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Competitiveness and environmental policies in a dynamic model

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Abstract: This paper discusses the issue of competitiveness and environmental regulation in a dynamic framework. It presents an example and a general model. It is shown that the dynamic framework cannot lend general support to the hypothesis that strict environmental policies result in an increase in competitiveness. Instead, the paper shows that the dynamization of the model adds further ambiguity to the results of the static models as they were discussed in Stähler (1998).

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Competitiveness and environmental policies in a dynamic model

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 dynamic aspects of this discussion. Other chapters on intersectoral effects in a general equilibrium framework and on the contribution of the theory of strategic environmental policies can be found in the Kiel Working Papers No. 857 and 858, respectively. We gratefully acknowledge financial support by the Fritz Thyssen Foundation.

1 Introduction

Stähler (1998) discussed models of strategic environmental policies. These models have dealt with research and development only in terms of a strategic decision which precedes the strategic decision of firms in the marketplace. From that perspective, investment in research and development does not differ from the specification of environmental quality or any other quality decision of a producer. It has been shown in Stähler (1998) that the results are rather ambiguous on a general level and that the Porter Hypothesis is far away from being able to be supported in general. However, one may think of the Porter Hypothesis not only as a static strategic result but also as a long-run forecast. In this case, the role of research and development has to be considered in a dynamic framework.

In this paper, we will consider the problem from such a dynamic perspective, taking into account that the choice of a technology is not only a function of current investment but a function of all previous investment decisions. This assumption allows us to discuss the potential long-run effects of a unilateral environmental policy on the competitive position of an industry. Even more, this dynamic framework is able to capture the Porter Hypothesis properly since it was obviously Porter's intention to emphasize the long-run effects of strict environmental policies. Therefore, the discussion of the Porter Hypothesis can not be restricted to static models.

The discussion of research and development has meanwhile a long tradition in economics. Since the pathbreaking paper of Solow (1957), a lot of papers have dealt with the role of research of development for both the behavior of an industry and the wealth of a country. Solow found out that the huge part of productivity growth in the United States could not be explained by physical capital accumulation. Hence, the formation of human capital and successful research and development are now considered as crucial for the growth of an economy. From this perspective, the Porter Hypothesis can be seen as a long-run forecast that a strict environmental policy leads to an increased level of research and development which increases the wealth of a country in the long run.

Following Solow's paper, the discussion of research and development has been a main issue in the industrial organization literature (see any textbook, for example Tirole, 1988 or Martin, 1993). The reason for this development is that research and development done by a firm implies substantial strategic effects. Some of them were already mentioned in Stähler (1998). If a firm is successful in research and development, it may be able to reduce competition in a sector or even monopolize the market. Several features can be observed in markets which are subject to research and development. First, the profitability of research and development depends on the degree of appropriability of the success of research and development. If a firm is only able to appropriate a part of the success, the incentive to do research and development is decreased. This might be the case if an invention can be copied by other firms without compensation or if the invention is a public good. Second, different types of competition may be distinguished. On the one hand, research and development of different technological firms may lead to success of more than one of them because, for example, different technological opportunities may exist for improving a certain technology. On the other hand, only one successful option may exist such that the winner is able to take the whole market when he is the first one to be successful.

In general, it is not known whether there is too much or too little research and development. Too little research and development can be expected if a certain market is monopolized since a monopolist increases competition with himself by a high degree of research and development (Arrow, 1962). Additionally, a substantial spillover effect reduces the incentive for research and development. If only one firm can win a research and development race, it is known that expenditures are too high compared to the socially optimal level because the prospect to monopolize a market makes it profitable for each firm to spend a large amount on research and development.

Due to the different possible strategic interactions, it is not easy to deal with research and development on a rather general level (for an overview, see Reinganum, 1984). In this paper, we will therefore assume that research and development will reduce environmental compliance costs of a certain firm deterministically. By this assumption, we are able to focus on the long-run effects of stricter environmental policies which are claimed to be beneficial by the Porter Hypothesis. This paper is organized as follows. Section 2. will present a specified dynamic model which is able to demonstrate the effects of strict environmental policies in a dynamic framework. It will be shown that a general validity of the Porter Hypothesis can also not be concluded in this model. Since the model is very specific, Section 3 will present a more general treatment of the Porter Hypothesis in dynamic models. Obviously, a more general treatment will not be able to resolve the ambiguity a specified model produces. But this general model will also show the additional effects assumed by the Porter Hypothesis in a general setting which cannot be captured by the static approach as it was discussed in Stähler (1998). However, it will also be shown that the dynamic model does not differ substantially from the static model except for these effects. Section 4 will conclude.

2 A specified dynamic model

This section will present a numerical example in order to discuss the potential validity of the Porter Hypothesis in a dynamic setting. The numerical example assumes two countries which are able to introduce a certain environmental program. This program reduces a certain environmental damage and imposes costs to the firms. There are only two firms in a market, each in a different country, and market entry is not possible. These firms produce a certain homogeneous good and the sum of production determines the price to be realized by each firm. Table 1 summarizes the assumptions.

Table 1: Overview of the dynamic model

industry under consideration	one firm in each of the two countries, firms specify quantities	inverse market demand function: $p = 4 - [x_1 + x_2]$ cost function: $C_i = 0,5x_i^2$
environmental problem	emissions equal production without abatement	emission function: $E_i = x_i$
abatement option	end-of-pipe-technology	abatement costs: $D_i(t) = \frac{\rho_i(t)}{2} y_i^2$
Research and development	binary choice of pursuing a R&D program	costs of a R&D-program: $r_i(t) \in \{0;0,1\}$
effects of R&D	cost parameter ρ declines with the sum of R&D programs	$\rho_i(t) = \begin{cases} 1 - \sum_{\tau=0}^{t-1} r(\tau) & \text{for } \sum_{\tau=0}^{t-1} r(\tau) \leq 0.5 \\ 0.5 & \text{for } \sum_{\tau=0}^{t-1} r(\tau) > 0.5 \end{cases}$ $\rho(0) = 1$
environmental program	emission limit	$E_i \leq 0.5$
environmental policy behavior	balancing of benefits and the abatement cost parameter	$\hat{\rho}_1 = 1, \ \hat{\rho}_2 = 0.7$

The inverse demand function is linear. Without any abatement efforts, emissions are released in the same quantity as production. Abatement is possible and implies quadratic costs which depend on a technology parameter ρ as a function of time. This technology parameter can be changed by pursuing a research and development (R&D) program. The example assumes that a R&D program incurs costs of 0.1 if it is done (and, of course, zero costs if it is not). The assumption of a binary choice of either doing R&D or not will simplify the discussion of strategic options which a domestic firm has which is subject to a stricter environmental regulation. The R&D program has a deterministic effect: it lowers the technology parameter ρ in the next period. Hence, a program done today shifts the abatement cost function down for tomorrow. This shift, however, is restricted such that only five programs can be successful and that any further program has no effect on the technology parameter. Figure 1 shows the behavior of the technology parameter with the sum of R&D programs.

Figure 4.1: Reduction costs as a function of aggregated R&D programs

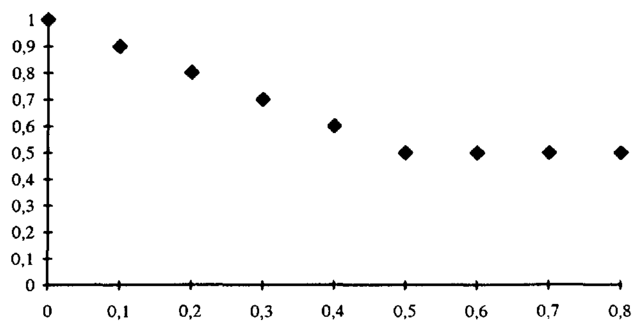

Figure 1 shows that any further R&D program is useless when already five programs have been undertaken. The effect of R&D is deterministic in this model. The results would not change substantially if they were subject to uncertainty and Figure 1 gave the expected reduction of the technology parameter. But the analysis would be more involved since it had to be taken into account that R&D could fail in a certain period and that therefore plans have to be revised.

The environmental program introduced by the government is assumed to imply a certain emission limit such that the emission of the firm should not exceed 0.5. Due to the specification of the demand and the cost function and the assumption that unregulated emissions are equal to production, this constraint is binding if the environmental program is introduced. Without any regulation, the production and emission level of each firm would be unity, given that each firm maximizes the current profits in each period.

The environmental policy behavior is assumed to be very simple: the environmental program is assumed to imply certain environmental benefits, and it implies certain costs for the industry. The policy makers are assumed to decide simply on the basis of a critical technology parameter. This critical technology parameter is an indicator how far the industry is supposed to be able to carry the burden of regulation. They are assumed to decide on the basis of the current parameter, and in order to create a problem of stricter environmental policies, country 1 assumes a critical parameter of unity and country 2 assumes a critical parameter of 0.7. These assumptions imply that country 1 will introduce the environmental program but country 2 will not. This assumed behavior might found to be too simplistic. However, we already employ a specified model and we are interested in first insights of the chances of the Porter Hypothesis. Hence, we may employ a simple decision rule to make the basic effects clear. The next section will employ a more sophisticated and proper decision rule which takes into account the intertemporal effects.

In addition to those features of the model given by Table 1, further assumptions are the following:

- Country 2 will introduce the environmental program as well if ρ has been reduced to 0.7.

  This assumption ensures that country 2 will follow country 1 if the technology parameter has been reduced to 0.7. If it is possible for the foreign firm to buy the abatement technology for this technology level, it will be forced to do so.

- A firm is able to sell an abatement technology to another firm for a price which surmounts the factual abatement costs.

This assumption ensures that the domestic firm can make profits with selling the technology. Since the lowest value which the technology parameter can reach is 0.5, the difference to 0.7 may be realized. One may think of this abatement technology as a separate unit of the plant which is run by the seller.

- Each firm maximizes its current profits.

  This assumption determines the behavior of each firm in the product market. It is not so obvious as it seems at first glance. Since the firms compete against each other not only once but always, it is well known that other than the non-cooperative equilibria of a single-stage game may give an equilibrium (see, for example, Fudenberg, Maskin, 1986). The so-called Folk Theorem proved that all rational and attainable outcomes may be the result of a game which repeats the singe-stage games infinitely. Here, we assume that the behavior of each firm is purely non-cooperative. This assumption is constructive also because here we find no repeated but a dynamic game (if R&D programs are introduced) for which the Folk Theorem does not hold in general as for repeated games (see Dutta, 1995, Stähler, Wagner, 1998).

- The foreign firm does not do own research and development.

  In general, firm 2 could also invest in research and development in order to reduce the technology parameter. This option will be ignored, and it can be shown easily for this model that this option is very unlikely to be profitable for firm 2.

When country 1 introduces the environmental program and country 2 does not, firm 1 faces three options:

- According to Option I, firm 1 reduces the abatement cost parameter until it is minimized. Since it makes no sense to delay such a policy, this will be done in the first periods after which this technology parameter has reached the intended level. For the sake of simplicity, we will restrict our attention to a policy which implies abatement cost minimization. It can be shown easily for this model that the technology parameter will be reduced to 0.5 (and not only to 0.6) in most cases if firm 1 intends to make profits with selling the technology.

- According to Option II, firm 1 reduces the technology parameter only to 0.7 in order to imply environmental regulation also in the other country. For the same reason as for Option I, this policy will be carried out in the first three periods. In this case, firm 1 is not able to make profits with selling the technology, but implies that the cost structure is the same for both firms after 0.7 has been reached by the technology parameter.
- According to Option III, firm 1 accepts the disadvantage due to unilateral environmental policies and refrains from any R&D program. In that case, the symmetric duopoly is changed into an asymmetric one in which firm 1 has to carry higher costs per production. We will restrict our attention to this option and will not discuss policies which reduce the technology parameter to 0.9 or 0.8, i.e. policies which do not imply the introduction in the other country but nevertheless a decrease in the technology parameter.

Table 2 gives the profits implied by Options I and II.

Table 2: Profits for options I and II

period	Option I: R&D programs until abatement costs are minimized					Option II: R&D programs until country 2 introduces the environmental program as well			
	ρ_1	ρ_2	Π_{1-}	Π_{1+}	Π_2	ρ_1	ρ_2	Π_1	Π_2
0	1	0	1.1882		1.6271	1	0	1.1882	1.6271
1	0.9	0	1.203		1.6182	0.9	0	1.203	1.6182
2	0.8	0	1.2188		1.6087	0.8	0	1.2188	1.6087
3	0.7	0	1.2357		1.5986	0.7	0	1.3357	1.5986
4	0.6	0.7	1.3555	0.0471	1.4259	0.7	0.7	1.4375	1.4375
5 ff.	0.5	0.7	1.4749	0.0921	1.4134	0.7	0.7	1.4375	1.4375

Notes: Π_{1-} denotes the profits of firm 1 in the commodity market, Π_{1+} denotes the profits realized by selling the abatement technology. ρ_1 and ρ_2 denote the state of the abatement technology employed by the respective firm. If $\rho_2 = 0$, firm 2 is not (yet) subject to any environmental regulation. Without any regulation the profits are $\Pi_1 = \Pi_2 = 1.5$.

If firm 2 decides for Option III, i.e. no R&D programs, the technology parameters and the profits for all periods are

(1) $\rho_1 = 1, \rho_2 = 0, \Pi_1 = 1.2882, \Pi_2 = 1.6271.$

Based on Table 2 and (1), one may now compute the sum of discounted profits of all three options in order to compare their relative profitability. Three computations for three different discount factors are shown in Table 3. The discount factor measures the time preference and depends on the time which elapses between subsequent periods. The longer the delay between investment in research and development and the effect on the technology parameter, the lower is the discount factor.

Table 3: Comparison of options for different discount factors by the sum of discounted profits

Discount factor	Option I	Option II	Option III
0.5	2.425777	2.441067	2.576446
0.75	5.152893	5.158882	5.126208
0.9	13.75721	13.66333	12.88223

From Table 3, we see that a sufficiently high discount factor is able to imply Option I. In this case, it pays for firm 1 to reduce the technology parameter to its minimum and to sell the abatement technology. When the discount factor is decreased, Options II and III become more profitable. Hence, we see already in this simplistic model that a stricter environmental policy does not necessarily increase the profits of the domestic firm in the long run. Additionally, Table 3 shows that the sum of discounted profits is about 13.76 for Option I for a discount factor of 0.9. Due to Table 2, the current profits without regulation are 1.5, and hence the sum of discounted profits without regulation for a discount factor of 0.9 is 15. Thus, the optimistic variant of the example shows only that the current profits of the domestic firm increase in the course of time due to research and development (after they have been decreased by regulation). But environmental regulation leads also to a decrease in the firm's value (measured by the sum of discounted profits) of about 1.24. From this example, we can therefore not conclude that profits are increased in absolute terms but in the best case in relative terms in future periods.

Additionally, all these results rely on very crucial requirements:

- The domestic firm cannot move.

  This assumption is crucial for this model because the sum of discounted profits is less under environmental regulation than without regulation. If the domestic firm could move, it would do so and increase its value by 1.24 in the case of a discount factor of 0.9.

- The firm must be able to commercialize the results of research and development.

  It must be guaranteed that the foreign firm is not able to copy the technology developed by firm 1 without compensation. This requirement is met if either research and development are embodied in human capital or the intellectual property rights of firm 1 are accepted by country 2. It is well known that the international acknowledgement of intellectual property rights is not guaranteed because country 2 would benefit from a technology transfer without compensation.

- Research and development must be carried by a domestic firm or by a domestic supplier of environmentally friendly technologies.

  If the technology is developed in another country, the additional profits will not be realized in the domestic industry. Hence, the profits from selling the technology are given only if no foreign firm is able to develop the technology.

If one of these requirements is violated, the optimistic result cannot become true.

Until now, the environmental benefits have not yet been considered. Even if profits are decreased and the technology is not sold, the net benefits of introducing the environmental program may be positive. But this possibility does not prove the Porter Hypothesis since this hypothesis claims that both the firm's profits and the environmental benefits are increased. Additionally, the whole analysis relies on a simple reaction mechanism of the other country. From these results, one may conclude that only special circumstances may imply a positive effect of stricter environmental policies on a domestic industry's performance in the long run.

3 A general dynamic model

The last section has discussed a specified and simplistic example of the potential long-run effects of strict unilateral environmental policies. This section will generalize the approach in order to pronounce the differences between this dynamic approach and the static models. It will discuss a dynamic two-period model in which the R&D decisions affect the profits of both firms in the second period. Table 4 gives the general structure of this model which assumes also two firms in two different countries.

Table 4: A dynamic approach

Period	Move
First stage	Government specifies environmental regulation.
Second stage	Firms specify research and development.
Third stage	Firms specify their market strategies for period 0.
Fourth stage	Firms specify their market strategies for period 1.

In order to simplify the analysis, the model assumes that there are no direct spillover effects of one firm's R&D to the other firm's profits. Additionally, it is assumed that each firm is able to appropriate its own R&D by selling, for example, an advanced technology on the market. A decisive assumption of the Porter Hypothesis is that green technologies and/or green products will have an increasing market share in the future. Since environmental problems are due to the public bad property of environmental degradation, it should be clear that this increasing market share must originate from political demand, i.e. from stricter environmental regulation by other countries in the course of time. In the model, we will capture this idea by a political response function for the second period:

$$(2) \qquad \hat{\alpha}_2(\alpha_1), \qquad \frac{d\hat{\alpha}_2}{d\alpha_1} > 0, \qquad \hat{\alpha}_2\left(\alpha_1^{Pigou}\right) = \alpha_2^{Pigou}$$

(2) gives the degree of regulation by country 2 in the second period as a function of the degree of regulation in country 1. We assume that regulation does not differ between periods for country 1 but that country 2 adjusts its policy for the second period as a response to the strictness of environmental policies in country 1. If country 1 introduces Pigouvian regulation (denoted by the superscript Pigou), country 2 will do as well. We will determine Pigouvian regulation soon, and we will assume in a first step that both countries introduce Pigouvian regulation. For this case, country 2 will not change its regulation in the second period, but if country 1 imposes a stricter regulation, a stricter regulation will be implied by country 2 in the second period. Starting from overall Pigouvian regulation, one may then explore the incentives of country 1 to make environmental regulation marginally stricter.

The profits of both firms are given by (3).

$$(3) \qquad \Pi_1 = \pi_1[s_1(0), s_2(0), r_1, \alpha_1] + \delta\pi_1[s_1(1), s_2(2), r_1, \alpha_1, \hat{\alpha}_2(\alpha_1)],$$

$$\Pi_2 = \pi_2[s_1(0), s_2(0), r_2, \alpha_2] + \delta\pi_2[s_1(1), s_2(2), r_2, \hat{\alpha}_2(\alpha_1)].$$

(3) shows that the profits are the sum of discounted profits over two period. One may consider the second period as comprising all future periods. The current profits are denoted by π. $s_i(t)$ denotes the market strategy level of firm i in period t, α_i denotes the level of environmental regulation in county i and r_i denotes the level of research and development of firm i. We assume that research and development incurs costs in the first period and increases profits by environmental compliance cost reduction in the second period. Additionally, the reaction of country 2 to country 1's policy specification has different impacts on both firms. Since we restrict our attention to a stricter policy, an increase in $\hat{\alpha}_2$ benefits firm 1 because firm 1 is now able to sell at least a part of its technology to firm 2. Conversely, this increase decreases firm 2's profits because it is now forced to more environmental protection.

Pigouvian regulation means in this case that each country chooses a regulation level for both periods which maximizes total welfare. Total welfare is defined by the difference between the firm's profits and the environmental damage, denoted by P for pollution:

$$(4) \qquad \frac{\partial W_i}{\partial \alpha_i} = \frac{\partial \Pi_i}{\partial \alpha_i} - \sum_t \delta^t \frac{\partial P_i(t)}{\partial \alpha_i} = 0$$

Similar definitions and assumptions were given in Stähler (1998). (2) to (4) imply a strategic game between both firms which can be influenced by country 1. Due to Table 4, the countries move first by specifying the degree of environmental regulation. (2) implies that only country 1 has a strategic option since country 2 is supposed to introduce Pigouvian regulation in the first period and a policy in the second period which responds to country 1's policy. By (2), it is therefore explicitly assumed that country 2 cannot behave strategically. This assumption is crucial and not without difficulty. If both countries could behave strategically, they would enter a prisoners' dilemma situation because both would gain by acting non-strategically but one country gains even more if it acts strategically given non-strategic behavior of the other country. Stähler (1998) has demonstrated this result which is prevented by assumption (2).

As in Stähler (1998), the game can be solved in the usual backward induction fashion. The first-order conditions with respect to the strategic variables are

$$(5)\qquad f_1^t(\cdot)=\frac{\partial\Pi_1}{\partial s_1(t)},\ f_2^t(\cdot)=\frac{\partial\Pi_2}{\partial s_2(t)}.$$

(5) gives four conditions since t denotes either period 0 or period 1. Note that we have not specified whether the market strategy variable is a price or a production level. We are therefore still rather general and the analysis will hold for both strategic substitutes and complements as they were introduced and explained in Stähler (1998). The conclusions of the last section's example were drawn on the basis of competition by strategic substitutes. (5) determines equilibrium strategy levels $s_i^*(t)$ which are a function of the research and development levels in the first period and the degree of environmental regulation. Under the use of these equilibrium strategy levels, we may now define indirect profit functions which determine the sum of discounted profits under the condition that (5) is fulfilled:

$$(6)\qquad \Pi_1^*(r_1,r_2,\alpha_1,\hat{\alpha}_2(\alpha_1)),\ \Pi_2^*(r_1,r_2,\alpha_2,\hat{\alpha}_2(\alpha_1))$$

(6) does only consider the regulation level of country 1 and the response of country 2 in the second period because (2) fixes the regulation level of country 2 for the first period. (6) determines the equilibrium profits which are possible in the last two stages of the game. In the second stage, both firms choose their R&D levels in order to maximize (6). The behavior on this stage is given by (7).

$$(7)\qquad g_1(\cdot)=\frac{\partial\Pi_1^*}{\partial r_1}=0,\qquad g_2(\cdot)=\frac{\partial\Pi_2^*}{\partial r_2}=0$$

We may then differentiate (7) totally with respect to both R&D levels and the environmental regulation in country 1. As a result we may derive a relationship between the marginal changes of firm 2's R&D to a marginal change of country 1's environmental regulation:

(8)

$$\frac{dr_2}{d\alpha_1}=\frac{1}{\gamma}\left[\frac{\partial^2\Pi_2^*}{\partial r_1\partial r_2}\left(\frac{\partial^2\Pi_2^*}{\partial r_1\partial\alpha_1}+\frac{\partial^2\Pi_2^*}{\partial r_1\partial\hat{\alpha}_2}\frac{d\hat{\alpha}_2}{d\alpha_1}\right)-\frac{\partial^2\Pi_1^*}{\partial r_1^2}\left(\frac{\partial^2\Pi_2^*}{\partial r_2\partial\alpha_1}+\frac{\partial^2\Pi_2^*}{\partial r_2\partial\hat{\alpha}_2}\frac{d\hat{\alpha}_2}{d\alpha_1}\right)\right]$$

(8) shows that this reaction is influenced substantially by the political response function (2). γ gives the product of the second derivatives of the indirect profit function with respect to its own market strategy variable minus the product of the second cross derivatives of the indirect profit functions. γ is assumed to be positive in order to guarantee that the effect of the own market strategy on own profits is larger than those of the opponent's market strategy. In Section 5 of Stähler (1998), it was shown that this is in fact just an assumption because it is not guaranteed by straightforward assumptions about the behavior of the basic profit functions.

Additionally, it was shown in Section 5 of Stähler (1998) that the sign of $dr_2/d\alpha_1$ cannot be determined in general. As Section 5 of Stähler (1998) employed a static model, the effect is obviously even more ambiguous in the setting of this paper because first effects are intertemporal (and therefore also influenced by the discount factor), and second the political response function enters expression (8) twice. (8) determines the change of profits of the domestic firm which is due to a stricter environmental policy:

(9)

$$\frac{d\Pi_1}{d\alpha_1}=\sum_t\frac{\partial\Pi_1}{\partial s_2(t)}\left(\frac{\partial s_2^*(t)}{\partial r_1}\frac{dr_1}{d\alpha_1}+\frac{\partial s_2^*(t)}{\partial r_2}\frac{dr_2}{d\alpha_1}\right)+\frac{\partial\Pi_1}{\partial r_1}\frac{dr_1}{d\alpha_1}+\frac{\partial\Pi_1}{\partial\alpha_1}+\frac{\partial\Pi_1}{\partial\hat{\alpha}_2}\frac{d\hat{\alpha}_2}{d\alpha_1}$$

We may ignore the first derivative with respect to the own market strategy levels due to the maximization carried out in (5). Since $\frac{\partial\Pi_1^*}{\partial r_1}=\sum_t\frac{\partial\Pi_1}{\partial s_2(t)}\frac{\partial s_2^*(t)}{\partial r_1}+\frac{\partial\Pi_1}{\partial r_1}=0$ due to (7), we may simplify (9):

$$(10)\qquad \frac{d\Pi_1}{d\alpha_1}=\sum_t \frac{\partial\Pi_1}{\partial s_2(t)}\frac{\partial s_2^*(t)}{\partial r_2}\frac{dr_2}{d\alpha_1}+\frac{\partial\Pi_1}{\partial\alpha_1}+\frac{\partial\Pi_1}{\partial\hat{\alpha}_2}\frac{d\hat{\alpha}_2}{d\alpha_1}$$

(10) shows that only the reaction of the opponent, the reaction of the other country and the direct cost effect of regulation are relevant for the change of profits. A similar result was demonstrated in Stähler (1998). Because we have chosen Pigouvian regulation to consider marginal increases in domestic environmental regulation, total differentiation of welfare under the use of (4) gives (11).

$$(11)\qquad \frac{dW_1}{d\alpha_1}=\sum_t \frac{\partial\Pi_1}{\partial s_2(t)}\frac{\partial s_2^*(t)}{\partial r_2}\frac{dr_2}{d\alpha_1}+\frac{\partial\Pi_1}{\partial\hat{\alpha}_2}\frac{d\hat{\alpha}_2}{d\alpha_1}$$

(11) shows that the total welfare effect depends only on the change caused by the market strategy reactions and the political response. The only general difference between this dynamic and the static models is the last term giving the political response. Since one may assume that increased regulation in the foreign country increases the domestic firm's profits because it is able to sell green technologies, this effect is positive if environmental regulation is marginally stricter than Pigouvian regulation. However, the first term is ambiguous and may have a negative sign. A negative sign can be produced by strategic substitutes and strategic complements since the R&D effect is totally unclear. Even if one could separate market strategy decision in the first stage from R&D decisions, the total effect remains ambiguous:

$$(12)\qquad \text{If } \frac{\partial s_1^*(0)}{\partial r_2}=0:\quad \frac{dW_1}{d\alpha_1}=\frac{\partial\Pi_1}{\partial s_2(1)}\frac{\partial s_2^*(1)}{\partial r_2}\frac{dr_2}{d\alpha_1}+\frac{\partial\Pi_1}{\partial\hat{\alpha}_2}\frac{d\hat{\alpha}_2}{d\alpha_1}.$$

From (11) and (12), we may conclude that the dynamic model produces ambiguity as well. Therefore, even the optimistic assumption (2) which excludes strategic behavior of the foreign country can not make a case for the Porter Hypothesis. Additionally, the political response function itself makes it harder to compute the reaction of the foreign firm's R&D to a stricter regulation since it changes the market behavior of firms.

4 Conclusions

This paper has discussed the Porter Hypothesis in a dynamic framework since this hypothesis was obviously intended as a long-run forecast. However, the dynamic framework could not support the Porter Hypothesis in general as well. The specified and simplistic example has demonstrated that the Porter Hypothesis may hold only under very artificial conditions. Even more, the example showed merely that the relative profits were increased in the course of time by strict domestic environmental policies, but the total value of the firm was decreased. Basically, the question is of empirical nature but the theoretical discussion has shown that a lot of conditions have to be fulfilled. In particular, we would like to stress three important factors which will obviously be also very relevant for the empirical discussion:

- The effect of strict environmental regulation is very involved and changes the market behavior of firms in an unpredictable way. It depends on the reaction of R&D to stricter environmental policies and the type of competition in the market. If there is free market entry and the possibility to move, the optimistic variant cannot become true.
- If a firm in a third country or a multinational firm develops the technology, the benefits of R&D cannot be realized.
- The success of R&D must be appropriable in order to give incentives to introduce a R&D program.

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