental damages since this example shows that unilateral ecological dumping may improve a country's welfare. Nevertheless, another example may show that strategic policies may also imply stricter environmental regulation as it is claimed by the Porter Hypothesis. Suppose now that not strategy I but strategies II and III are the "dirty" options. Assume that country 1 introduces a stricter environmental regulation for these options which decrease the profits of both options by 15 and the damage by 10. Table 3 gives the revised payoffs.

Table 3: The influence of strategic taxes on profits

Firm 1 chooses rows Firm 2 chooses columns	I	II	III
I	(0,0)	(50,5)	(80,10)
II	(-10,50)	(45,60)	(25,5)
III	(-5,80)	(-10,40)	(-15,0)

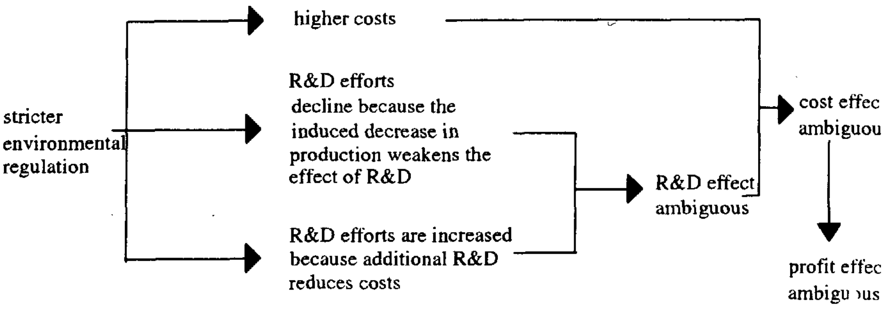
In this case, strategic policies may be called strategic taxation since the domestic firm has to bear a regulatory burden if it chooses II or III which is larger than optimal. But this bias brings the domestic firm also in a leadership position as strategic subsidies did. The effect is identical since removing 15 units of profits from II and III implies the same incentive as adding 15 units of profits to I. Again, firm 1 will choose strategy I now irrespective of the choice of firm 2, and then firm 2 cannot do better than to choose strategy III. Since too strict regulation does not apply because I is chosen, social welfare is increased by the same amount as the profits of the domestic firm, i.e. 20 units. In this case, profits are increased and the environmental damage remains constant.

Both examples show that there is no unambiguous effect of a stricter environmental policy on profits and welfare. In the general models of the subsequent sections, it will be shown that the incentive to regulate either stricter or laxer compared to the Pigouvian solution depends only on the changes of the strategic variables of the other firm. Hence, strategic environmental policy is in fact industrial policy which intends to influence the behavior of foreign competitors in a way which benefits the domestic industry.

In the literature, two different types of strategic environmental policies are discussed, and this result holds for both types. In a two-stage version, firms decide on their strategic variables after governments have specified environmental regulation. In this case, it is not possible that profits are increased and environmental damage is decreased. Instead, either profit is increased for the cost of more damage or damage is decreased for the cost of less profit. Hence, the Porter Hypothesis can never hold in the two-stage version of strategic environmental policies. The reason is that research and development or the specification of environmental quality which is appreciated by consumers plays no role in this setting.

If research and development or environmental policy (both are referred to as R&D in the subsequent sections) should play a role, strategic environmental policy models comprise three stages. The first and the third stage are identical with the first and the second stage of the two-stage version, respectively. Before firms determine their market strategy, however, they are assumed to determine the level of research and development or the environmental quality of their products. In the case of research and development, each firm is able to increase the environmental and/or production efficiency by research and development. In the case of environmental quality to be specified, each firm may make a certain product "greener" such that consumers are willing to pay a higher price for them compared to a product which is less green. In these settings, it is possible that a unilateral increase in environmental regulation increases the profits of the domestic firm and decreases the environmental damage. The analysis of these cases is very involved but an example can make the possible effects clear. Assume that research and development is able to decrease environmental compliance costs. The effects of a stricter environmental regulation are shown in Figure 1.

Figure 1: The impact of stricter environmental regulation on research and development and costs



The effect of a stricter environmental regulation is threefold. The first arrow gives the direct cost effect of stricter environmental regulation which obviously increases the costs of the firm. The other two arrows give the indirect effects: on the one hand, higher costs will imply lower production, and lower production lowers the productivity of research and development. On the other hand, additional research and development is able to compensate for higher costs. This effect increases research and development. Since the first two effects and the third effect are opposite in sign, the total effect is ambiguous. Hence, it is possible that the last cost-decreasing effect is stronger than the other two effects such that costs are decreased. If the costs of research and development are not too high and the other firm decreases its research and development in response (thereby implying higher costs), it might turn out that even profits are increased. In this case, stricter environmental regulation leads to more research and development and higher profits of the domestic firm.

However, the cases in which stricter environmental regulation leads to increased profits are rather artificial, and there is no general theoretic evidence that the Porter Hypothesis holds in this setting. Additionally, all these approaches assume that the other country does not change its environmental policy which does not yet take into account strategic aspects. But this is not an optimal strategy. Instead, the incentive for the other country will be identical in the case of symmetric countries and symmetric firms. If both countries pursue a certain policy which takes into account the strategic effects, they enter a prisoners' dilemma situation: every country is worse off compared to no strategic policies but - as it was shown - each country increases its welfare if it introduces strategic policies when the other country does not. An example can make this point clear. Consider Table 2 which discussed unilateral subsidization. If both countries subsidize, the payoffs are given by Table 4.

Table 4: The influence of bilateral strategic subsidies on profits

Firm 1 chooses rows Firm 2 chooses columns	I	II	III
I	(15,15)	(65,5)	(95,10)
II	(5,65)	(60,60)	(40,5)
III	(10,95)	(5,40)	(0,0)

Due to bilateral subsidization, the equilibrium strategy pair is now (I,I) which defines the dirtiest option. The profits of each firm are decreased by 45 (from 60 to 15) and the damage is increased by 20 by assumption. Hence, bilateral subsidization incurs losses for each country of 65! Note that these losses will in fact be realized because a unilateral abolishment of strategic policies would lead to Table 2 such that it would not be followed by an abolishment of the other country.

The result that strategic policies lead to prisoners' dilemma situations is common to all models. Therefore, the Porter Hypothesis is hard to justify in this setting unless there are good reasons to assume that one country behaves strategically but the other country does not. One may conclude that another framework is necessary in order to be able to arrive at more optimistic results for the impact of strict environmental policies on competitiveness. Stähler (1998) will be an attempt and will discuss the Porter Hypothesis in a similar strategic framework which is extended to several periods.

3 Environmental policies and technology choice

Before turning to strategic environmental policy models in detail, it is helpful to demonstrate why strategic aspects are so important. This exercise will be done by a rather general approach in this section. This section will show that increased environmental regulation is not able to increase the profits of a firm when strategic effects are absent. It will employ a microeconomic model which was used by Oates, Palmer and Portney (1993). This framework analyzes the effect of environmental regulation in a microeconomic partial equilibrium framework of technology choice. In this section improvements in competitiveness is understood as a reduction of costs. A single firm is assumed which currently employs a technology that leads to emissions P_0 for which it is charged an emission tax w_{P_0}. The firm has the possibility to switch technology at date T, such that emissions are only P_1. Switching, however, is costly and cannot be done unless a sunk investment cost, I, is incurred. The firm minimizes the present value of its future cost through the choice of its switching date T. Therefore, the cost minimization problem can be stated as:

$$(1) \qquad C(w_P) = \min_T = \int_0^T w_P P_0 e^{-rt} dt + \int_T^\infty w_P P_1 e^{-rt} dt + I e^{-rT}.$$

The solution to this simple problem is the following corner solution.

$$(2) \qquad w_P P_0 \mathop{\lessgtr}^{\geq}_{<} w_P P_1 + rI \Rightarrow T = \begin{cases} 0 \\ \infty \end{cases}.$$

If the current cost of technology 0 is larger than the sum of the current cost of technology 1 plus the annuity value of the sunk switching cost, the switching date is zero. Otherwise the switching date is infinity. If the switching date is zero, technology 0 is immediately abandoned for technology 1, otherwise technology 1 is never chosen.

Environmental regulation is equivalent to raising the emission tax from w_{P_0} to w_{P_1}. Before the tightening of the environmental regulation the firm chooses the dirty technology 0. Therefore, we must have for $w_{P_0} < w_{P_1}$:

$$w_{P_0} P_0 < w_{P_0} P_1 + rI,$$

such that the clean technology is never chosen. If the increase in the environmental regulation is strong enough, such that the clean technology is chosen the new equilibrium must be:

$$w_{P_1} P_0 \geq w_{P_1} P_1 + rI.$$

One interpretation of the Porter Hypothesis is that in the new equilibrium it is possible that costs are lower than in the initial equilibrium. In other words, $C(w_{P_0}) > C(w_{P_1})$. Integrating (1) and considering the necessary condition (2), the Porter Hypothesis can be stated as:

(3) $$w_{P_0} P_0 \geq w_{P_1} P_1 + rI.$$

Since $w_{P_0} < w_{P_1}$, w_{P_1} can be expressed as $w_{P_0} + a$, where $a > 0$. In this case (3) can be rewritten as:

$$w_{P_0} P_0 \geq w_{P_0} P_1 + rI + aP_1.$$

If this inequality is fulfilled also $w_{P_0} P_0 \geq w_{P_0} P_1 + rI$ is fulfilled. However, in this case it would have not been optimal for the firm to choose technology 0 in the initial equilibrium. Thus, in this simple framework the Porter Hypothesis cannot be true if the firms are always minimizing their costs. In other words, in this simple model environmental policy always increases costs. Environmental policy cannot yield an international competitive advantage, but only a disadvantage, since the costs of firms, subject to the increase in environmental regulation, will experience an increase in costs.

Now, one can ask which effects have to be introduced in this simple model such that this result changes and the Porter Hypothesis can become true. General equilibrium effects might play an important role. For example environmental regulation might lead to a reallocation of resources. Therefore, factor prices change and some sectors of the economy might be overcompensated for the increase in environmental regulation. Scholz (1998) has dealt explicitly with these effects. Another possible effect that might play an important role is strategic interaction or the possibility to accumulate knowledge which can be sold to other firms or lead to a comparative advantage. This possibility will be investigated in the next two sections. This section, however, has shown that the Porter Hypothesis can never hold in a partial equilibrium setting when there are no strategic interactions among firms.

4 A general approach to strategic environmental policies and competitiveness I: The two-stage game

This section will show that strategic environmental policy is in fact industrial policy. It will show that environmental policy serves merely as a tool for influencing the behavior of the foreign industry such that the profits of the domestic industry increase more than the costs of this policy or such that the profits of this industry decrease less than the benefits of this policy. Compared to strategic trade theory, the welfare effects do imply not only changes of the producer rent but also of the environmental net benefits.

One may distinguish between two different approaches to strategic environmental policies. The first case deals with a two-stage approach. In these models, two stages constitute a game such that when the first stage is specified, there is no option to change the results of the first stage in the second stage. This assumption makes it possible to solve the game in the usual backward induction fashion, i.e. to solve the second stage first for a given result of the first stage, and then to use these results of the second stage in order to determine the results in the first stage. The strict mover structure makes only this solution subgame-perfect. All other different Nash equilibria involve an incredible threat. Table 1 shows the structure of the two-stage game.

Table 1: The two-stage approach

Period	Move
First stage	Government specifies environmental regulation.
Second stage	Firms specify their market strategy.

In the two-stage game, the government specifies environmental regulation first which is given (and cannot be changed) for the firms which decide on their market policy in the second stage. When firms have determined their market policy, the game is finished.

Let the profit functions of each firm be denoted by Π:

$$(4) \qquad \Pi_1[s_1, s_2, \alpha_1], \; \Pi_2[s_1, s_2, \alpha_1]$$

(4) gives the profit of each firm as a function of the strategy levels of this firm and of the other firm. α_1 denotes the policy parameter of country 1 which will be changed marginally in order to determine the marginal welfare effects. α_1 may represent an emission tax, a minimum environmental quality of the produced good or any other environmental regulation. In the two-stage game, however, we will restrict our attention to policy measures like taxes because the strategy level is assumed to be a scalar (and therefore cannot comprise quality decisions as well). Each firm has only its strategy level under control but has no influence on the other firm's strategy level. The strategy spaces of each firm may either consist of prices which the firm may charge for its product or of non-negative quantities which determine the capacity which will be produced. (4) does not consider α_2 since only variations of α_1 will be discussed.

Instead of solving the general game, the strategic incentives can be made clear by considering marginal changes of the market equilibrium. Suppose that environmental regulation in both countries leads to Pigouvian internalization of externalities:

$$(5) \qquad W_i(\cdot,\alpha_i) := \Pi_i(\cdot,\alpha_i) - P_i(\alpha_i)$$

$$\frac{\partial W_i}{\partial \alpha_i} = \frac{\partial \Pi_i}{\partial \alpha_i} - \frac{dP_i}{d\alpha_i} = 0$$

The social welfare, W, of each country is determined by the profits of the domestic firm, Π, minus the environmental damage caused by pollution, P. (5) assumes that environmental damage depends on the degree of environmental regulation. This specification might look strange because one might expect that damages depend on emissions, for example. But in order to be able to be very general, (5) assumes that increased regulation leads to less pollution because, for example, emissions are reduced. Then, the environmental damage can be made dependent on the level of environmental policies.

Additionally, it is assumed that externalities do not imply a transboundary pollution problem which is likely to imply a strategic environmental policy problem between both countries. This assumption implies that (5) is a first-best environmental policy. If instead transboundary pollution were assumed, (5) would give an inefficient outcome since the effect on the other country would not be taken into account. Then, $P_i(\alpha_1,\alpha_2)$ substitutes for $P_i(\alpha_i)$ and the cooperative Pigouvian solution would imply

$$\frac{\partial \Pi_i}{\partial \alpha_i} - \sum_j \frac{dP_i}{d\alpha_i} = 0.$$

Since this analysis focuses on the effects of environmental policies on profits, transboundary pollution will not be assumed. However, it should be clear that a stricter (laxer) environmental policy of a country increases (decreases) the welfare of the other country through reduced (increased) transboundary pollution. One may then conclude that a bilateral incentive for stricter (laxer) environmental policy compensates (pronounces) the welfare losses which are due to uncoordinated international environmental policies.

As in Section 2, two firms in two different countries are assumed. Each firm is assumed to maximize its current profits. Maximization of (4) determines the reaction functions $s'_1(s_2)$ and $s'_2(s_1)$ which can be given as implicit functions f_1 and f_2:

$$(6) \qquad f_1(\cdot) = \frac{\partial \Pi_1}{\partial s_1}(\cdot) = 0, \qquad f_2(\cdot) = \frac{\partial \Pi_2}{\partial s_2}(\cdot) = 0$$

The reaction functions give the optimal strategy level of a firm for a given strategy level of the other firm. Duopolists compete by strategic substitutes (complements) if each firm's best reaction to an increase of the other firm's strategy variable is to decrease (increase) its own strategy variable (Bulow, Geanakoplos and Klemperer, 1985). The slope of the reaction curve is

$$(7) \qquad \frac{ds'_i}{ds_j} = -\frac{\partial^2 \Pi_i / \partial s_i \partial s_j \left[s'_i(s_j), s_j\right]}{\partial^2 \Pi_i / \partial s_i^2 \left[s'_i(s_j), s_j\right]} \qquad \forall i \neq j \in \{1,2\}$$

which is negative (positive) for strategic substitutes (complements). Since the second derivative with respect to the own strategy level must be negative along the reaction curve in order to guarantee a global profit maximum, the cross derivative determines the slope of the reaction curve. Markets for strategic substitutes are markets in which firms set quantities, markets for strategic complements are markets in which firms compete by prices. Hence, the vector of both firms' strategies is constrained by the condition that a maximum quantity exists for which demand is saturated (strategic substitutes) or by the condition that a maximum willingness to pay exists by which demand is choked off (strategic complements). The following condition guarantees that the standard comparative statics results hold:

$$(8) \qquad \frac{ds'_i}{ds_j}\frac{ds'_j}{ds_i} < 1$$

Condition (8) guarantees that the effects of the own strategy level on own profits is stronger than the effect of the other firm's strategy level. Since this condition is assumed to hold in general (and not only at a certain point), it guarantees also that the equilibrium is unique. In order to determine the marginal welfare changes, it is necessary to determine the total differentials of the reaction functions:

(9)

$$df_1 = \frac{\partial^2 \Pi_1}{\partial s_1^2} ds_1 + \frac{\partial^2 \Pi_1}{\partial s_1 \partial s_2} ds_2 + \frac{\partial^2 \Pi_1}{\partial s_1 \partial \alpha_1} d\alpha_1 = 0$$

$$df_2 = \frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2} ds_1 + \frac{\partial^2 \Pi_2}{\partial s_2^2} ds_2 + \frac{\partial^2 \Pi_2}{\partial s_2 \partial \alpha_1} d\alpha_1 = 0$$

The response of firm 2's strategy to a change of the policy parameter can be computed by solving (9) for $ds_2/d\alpha_1$:

(10) $$\frac{ds_2}{d\alpha_1} = \frac{1}{\beta}\left[\frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2}\frac{\partial^2 \Pi_1}{\partial s_1 \partial \alpha_1} - \frac{\partial^2 \Pi_1}{\partial s_1^2}\frac{\partial^2 \Pi_1}{\partial s_2 \partial \alpha_1}\right]$$

with $$\beta := \frac{\partial^2 \Pi_1}{\partial s_1^2}\frac{\partial^2 \Pi_2}{\partial s_2^2} - \frac{\partial^2 \Pi_1}{\partial s_1 \partial s_2}\frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2} > 0$$

β is positive due to (8). Since it is assumed that the strategy levels of both firms are scalars and hence the policy intervention is a tax or a similar measure, we may exclude any direct effect of the policy measure on firm 2's profits except those which are due to firm 2's reaction. If there is no direct effect of regulation in country 1 on profits of firm 2, (11) which defines individual profits and its change with the policy parameter holds.

(11) $$\Pi_2 = p_2(\cdot)x_2(\cdot) - C_2[x_2(\cdot)]$$

$$\Rightarrow \frac{\partial \Pi_2}{\partial \alpha_1} = 0, \frac{\partial^2 \Pi_2}{\partial s_2 \partial \alpha_1} = -\frac{\partial^2 C_2}{\partial x_2 \partial \alpha_1}\frac{\partial x_2}{\partial s_2} = 0, \qquad \forall s_2.$$

(11) defines the profits as the difference between individual demand $p_2(\cdot)x_2(\cdot)$ for firm 2 and the individual costs of firm 2. Individual demand is the product of the

realized price p_2 and the realized quantity x_2. In the case of strategic substitutes, firms compete by specifying quantities so that $s_i = x_i$ and $dx_i = ds_i$. In this case, the individual price is a function of both firms' strategies but the quantities themselves are no function of further strategic variables. In the case of strategic complements, firms compete by specifying prices so that $s_i = p_i$. Then, there is an inverse relationship between strategy variable and individual output so that dx_i/ds_i is negative. In that case, the individual quantity is a function of both firms' strategies but the prices themselves are no function of further strategic variables. (11) specifies that the policy parameter has no direct influence on the profits of firm 2. Note that a similar relationship does not hold for firm 1 since the marginal profits are only zero for strategy levels on the reaction curve.

Under this assumption, the impact of a policy change on the strategic variable of firm 2 is unambiguous for the cases under consideration:

(12) $$\frac{\partial^2 \Pi_2}{\partial s_2 \partial \alpha_1} = 0 \Rightarrow \frac{ds_2}{d\alpha_1} = \frac{1}{\beta} \frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2} \frac{\partial^2 \Pi_1}{\partial s_1 \partial \alpha_1} > 0$$

(12) can be proved by considering the case of strategic complements and the case of strategic substitutes. For strategic complements, (13) holds:

(13) $$s_i = p_i, \Pi_1 = p_1 x_1(p_1, p_2) - C_1[x_1(p_1, p_2), \alpha_1]$$

$$\frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2} > 0, \qquad \frac{\partial^2 \Pi_1}{\partial s_1 \partial \alpha_1} = -\frac{\partial^2 C_1}{\partial x_1 \partial \alpha_1} \frac{\partial x_1}{\partial p_1} > 0$$

In the case of strategic complements, the strategy variable is the price charged by a firm. (13) gives the definition of profits, the definition of strategic complements, and derives the second derivative of the profit function with respect to the strategy variable and the policy parameter. $\partial^2 C_1/\partial x_1 \partial \alpha_1$ describes how marginal costs are increased by stricter regulation and is therefore positive. The derivation of the firm's demand function with respect to its own price is obviously negative. These properties lead to a positive sign of $ds_2/d\alpha_1$, stating that the foreign firm will increase its price as a reaction to a stricter environmental regulation of the domestic firm. In the case of strategic substitutes, the strategy variable is the production of a firm:

$$(14)\qquad \Pi_1 = p_1(x_1, x_2)x_1 - C_1[x_1, \alpha_1] \qquad \frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2} < 0,$$

$$\Rightarrow \frac{\partial^2 \Pi_1}{\partial s_1 \partial \alpha_1} = -\frac{\partial^2 C_1}{\partial s_1 \partial \alpha_1}$$

(14) gives the definition of profits, the definition of strategic substitutes, and the second derivative of the profit function with respect to the strategic variable and the policy parameter. The properties imply a positive sign of $ds_2/d\alpha_1$ as well. One may wonder whether it is not also necessary to consider $ds_1/d\alpha_1$. But as it can be seen soon, $ds_1/d\alpha_1$ does not play any role for determining the incentive for strategic environmental policies. Under the use of (6), the change of profits of firm 1 is given by

$$(15)\qquad \frac{d\Pi_1}{d\alpha_1} = \frac{\partial \Pi_1}{\partial s_2}\frac{ds_2}{d\alpha_1} + \frac{\partial \Pi_1}{\partial \alpha_1}.$$

(15) uses the property that firm 1 maximizes its profits in the second stage so that $d\Pi_1/ds_1 = 0$. Obviously, one may expect a negative direct effect of stricter regulation on profits so that $d\Pi_1/d\alpha_1$ is negative. Due to (12), the sign of the first term is equal to the sign of $d\Pi_1/ds_2$, i.e. the impact of a change of the foreign firm's strategy variable on the domestic firm's profits. In the case of price competition (strategic complements), $d\Pi_1/ds_2$ is positive since an increase in the competitor's price increases own profits. In the case of quantity competition (strategic substitutes), $d\Pi_1/ds_2$ is negative since an increase in the competitor's production decreases own profits. From (15), it can therefore be seen that a stricter (laxer) regulation increases (decreases) the domestic firm's profits in the case of strategic substitutes. In the case of strategic complements, the two effects are opposite: a stricter (laxer) environmental regulation decreases (increases) profits directly (second term) but increases (decreases) profits indirectly through the strategic effect (first term).

Due to (5), the change of welfare is

(16) $$\frac{dW_1}{d\alpha_1} = \frac{\partial \Pi_1}{\partial s_2}\frac{ds_2}{d\alpha_1}.$$

From (16), it can be seen directly that the marginal welfare effect of a stricter environmental regulation depends only on the type of competition and the reaction of the opponent. In the case of strategic complements, a country has an incentive to impose stricter environmental regulation on the domestic firm since the decrease in profits is overcompensated by the decrease in environmental damage. In the case of strategic substitutes, a country has an incentive to relax environmental regulation. A similar result for strategic trade policies was found by Eaton and Grossman (1986).

(15) and (16) use the envelope theorem because around the nòn-cooperative equilibrium only effects of other strategy level change and the policy change but no own strategy effect matters since marginal profits are zero. (16) is the central result of strategic policies in two-stage games. It demonstrates that the Porter Hypothesis can never hold in this type of games because either both the profits and the environmental damage are increased or both are decreased. Hence, this section finds that other strategic variables must also enter the stage to make the Porter Hypothesis possible. Section 5 will introduce another strategy option of firms.

5 A general approach to strategic environmental policies and competitiveness II: The three-stage game

Since the Porter Hypothesis emphasizes the role of innovations, a straightforward extension of the model of the previous section is to consider the role that research and development or the specification of environmental quality (both will be referred to as R&D) could play. R&D is included in models of strategic environmental policies by an additional stage: after the governments have specified environmental regulation, firms decide on R&D which either affects their production and/or environmental compliance costs or determines the environmental quality of their product. After that decision, the firms specify their market strategy. Table 2 shows the structure of three-stage models.

Table 2: The three stage approach

Period	Move
First stage	Government specifies environmental regulation.
Second stage	Firms specify research and development or the environmental quality of their products.
Third stage	Firms specify their market strategies.

In this setting, four strategic variables may influence the profits of each firm: the market strategies and the R&D levels. In general, the profit function is therefore given by

$$(17) \qquad \Pi_i(s_1, s_2, r_1, r_2, \alpha_1).$$

Due to the strict specification of moves, however, one may solve the game in the usual backward induction fashion. When environmental regulation and R&D have been specified, the firms maximize their profits by setting the first derivative of their profit function with respect to their market strategy variable equal to zero:

$$(18) \qquad g_1(\cdot) = \frac{\partial \Pi_1}{\partial s_1}(\cdot) = 0, \qquad g_2(\cdot) = \frac{\partial \Pi_1}{\partial s_2}(\cdot) = 0.$$

g_1 and g_2 denote the reaction function of this stage. Assuming that g_1 and g_2 lead to a unique equilibrium at this stage irrespective of R&D and environmental regulation, one may write the equilibrium market strategies of the third stage as functions of R&D and environmental regulation in country 1:

(19) $s_i^*(r_1, r_2, \alpha_1)$.

The star denotes the equilibrium market strategy. By means of (19), one can define indirect profit functions in which the market strategies are replaced by the equilibrium strategies as determined by (18):

$$\Pi_1^*(r_1, r_2, \alpha_1) := \Pi_1\left[s_1^*(r_1, r_2, \alpha_1), s_2^*(r_1, r_2, \alpha_1), r_1, r_2, \alpha_1\right], \tag{20}$$

$$\Pi_2^*(r_1, r_2, \alpha_1) := \Pi_2\left[s_1^*(r_1, r_2, \alpha_1), s_2^*(r_1, r_2, \alpha_1), r_1, r_2, \alpha_1\right]$$

These indirect profit functions allow the behavior in the second stage to be determined. Before turning to this behavior, one may consider how the equilibrium market strategies change with R&D. In particular, it is interesting to explore how s_1^* and s_2^* change with r_1 since this change is relevant for determining the behavior in the second stage. Total differentiation of (18) leads to

$$dg_1^i = \frac{\partial^2 \Pi_1}{\partial s_1^2} ds_1 + \frac{\partial^2 \Pi_1}{\partial s_1 \partial s_2} ds_2 + \frac{\partial^2 \Pi_1}{\partial s_1 \partial r_i} dr_i = 0, \tag{21}$$

$$dg_2^i = \frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2} ds_1 + \frac{\partial^2 \Pi_2}{\partial s_2^2} ds_2 + \frac{\partial^2 \Pi_2}{\partial s_2 \partial r_i} dr_i = 0.$$

The superscript i denotes either 1 or 2 because due to the standard zero conjecture assumption only the own effects on the equilibrium market strategies will be taken into account. From (21), one finds that the equilibrium market strategies change with R&D according to

$$\frac{\partial s_1^*}{\partial r_i} = \frac{1}{\beta}\left[\frac{\partial^2 \Pi_1}{\partial s_1 \partial s_2}\frac{\partial^2 \Pi_2}{\partial s_1 \partial r_i} - \frac{\partial^2 \Pi_2}{\partial s_2^2}\frac{\partial^2 \Pi_1}{\partial s_1 \partial r_i}\right], \tag{22}$$

$$\frac{\partial s_2^*}{\partial r_i} = \frac{1}{\beta}\left[\frac{\partial^2 \Pi_2}{\partial s_1 \partial s_2}\frac{\partial^2 \Pi_1}{\partial s_2 \partial r_i} - \frac{\partial^2 \Pi_1}{\partial s_1^2}\frac{\partial^2 \Pi_2}{\partial s_2 \partial r_i}\right].$$

(22) enters the determination of equilibrium R&D. The reaction functions with respect to R&D are denoted by h_i:

(23) $$h_1(\cdot)=\frac{\partial\Pi_1^*}{\partial r_1}=\frac{\partial\Pi_1}{\partial s_1}\frac{\partial s_1^*}{\partial r_1}+\frac{\partial\Pi_1}{\partial s_2}\frac{\partial s_2^*}{\partial r_1}+\frac{\partial\Pi_1}{\partial r_1}=\frac{\partial\Pi_1}{\partial s_2}\frac{\partial s_2^*}{\partial r_1}+\frac{\partial\Pi_1}{\partial r_1}=0,$$

$$h_2(\cdot)=\frac{\partial\Pi_2^*}{\partial r_2}=\frac{\partial\Pi_2}{\partial s_1}\frac{\partial s_1^*}{\partial r_2}+\frac{\partial\Pi_2}{\partial s_2}\frac{\partial s_2^*}{\partial r_2}+\frac{\partial\Pi_2}{\partial r_2}=\frac{\partial\Pi_2}{\partial s_1}\frac{\partial s_1^*}{\partial r_2}+\frac{\partial\Pi_2}{\partial r_2}=0.$$

Total differentiation leads to

(24) $$dh_1=\frac{\partial^2\Pi_1^*}{\partial r_1^2}dr_1+\frac{\partial^2\Pi_1^*}{\partial r_1\partial r_2}dr_2+\frac{\partial^2\Pi_1^*}{\partial r_1\partial\alpha_1}d\alpha_1=0,$$

$$dh_2=\frac{\partial^2\Pi_2^*}{\partial r_1\partial r_2}dr_1+\frac{\partial^2\Pi_2^*}{\partial r_2^2}dr_2+\frac{\partial^2\Pi_2^*}{\partial r_2\partial\alpha_1}d\alpha_1=0.$$

Before turning to comparative statics results, a closer inspection of the derivatives of the indirect profit function is helpful for pronouncing the high degree of complexity and ambiguity in three-stage games. Since the structure of the game implies

$$\frac{\partial\Pi_1}{\partial s_1}=\frac{\partial\Pi_2}{\partial s_2}=0,$$

the derivatives of the indirect profit functions are

(25) $$\frac{\partial^2\Pi_1^*}{\partial r_1^2}=\frac{\partial^2\Pi_1}{\partial s_1\partial r_1}\frac{\partial s_1^*}{\partial r_1}+\frac{\partial^2\Pi_1}{\partial s_2\partial r_1}\frac{\partial s_2^*}{\partial r_1}+\frac{\partial\Pi_1}{\partial s_2}\frac{\partial^2 s_2^*}{\partial r_1^2}+\frac{\partial^2\Pi_1}{\partial r_1^2}<0$$

(26) $$\frac{\partial^2\Pi_1^*}{\partial r_1\partial r_2}=\frac{\partial^2\Pi_1}{\partial s_1\partial r_2}\frac{\partial s_1^*}{\partial r_1}+\frac{\partial^2\Pi_1}{\partial s_2\partial r_2}\frac{\partial s_2^*}{\partial r_1}+\frac{\partial\Pi_1}{\partial s_2}\frac{\partial^2 s_2^*}{\partial r_1\partial r_2}+\frac{\partial^2\Pi_1}{\partial r_1\partial r_2}$$

(27) $$\frac{\partial^2\Pi_1^*}{\partial r_1\partial\alpha_1}=\frac{\partial^2\Pi_1}{\partial s_1\partial\alpha_1}\frac{\partial s_1^*}{\partial r_1}+\frac{\partial^2\Pi_1}{\partial s_2\partial\alpha_1}\frac{\partial s_2^*}{\partial r_1}+\frac{\partial\Pi_1}{\partial s_2}\frac{\partial^2 s_2^*}{\partial r_1\partial\alpha_1}+\frac{\partial^2\Pi_1}{\partial r_1\partial\alpha_1}$$

(28) $$\frac{\partial^2\Pi_2^*}{\partial r_1\partial r_2}=\frac{\partial^2\Pi_2}{\partial s_1\partial r_1}\frac{\partial s_1^*}{\partial r_2}+\frac{\partial\Pi_2}{\partial s_1}\frac{\partial^2 s_1^*}{\partial r_1\partial r_2}+\frac{\partial^2\Pi_2}{\partial s_2\partial r_1}\frac{\partial s_2^*}{\partial r_2}+\frac{\partial^2\Pi_2}{\partial r_1\partial r_2}$$

(29) $$\frac{\partial^2\Pi_2^*}{\partial r_2^2}=\frac{\partial^2\Pi_2}{\partial s_1\partial r_2}\frac{\partial s_1^*}{\partial r_2}+\frac{\partial\Pi_2}{\partial s_1}\frac{\partial^2 s_1^*}{\partial r_2^2}+\frac{\partial^2\Pi_2}{\partial s_2\partial r_2}\frac{\partial s_2^*}{\partial r_2}+\frac{\partial^2\Pi_2}{\partial r_2^2}<0$$

(30) $$\frac{\partial^2\Pi_2^*}{\partial r_2\partial\alpha_1}=\frac{\partial^2\Pi_2}{\partial s_1\partial\alpha_1}\frac{\partial s_1^*}{\partial r_2}+\frac{\partial\Pi_2}{\partial s_2}\frac{\partial^2 s_1^*}{\partial r_2\partial\alpha_1}+\frac{\partial^2\Pi_2}{\partial s_2\partial\alpha_1}\frac{\partial s_2^*}{\partial r_2}+\frac{\partial^2\Pi_2}{\partial r_2\partial\alpha_1}$$

(25) and (29) must be negative in order to ensure that the necessary conditions for an optimal R&D level are also sufficient. (26) and (28) are negative (positive) if R&D levels are strategic substitutes (complements). If they are strategic substitutes (complements), an increase in one firm's R&D level implies a decrease (increase) in the other firm's R&D level (note that the model is still general and R&D may stand for research and development or environmental quality). (25) to (30) demonstrate that the derivatives in (24) are not easy to determine and that different effects are likely to make these derivatives ambiguous in sign, if, for example, second-order changes of the equilibrium market strategies are considered. Hence, these derivatives cannot be interpreted such straightforwardly as it was possible for (9) in the two-stage game.

The standard comparative statics results hold if the effect of own R&D changes are stronger than those of the other firm. This condition is fulfilled if (31) holds:

$$\text{(31)} \qquad \gamma := \frac{\partial^2 \Pi_1^*}{\partial r_1^2}\frac{\partial^2 \Pi_2^*}{\partial r_2^2} - \frac{\partial^2 \Pi_2^*}{\partial r_1 \partial r_2}\frac{\partial^2 \Pi_1^*}{\partial r_1 \partial r_2} > 0.$$

Then, one is able to determine the change of the R&D of the other firm as a response to policy variations:

$$\text{(32)} \qquad \frac{dr_2}{d\alpha_1} = \frac{1}{\gamma}\left[\frac{\partial^2 \Pi_2^*}{\partial r_1 \partial r_2}\frac{\partial^2 \Pi_1^*}{\partial r_2 \partial \alpha_1} - \frac{\partial^2 \Pi_1^*}{\partial r_1^2}\frac{\partial^2 \Pi_2^*}{\partial r_2 \partial \alpha_1}\right]$$

It is not necessary to determine $dr_1/d\alpha_1$ for similar reasons as in the previous section. The impact of regulation on the domestic firms profits is given by (33):

$$\text{(33)} \qquad \frac{d\Pi_1}{d\alpha_1} = \frac{\partial \Pi_1}{\partial s_2}\frac{\partial s_2^*}{\partial r_2}\frac{dr_2}{d\alpha_1} + \frac{\partial \Pi_1}{\partial r_2}\frac{dr_2}{d\alpha_1} + \frac{\partial \Pi_1}{\partial \alpha_1}.$$

(33) makes use of two properties: first, the change of profits of firm 1 may be simplified by the property that the first derivative with respect to the own strategy level is zero, second, one may use (23) to substitute for the first derivative with respect to own R&D, such that only the effect on the other firm's R&D prevail. Due to Pigouvian regulation, i.e.

$$\frac{\partial \Pi_i}{\partial \alpha_i} = \frac{\partial P_i}{\partial \alpha_i}$$

the effect on welfare is

$$(34) \qquad \frac{dW_1}{d\alpha_1} = \frac{\partial \Pi_1}{\partial s_2}\frac{\partial s_2^*}{\partial r_2}\frac{dr_2}{d\alpha_1} + \frac{\partial \Pi_1}{\partial r_2}\frac{dr_2}{d\alpha_1}.$$

(34) shows that the welfare effect depends only on the reaction of the foreign firm's equilibrium market strategy to the foreign firm's R&D and the reaction of the foreign firm's R&D to the policy variation. The first term gives the direct effect through the strategic market interaction, the second term gives the spillover effect. From (34), one may conclude that the incentive to introduce a certain policy does not depend on the effects on the home country's behavior but only on the changes of the foreign firm's behavior.

In the case of no spillovers, welfare and profit changes are

$$(35) \qquad \frac{dW_1}{d\alpha_1} = \frac{\partial \Pi_1}{\partial s_2}\frac{\partial s_2^*}{\partial r_2}\frac{dr_2}{d\alpha_1}, \quad \frac{d\Pi_1}{d\alpha_1} = \frac{\partial \Pi_1}{\partial s_2}\frac{\partial s_2^*}{\partial r_2}\frac{dr_2}{d\alpha_1} + \frac{\partial \Pi_1}{\partial \alpha_1}$$

From (35), one can see that it is possible that both profits are increased and environmental damage is decreased. Since it is known that in the case of strategic substitutes (complements)

$$\frac{\partial \Pi_1}{\partial s_2} < (>) 0$$

holds, one finds that if

$$\frac{\partial s_2^*}{\partial r_2}\frac{dr_2}{d\alpha_1} < (>) 0,$$

social welfare increases and profits might increase as well if the strategic effect is stronger than the direct cost effect. The reason is that research and development or the specification of the environmental quality introduces a good deal of ambiguity. As (25) to (30) have shown, a lot of effects can be at work which work in opposite directions or are even themselves ambiguous in sign. This feature holds even for a very simple example which will now be presented. The example can also be found in Ulph (1994).

The example assumes constant unit costs and strategic substitutes in the product market. The environmental problem is simple: if there is no regulation, harmful emissions are released which are equal to production. If whatever regulation is introduced, the firm faces an additional cost to production costs. However, it is able to decrease this part of the constant costs by R&D which is research and development in this model. (36) gives the unit cost function of a firm:

$$(36) \qquad c_i = \overline{c_i} + \alpha_i e_i(r_i), \qquad e_i' < 0,\ e_i'' > 0,$$

$$e_i(0) > 0, \qquad \lim_{r_i \to \infty} e_i(r_i) = 0$$

Due to (36), unit costs consist of a constant term and the shadow price imposed by regulation which can be decreased by an emission abatement technology whose costs can be decreased by R&D. The assumption of constant unit costs is very constructive because several second-order effects which would have to be considered under increasing marginal costs are equal to zero. Additionally, the assumption of innovation activities in the second stage is very helpful since it ensures that there are no R&D effects on the demand side. The problem would be rather more complex, if one assumed instead that firms determine environmental quality (in reaction to regulation) which affects both costs because a higher quality implies higher R&D costs and sales because a higher quality faces a higher willingness to pay on the consumer side.

The assumption of strategic substitutes, i.e. $s_i = x_i$, leads to profits of

$$(37) \qquad \Pi_i = p_i(x_1, x_2)x_1 - \left[\overline{c_i} + \alpha_i e_i(r_i)\right]x_i - r_i.$$

Profits are a function of the individual demand function p_i with negative derivatives with respect to both firms' production x_1 and x_2, the firm's production and R&D. Another helpful property of this model is that β does not depend on α_i and r_i. This property simplifies the determination substantially, in particular the determination of the derivatives of the equilibrium market strategies. Note that this nice property does not hold for the twin model of strategic complements. Hence, the degree of complexity is already tremendously increased when this simple model is taken to investigate price competition.

This simple model implies that several terms in (25) to (30) can be set equal to zero. One finds that the equilibrium output of the opponent is increased when the opponent increases its research and development:

$$(38) \qquad \frac{\partial x_2^*}{\partial r_2} = -\frac{1}{\beta}\frac{\partial^2 \Pi_1}{\partial x_1^2}\frac{\partial^2 \Pi_2}{\partial x_2 \partial r_2} > 0.$$

It can be shown that $\partial^2\Pi_2/\partial x_2\partial r_2$ is positive for this model such that an unambiguous sign can be determined. The unambiguous sign of (38), however, cannot avoid that the response of the opponent's research and development to a change in the policy parameter, i.e.

$$(39) \qquad \frac{dr_2}{d\alpha_2} = \frac{1}{\gamma}\frac{\partial^2 \Pi_2^*}{\partial r_1 \partial r_2}\frac{\partial^2 \Pi_1^*}{\partial r_1 \partial \alpha_1},$$

is ambiguous. On the one hand, the sign of (39) is determined by (40) which is unambiguously negative:

$$(40) \qquad \frac{\partial^2 \Pi_2^*}{\partial r_1 \partial r_2} = \frac{\partial^2 \Pi_2}{\partial x_1 \partial r_1}\frac{\partial x_1^*}{\partial r_2} < 0.$$

(40) shows that the levels of research and development are strategic substitutes in this model since an increase in one firm's R&D makes the other firm decrease its R&D. On the other hand, the sign of (39) is determined by (41) which is ambiguous in sign:

$$(41) \qquad \frac{\partial^2 \Pi_1^*}{\partial r_1 \partial \alpha_1} = \frac{\partial^2 \Pi_1}{\partial x_1 \partial \alpha_1}\frac{\partial x_1^*}{\partial r_1} + \frac{\partial \Pi_1}{\partial x_2}\frac{\partial^2 x_2^*}{\partial r_1 \partial \alpha_1} + \frac{\partial^2 \Pi_1}{\partial r_1 \partial \alpha_1}$$

It can be shown that the second product and the third term are positive in sign and that the first product is negative in sign. The reason for the ambiguity is that different effects are at work as it was shown in Figure 1. The direct effect of stricter regulation increases the costs of the domestic firm, and since the productivity of R&D is decreased because output is decreased, an additional indirect effects increases costs further. Although these two effects increase the costs as a reaction to stricter regulation, the third effect decreases costs. This effect decreases costs because an increase in R&D decreases the regulatory burden. If this effect is dominant, costs are decreased and profits can be increased if the cost reduction effect is stronger than the direct cost effect caused by additional R&D. From (35), one may find that $dW_1/d\alpha_1$ is positive and $d\Pi_1/d\alpha_1$ might be positive as well, if $dr_2/d\alpha_1$ is negative. But the example demonstrates that even in a very specific model the effects are rather ambiguous such that a general validity of the Porter Hypothesis can not be concluded. This result is pronounced by the fact that the twin model of price competition leads to ambiguity already at a very early stage of the model as it was mentioned above.

5 Environmental policies, free market entry and the location of industries

The beneficial effect of strategic environmental policies was not only due to the assumption that the other country does not react. Additionally, the assumption of no market entry and the assumption of no relocation of a firm was decisive for the result. This section will discuss informally the effects of relaxing these assumption.

If market entry were free, the market equilibrium would be determined by the condition that an additional firm entering would suffer losses. If firms have to carry fixed costs in order to be able to enter the market, the market structure is oligopolistic since the market is able to carry the fixed costs only of a certain number of firms. In this case, strategic policies are no longer able to alter the profits of a domestic industry since profits are always equal to zero in equilibrium. Under free market entry, strategic effects vanish and any environmental policy would be determined only by the effects of industry production on pollution.

If firms were able to move to those countries with a lax environmental regulation, one might believe that a polluting industry should be concentrated in those countries imposing the laxest environmental regulation. This assumption might become true; however, there are certain effects which may prevent this extreme outcome. First, firms have to invest when building up a new production site. When considering to move, they take these set up costs into account. These costs are in most cases sunk for the current location such that they compare the benefits of moving minus the set up costs with the benefits of staying in the home country. Only if the benefits of moving are very high compared to no relocation, a firm can be expected to move. If the differences are small, a firm will not move because the lax environmental regulation would not compensate for the set up costs.

Second, environmental regulation patterns are not always specified in a way that they treat every firm alike independent of the number of polluting firms. Consider for example a certain quality standard for ambient air which is polluted by emissions released by the firms of a certain industry. Suppose that the foreign country has introduced a lower quality standard than the home country, and that the number of firms in the foreign country is equal to the number of firms in the home country in the beginning. If a certain number of firms moves to the foreign countries, two effects can be observed: first, it will become harder for all firms in the foreign country to meet the quality standard. Thus, the benefits of moving are reduced by movement; and if the firms moving have to carry overproportional efforts to meet the standards compared to foreign firms in the foreign country, these benefits are even more strongly reduced by movement. Second, the remaining firms can meet the stricter domestic standard more easily which makes movement less profitable. From both effects, it is easy to see that not all firms can be expected to move, and that cases are possible in which even no firm moves despite the stricter regulation. If the market is not open for market entry and regulation is not to different in order to imply relocation of plants, the effects of the last section may be also observed.

6 Conclusions

This paper has shown that strategic environmental policy is in fact industrial policy. The incentive to regulate stricter or laxer depends on the type of competition and the multiple effects of research and development or environmental quality specification. In the simple model, the Porter Hypothesis can never hold because either profits and damages are increased or both are decreased. It is possible to increase profits and to decrease damage in extended models but this result relies on rather artificial assumptions. In general, the effect is ambiguous, and the incentive of strategic policies depends only on the reaction of the opponent to a changed domestic regulation.

Furthermore, it is well known that all these effects do only hold if the foreign country does not react. If it reacts, both countries will be in a prisoners' dilemma situation and hence worse off compared to Pigouvian environmental policies. Therefore, any strategic policy can be successful only if there are good reasons to assume that the other country will not react. If it does, the result will be worse and the Porter Hypothesis cannot hold even under the artificial assumptions to be made for unilateral strategic policies. Since strategic policies are in fact industrial polices and the effect on the consumer side was ignored, the best cooperative policy for both countries would be to promote merger of both firms. Since merger implied monopolization, joint profits would be maximized. This result shows that the results of this paper are valid only if consumer effects can be ignored. If they cannot be ignored, the incentives can be different because significant consumer rent effects can initiate a policy which intends to increase the production levels. Hence, considering consumer effects will further increase the degree of ambiguity in strategic environmental policy models.

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