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Environmental policy under product differentiation and asymmetric costs – Does Leapfrogging occur and is it worth it?

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Abstract

This paper studies the influence of environmental policies on environmental quality, domestic firms, and welfare. Point of departure is Porter's hypothesis that unilateral environmental regulation may enhance the competitiveness of domestic firms. This hypothesis has recently received considerable support in theoretical analyses, especially if imperfectly competitive markets with strategic behavior on behalf of the agents are taken into account. Our work contributes to this literature by explicitely investigating the implications of asymmetric cost structures between a domestic and a foreign firm sector. We use a partial-equilibrium model of vertical product differentiation, where the consumption of a product causes environmental harm. Allowing for differentiated products, the domestic industry can either assume the market leader position or lag behind in terms of the environmental quality of the produced product. Assuming as a benchmark case that the domestic industry lags behind, we investigate the possibility of the government to induce leapfrogging of the domestic firm, i.e. a higher quality produced by the domestic firm after regulation than that of the competitor prior to regulation.

It is shown that in the case of a cost advantage for the domestic firm in the production process the imposition of a binding minimum quality standard can serve as a tool to induce leapfrogging. In case of a cost disadvantage the same result can be achieved through an adequate subsidization of quality dependend production costs. Thus, careful regulation enables the domestic firm in both scenarios to better its competitive position against foreign competitors and to earn larger profits. Additionally, environmental quality and welfare can be enhanced.

JEL-Classification: Q 2, L 1

1. Introduction

This paper investigates the impact of environmental policies on environmental quality, domestic firms, and welfare. Usually the goal of environmental policies is to protect the environment by imposing restrictions on firms and/or consumers. These policies are often critizised as it is claimed that the international competitiveness of domestic firms is reduced. However, in contrast to this cost biased argument Michael Porter formulated the hypothesis that environmental policies could also serve as a vehicle to enhance the competitiveness.

The objective of this paper is to investigate this conjecture in the context of a formal economic model under imperfect competition, in which firms undertake product differentiation and the government either regulates the environmentally harmful product properties or subsidizes the quality dependend production costs. Our analysis shows that there indeed situations exist, in which the policies can act as a credible lever for the domestic firms to change their behaviour and thus gain competitive advantages over foreign competitors.

However, even with these results in mind the intention of our analysis is not a recommendation to formulate a „strategic environmental policy“. The needed informational requirements on the side of the government would be extraordinary high. Instead our aim is to show that environmental policies must not necessarily go along with a loss of domestic firms‘ competitiveness, but that they can help in attaining two things, a healthier environment together with a strengthened domestic firm sector.

2. Environmental policy and international competitiveness

Since the early eighties there has been a lively debate concerning the question whether environmental policies will tend to harm the competitiveness of domestic enterprises engaged in international trade. Following the argument that international trade is mainly determined by comparative cost advantages, environmental policies would worsen the competitive position since they often are accompanied by cost increasing compliance efforts.

Porter (1991) was the first who claimed that such policies could actually be beneficial for the firms‘ performance despite the resulting extra costs. He argued that environmental regulation in one country could enhance the competitiveness of firms in this country even if – or rather, exactly if – it was more stringent than the regulation faced by competitors in other countries. Properly designed environmental policy measures could induce innovation within firms which would otherwise not be undertaken. The realization of these innovation opportunities would create net savings for these firms which he referred to as “innovation offsets”. This claim became subsequently known as the “Porter hypothesis”.

From a theoretical point of view, the Porter hypothesis is not straightforward. Its validity has been questioned in several lines.[1] Among others, Palmer, Oates and Portney (1995) criticize Porter for implicitly assuming that the private sector systematically overlooks profitable opportunities for innovations.

Yet under a theoretical setting that incorporates market imperfections the conclusion that environmental regulation may indeed raise domestic firms' competitiveness in the world market can be derived. Recent contributions, which can best be summarized under the heading of "strategic environmental policy", allow for imperfect competitive markets with strategic behavior on behalf of the agents. Under certain circumstances – depending e.g. on the nature of the behavior of the firms, the market structure, the number of market participants or the composition of the capital stock – strict environmental standards (where strict means that the marginal costs of abatement exceeds the marginal environmental damage) will shift profits from foreign to domestic enterprises.[2] For instance, this will occur under an international duopoly setting, when enterprises compete in a Cournot fashion. The result can be obtained if asymmetric industry structures (Barrett 1994), innovative activities (Simpson and Bradford 1996, Stähler 1998), differentiated products and consumer preferences (Farzin 1996) or an X-inefficient management (Klein and Rothfels 1999) are introduced. Under these settings strong environmental regulation can raise the competitiveness of domestic firms.[3]

As the above discussion shows a great part of the theoretical work on the validity of the Porter Hypothesis focuses on the regulation of production processes of firms acting in Cournot competition and producing homogenous products. However, in many product markets product differentiation prevails. This enables the government to use standards for environmental product qualities as policy instruments. Examples for product standards are the prohibition of CFC as a propellent gas or the use of catalysts in motor vehicles. These regulations alter the product qualities in the sense that the products become environmentally friendlier. A suitable framework for the analysis of the impact of environmental regulation on firm behaviour is then to assume Bertrand competition.

Analyses of the impact of environmental policy instruments assuming Bertrand competition do exist, but they are less frequent. Motta und Thisse (1993) have shown that in the case of symmetric firms in the countries concerned environmental product standards can result in larger domestic profits and welfare. Strict emission standards will raise marginal costs of domestic firms and hence the price of the commodity. In response, foreign firms raise their prices as well, which results in higher demand for the domestically produced good and in higher profits for domestic firms.[4] However, in a different theoretical setting we can get different results. Rauscher (1997) shows e.g. for

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1 See e.g. Palmer, Oates and Portney (1995), Simpson/Bradford (1996), Ulph (1997).

2 See e.g. Barrett (1994), Rauscher (1997), Xepapadeas and de Zeeuw (1998), and Schmutzler (1998).

3 For a survey of the literature see Rothfels (2000).

4 No clear cut results can be achieved when the assumptions on the firms' profit functions are relaxed. See Rauscher (1997).

the case of monopolistic competition with market entry, that environmental policies can be without any effect at all.

However, the impact of product standards has so far only been analysed for symmetric, i.e. identical cost structures of domestic and foreign competitors. But in the real world cost asymmetries exist, firms that compete on a product market will typically have different structures of operating and/or fixed costs. Of course, technological imitation and diffusion will tend to neutralize large differences in the technological production possibilities. But factor costs typically differ between different states and therefore production costs differ, too. By taking these asymmetries into account, this paper contributes to the ongoing research debate of the impact of environmental policies.

Our model goes beyond existing analyses in several respects: First, we investigate a cost advantage as well as a cost disadvantage of the domestic firm. Second, not only do we analyse the impact of an environmental product standard, but also of a subsidy which in reality is a quite common environmental policy instrument. Additionally, we introduce the concept of a "self-financing" subsidy which turns out to be helpful in the following welfare analyses.

3. The model

3.1 The basic structure

In order to analyse the impact of environmental policy we slightly vary a standard model of vertical product differentiation and endogenous product qualities.[5] The basic structure of the model is as follows: The demand side consists of a continuum of consumers indexed by θ, $\theta \in [0, \bar{\theta}]$. θ can be seen as an income parameter which is uniformly distributed with density one. One consumer buys at most one unit of the good that is supplied in the home country. Consumption of this good causes environmental harm. The higher the product quality ω, the lower is the environmental damage resulting from the consumption. Should the consumer refrain from purchasing the good his or her utility is zero. If a consumer θ purchases it at price p he or she experiences the utility

$$u_\theta = \theta\omega - p. \tag{1}$$

Therefore, θ measures the consumer's willingness to pay for environmentally higher quality.

Two firms, one domestic and one foreign, operate on the output market by setting prices. Both firms face production costs that are increasing and quadratic functions of the produced product quality. Total quality dependend costs c_j depend on the quality chosen and a cost parameter b_j

$$c_j = b_j\omega^2 \tag{2}$$

[5] See e.g. Gabszewicz and Thisse (1979) and Shaked and Sutton (1982). For an application of the standard model to environmental policy see Motta and Thisse (1993). Herguera and Lutz (1996) use a similar model to analyse minimum quality standards as means of strategic trade policy.

with $j = d, f$ for the domestic and the foreign firm, respectively. These costs are fixed for a certain production level and can e.g. be understood as R&D expenses that are necessary to develop a certain environmentally relevant quality. Quantity dependend costs are equal for both firms and have constant marginal costs. This allows us to neglect them as well as transportation costs in the following.

Competition between the domestic and the foreign firm is modeled as a two-stage game. In the first stage, firms choose simultaneously the environmental qualities to be produced. In the second stage, they simultaneously determine the prices of the product. The solution concept used is that of a subgame perfect Nash equilibrium. As usual, the game is solved by backward induction. To get a benchmark case we first solve this model for the unregulated case, the market equilibrium. Later on, the framework allows us to analyse the impact of a minimum environmental standard on prices and produced qualities.

3.2 Price competition

Since consumers differ in their willingness to pay (according to their θ) they will demand different environmental qualities. Thus it is optimal for the firms to produce different qualities. By assumption they can decide between a relatively low product quality ω_l and higher quality ω_h, whereby one firm can only produce one quality. The quantities demanded of each quality can be derived from equation (1). Setting $u_l = u_h$ and solving for θ_h we derive the income parameter of the consumer who is indifferent between the lower and the higher quality:

$$\theta_h = \frac{p_h - p_l}{\omega_h - \omega_l}.$$

The demand for the high quality product is then $q_h = \overline{\theta} - \theta_h$. Similarly, we obtain $\theta_l = \frac{p_l}{\omega_l}$ for the consumer indifferent between the low quality and not consuming at all and $q_l = \theta_h - \theta_l$ for the low quality demand. Consumers with $\theta < \theta_l$ do not buy any product at all.

This allows us to derive the profit functions of the high quality and the low quality supplier:

$$\pi_h = p_h q_h - c_h = p_h(\overline{\theta} - \theta_h) - b_j \omega_h^2$$

and

$$\pi_l = p_l q_l - c_l = p_l(\theta_h - \theta_l) - b_j \omega_l^2.$$

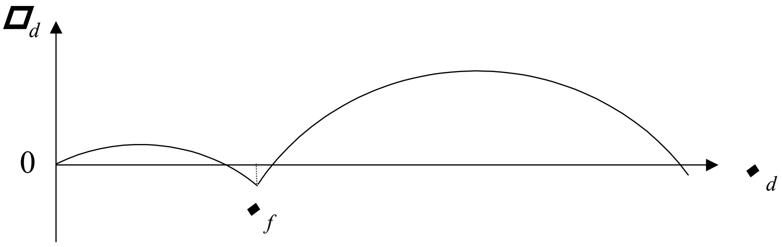
Since each firm can potentially produce the low or the high quality, the total profit function of the domestic firm consists of two segments, depending on the quality produced:[6]

[6] See Appendix for a more detailed derivation of the profit function.

$$\pi_d = \begin{cases} \dfrac{4\bar{\theta}^2\omega_h^2(\omega_h-\omega_f)}{(4\omega_h-\omega_f)^2} - b_d\omega_h^2 & \text{für} \quad \omega_h = \omega_d\,, \omega_d \geq \omega_f \\[2ex] \dfrac{\bar{\theta}^2\omega_f(\omega_f-\omega_l)\omega_l}{(4\omega_f-\omega_l)^2} - b_d\omega_l^2 & \text{für} \quad \omega_l = \omega_d\,, 0 < \omega_d \leq \omega_f \end{cases} \tag{3}$$

Graphically, the segmentation yields a kinked profit function (see Figure 1).

Figure 1: Profit function of the domestic firm



In equilibrium, the firms do not supply identical qualities because then they would end up with a loss equal to the fixed quality dependend costs (compare the point $\omega_f = \omega_d$ in Figure 1). Therefore, it is optimal to supply different qualities. This product differentiation relaxes price competition between the firms and allows them to earn positive profits. Under these circumstances the supplier of the higher quality earns a larger profit than his competitor.

3.3 Quality competition

To derive the qualities supplied by the firms we have to investigate the profit function (3) in greater detail. The optimal response of a firm to a given competitor‘s quality is shown by its reaction function.[7] Due to the segmented profit function the reaction function $r_d(\omega_f)$ is also segmented with a switching point ω_f^*. ω_f^* is the quality of the foreign supplier where the domestic firm is indifferent between supplying the high or the low quality, i.e. it is given by

$$max_{\omega_h}\,\pi_d(\omega_f^*) = max_{\omega_l}\,\pi_d(\omega_f^*)\,.$$

In terms of Figure 1 this means that the two segments of the profit function have identical altitudes. As ω_f increases the peak of the right segment falls while the other peak rises. If $\omega_f > \omega_f^*$ the domestic firm produces a lower quality and vice versa.

[7] See Appendix for the derivation of the reaction function.

Figure 2: Reaction function of the domestic supplier

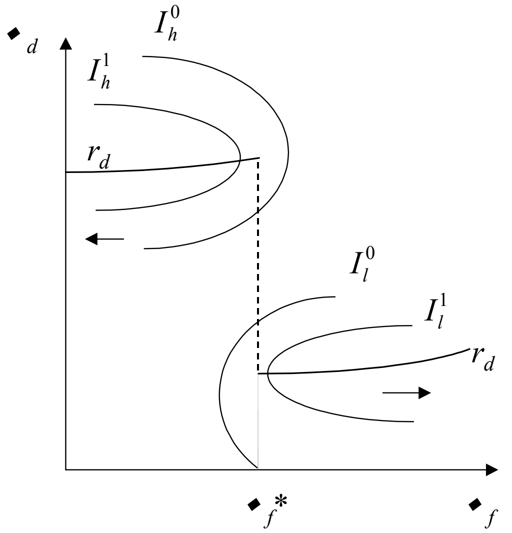


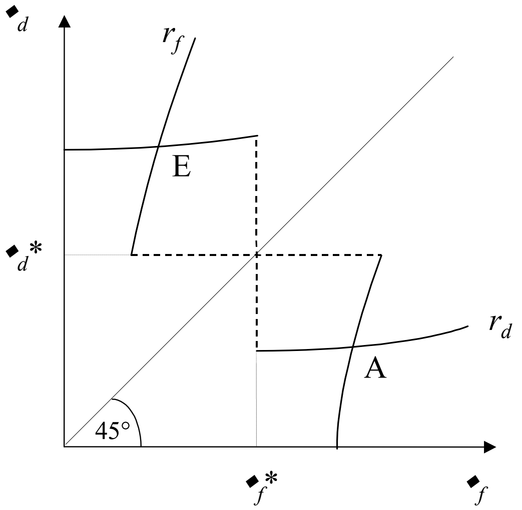
Figure 2 shows the reaction function of the domestic supplier together with corresponding isoprofit curves. The reaction curve is positively sloped reflecting the fact that the qualities are strategic complements: Whenever the high quality supplier increases his quality, price competition is relaxed. From the viewpoint of the low quality supplier it is then optimal to increase his own too, as the rise of his returns exceeds the increase in production costs which increases his profits. Analogously, when the high quality supplier lowers the quality of the product, price competition intensifies. For the low quality supplier it is now sensible to reduce the quality of the product as well.

The curves I_h^0 and I_l^0 represent those combinations of domestic and foreign qualities that result in a zero profit for the domestic firm as a supplier of either the high or the low quality, respectively. I_h^1 and I_l^1 represent quality combinations associated with positive profits. The arrows in Figure 2 thus indicate the directions of increasing profits for the domestic firm.

Putting the reaction curves of the domestic and foreign firm together it is possible to derive the equilibrium qualities. Let us first assume that the firms are identical, i.e. their cost functions exhibit the same cost parameter *b*. In this case, two possible quality equilibria result, namely at the two points of intersection of the corresponding reaction curves, A and E (see Figure 3). *Ex-ante* the question which firm produces the high and which the low quality is indeterminate. The domestic firm can supply either the low quality (point A) or the high quality (point E). Both equilibria are subgame perfect, i.e. no firm has an incentive to deviate from the quality supplied in these equilibria. The supplier of the low quality product can not raise his profit by enhancing its product quality, since his own quality given an unchanged quality of the competitor would result in a lower profit.

Numerically the two equilibrium qualities can be found, depending on the cost parameters b and the maximal domestic income $\bar{\theta}$.[8]

Figure 3: Reaction functions and equilibria with idential cost structures



Now the properties of the market equilibrium are derived that serve as benchmark for the following analysis of the regulated equilibria.

3.4 Market equilibrium and welfare

Welfare is given by the sum of the domestic firm's profit π_d and the consumer surplus CS minus the environmental damage D that results from the consumption of the good in the home country:

$$W_d = \pi_d + CS - D. \tag{4}$$

The profit function of the domestic firm is

$$\pi_d = pq - b_d \omega^2. \tag{5}$$

The consumer surplus results from the sum of the utilities of all those consumers who either buy the high quality good or the low quality good:

$$CS = \int_{\theta_h}^{\bar{\theta}} (\theta \cdot \omega_h - p_h) d\theta + \int_{\theta_l}^{\theta_h} (\theta \cdot \omega_l - p_l) d\theta. \tag{6}$$

The extent of environmental damage depends on the quantities consumed in the home country, weighted with a factor that gives the damage resulting from the consumption of one product unit. We assume that the environmental damage declines inverse proportionally with the product quality.[9]

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[8] See Appendix.

[9] Contrary to other analyses in this field of research, we take the environmental quality explicitely into account. This makes sense because environmental policy results in a quantity and a quality reaction and the impact on environmental quality is not ex-ante certain. However, the inclusion of

$$D = \frac{1}{\omega_h} q_h + \frac{1}{\omega_l} q_l \tag{7}$$

This basic model as developed above allows us to analyse the impact of environmental policies on the domestic firm's profit and the other welfare components also for the case that the firms exhibit different production costs.

4. Environmental regulation under cost advantage for the domestic firm

4.1 The starting point

We will now leave the symmetric world and assume that the domestic firm has a cost advantage in relation to its foreign competitor, i.e. $b_f = a b_d$ with $a > 1$. Further, we assume that at the outset the domestic firm produces the low quality good, whereas the foreign firm supplies the high quality good. Thus we start from point A in Figure 3 but with the difference that the reaction curves are no longer symmetric. Due to the cost differences the reaction curve of the foreign supplier now is more to the left and the switching point ω_d^* lies below the one of the symmetric case (see Figure 4).[10] The difference between high and low quality supplied by the two competitors is the smaller, the larger the cost advantage of the low quality supplier is. Since A is a subgame perfect equilibrium despite the cost differences, the domestic firm can not credibly threaten to alter its quality. Under these circumstances the domestic government has a twofold incentive to enforce changes in the product quality supplied by the domestic firm: First, with increasing quality the firm's profit increases, and, second, environmental quality can be enhanced.

The relevant question now is how the government can induce the domestic firm to alter the produced quality in order to increase its profit and to lower the environmental damage resulting from consumption. One possibilty to achieve this goal is to set the incentives in such a way that the domestic firm will produce a higher quality than its competitor. This sort of behaviour has been termend leapfrogging. The next section will take a closer look at the exact nature of the conditions that need to be fulfilled for leapfrogging to be possible.

4.2 Imposition of a minimum quality standard

One possible alternative lies in the imposition of a minimum quality standard ω_{min} by the government. After the standard has been set both firms have to supply a product quality which is at least as high as the minimum standard. If the standard exceeds the

environmental quality into the analysis is *not* a necessary condition for the derived positive welfare effects of the policy measures.

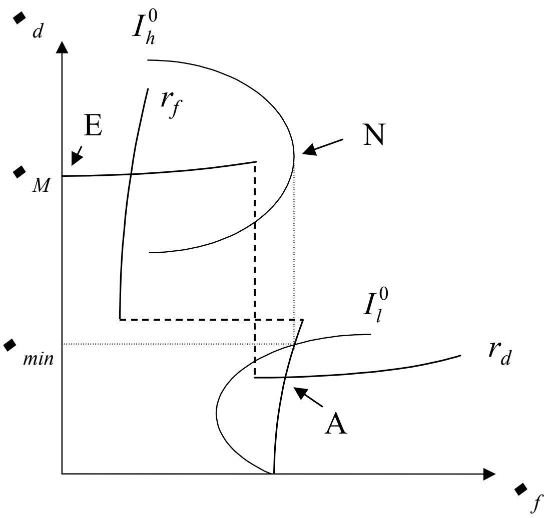
[10] With increasing cost difference the reaction curve moves further to the left up to the point where the point of intersection vanishes and A is not longer an equilibrium point.

formerly supplied low quality (i.e. if it is binding), the low-quality supplier must either enhance the produced quality or leave the market.

Proposition 1: *If the domestic firm enjoys a cost advantage over the foreign competitor and produces the lower product quality, the imposition of a binding minimum quality standard can induce the domestic firm to carry out a quality jump (i.e., to leapfrog). This results in higher profits of the domestic firm and the exit of the foreign firm from the domestic market.*

Proposition 1 can be proven graphically.[11] For leapfrogging to be a credible strategy, the standard has to meet certain conditions. First, the profit of the domestic firm after the quality change should not be lower than in the previous market eqilibrium. This condition is critical even if the competitor does not react to the quality jump and persists in producing the same quality as before. This situation is represented in Figure 4 by point N. The minimum standard ω_{min} is given by the intersection of the reaction curve of the foreign firm and the domestic firm's isoprofit curve for zero profits. Therefore, with a minimum standard defined in this manner the domestic firm is indifferent between producing the low quailty (ω_{min}) or change to a higher quality (point N). In both cases it would gain zero profits.

Figure 4: Reaction functions with cost advantage for the domestic firm and minimum product standard



However, in point N the produced qualities are quite similar and price competition will be strong. Since the domestic firm is able to gain positive profits if it produces a different quality than the one given by point N, N is not a stable equilibrium. It turns out that the best alternative for the domestic firm is to leapfrog the competitor and to

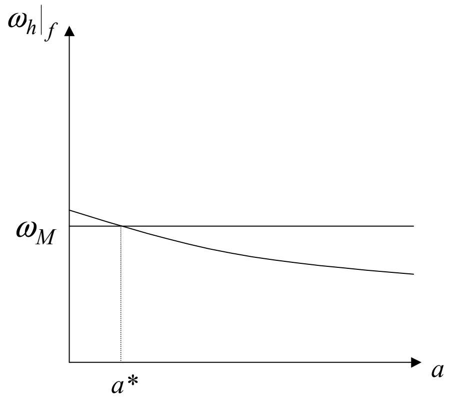
[11] See the Appendix for an analytical outline of the proof and for the results of simulations.

produce the monopolistic quality ω_M. ω_M can be derived by maximizing the upper part of equation (3) with respect to ω_h and setting $\omega_f = 0$. We get

$$\omega_M = \frac{\bar{\theta}^2}{8b_d}. \tag{8}$$

The sufficient condition for leapfrogging is that the cost advantage of the domestic firm has to exceed a certain threshold a^* (see Figure 5).[12] Should the cost advantage be less than a^* it will still be feasible for the domestic firm to produce a higher quality. However, this quality will not exceed the quality formerly supplied by the foreign firm $\omega_h|_f$, and no leapfrogging will occur. The larger the cost advantage, the less is the former quality differential making it easier for the domestic firm to leapfrog.

Figure 5: Monopolistic quality, leapfrogging and cost advantage



Additionally, under the given assumptions the foreign firm has to exit the market. This is easy to verify with the help of Figure 4: The optimal response of the foreign firm to the monopolistic quality of the domestic firm (given by a point on its reaction curve) is a quality lower than ω_{min} and therefore not allowed in the home country. Furthermore, as a producer of ω_{min} the foreign firm would incurr a loss, because ω_{min} was chosen in a way that the comestic firm earns zero profit. Thus it is not possible for the foreign firm with higher production costs than the domestic firm to profitably produce ω_{min}. The result is that the foreign firm can not further supply the product in the home country.

4.3 Welfare effects

Proposition 2: *Assuming that the domestic firm has a cost advantage over its foreign competitor and produces the lower product quality in the market equilibrium, the imposition of a minimum standard can enhance environmental quality and welfare.*

The imposition of a quality standard affects the seperate components of the welfare function (4) in different ways. As seen in the previous analysis the profits of the

[12] Compare Table 1 in the Appendix.

domestic firm increase as it now has a monopolistic position on the output market.[13] Also, the environmental quality is enhanced since the consumed quality after the imposition is higher than before. However, this quality effect is accompanied by a price effect that reduces the consumed quantity. The welfare in former market equilibrium is determined by equations (3) with $\omega_d = \omega_l$, (6) and (7) and takes the form:

$$W(\omega_l) = \frac{7\bar{\theta}^2\omega_h^2\omega_l^2 - 2\bar{\theta}^2\omega_h\omega_l^3 + 4\bar{\theta}^2\omega_h^3\omega_l - 2\bar{\theta}(4\omega_h^2 + 7\omega_h\omega_l - 2\omega_l^2)}{2\omega_l(4\omega_h - \omega_l)^2} - b_d\omega_l^2 .$$

Welfare in the new monopolistic case is given by

$$W(\omega_M) = \frac{3}{8}\omega_M\bar{\theta}^2 - b_d\omega_M^2 - \frac{\bar{\theta}}{2\,\omega_M} .$$

Using equation (8) the monopolistic quality can also be expressed as

$$W(\omega_M) = \frac{\bar{\theta}^4}{32b_d} - \frac{4b_d}{\bar{\theta}} .$$

It can be shown that under the assumption of a cost advantage for the domestic firm which renders leapfrogging possible, the inequality $W(\omega_M) > W(\omega_l)$ holds, i.e. the loss in consumer surplus is more than outweighted by the rise of environmental quality and of the firm's profit.[14]

Things are different when the domestic firm has a cost disadvantage instead of an advantage. Then a minimum quality standard does not induce leapfogging. However, we will show in the next section that even in the case of a cost disadvantage, environmental policies do not necessarily harm the competitiveness of the domestic firm. Critical in this respect is the use of a suitable chosen policy instrument.

5 Environmental policy under a cost disadvantage for the domestic firm

5.1 The starting point

Similar to the previous scenario we assume that the domestic firm supplies the low quality product. Additionally we alter the situation of the home country by assuming that the domestic firm exhibits now a cost disadvantage compared to its competitor, i.e. $b_d = a' b_f$ with $a' > 1$. Basically this means that we are again able to start the analysis in point A, but that the reaction curve r_d now lies below the one of the symmetric case (see Figure 6).

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13 Here we abstract from market entry of other firms.

14 This is shown in the Appendix. We show the existence of the equilibrium with the claimed properties locally (for one point in the parameter space). The validity for other parameter values results implicitely from the fact that the equilibrium results depend continually of the exogeneous variables and that, therefore, the results in the surrounding area of the assumed constellation correspond to the results of the assumed constellation.

5.2 Subsidizing quality dependend costs

In what follows we analyse the impact of an environmental subsidy on the quality decision of the firm.[15] To induce the firm to produce an environmental friendlier quality, the government offers the domestic firm a subsidy σ, i.e. a proportional reduction of the costs of providing quality with $\sigma \in (0,1)$. This implies a different cost parameter b_d', and the domestic firm's costs (net of subsidies) are now

$$c_d = (1-\sigma)b_d\omega^2 = b_d'\omega^2 . \qquad (9)$$

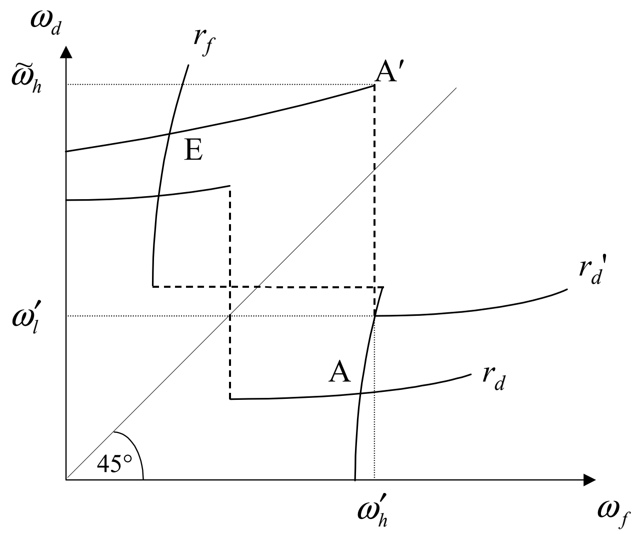
The reaction curve of the subsidized firm lies above the one without subsidy, as because of the now lower quality dependend costs, the firm is able to produce a higher quality at any given quality of its competitor. We show now that a subsidy exists which (a) induces the domestic firm to leapfrog and (b) is self-financing. The self-financing property means that the increase in profits going along with leapfrogging is at least as high as the subsidy expenditures of the government. A benefit of focussing on self-financing subsidies is that the two „monetary" terms of the welfare function, i.e. the profits and the subsidy, can easily be balanced against each other.

Proposition 3: *The subsidization of quality dependend costs can induce leapfrogging and result in a larger profit of the domestic firm even if the domestic firm has a cost disadvantage compared to the foreign supplier.*

Again, we illustrate the analytics graphically. To induce leapfrogging, the subsidy must result in indifference on behalf of the domestic firm between producing the low or the high quality for a given quality of its competitor. This condition is always fulfilled at the switching point of the reaction curve. Therefore, the subsidy has to be at least as high as to ensure that the reaction curve of the domestic firm is shifted upwards to the position shown in Figure 6: There it just touches the foreign firm's reaction curve, and the quality supplied by the foreign firm ω_h' coincides with the switching point of the domestic firm. This level of subsidy is called σ_{min}. As a consequence point A represents no longer a stable equilibrium. The domestic firm can now credibly leapfrog its competitor and switch to the higher quality.

[15] The possibility of leapfrogging under subsidization is also analysed by Herguera and Lutz (1997), but only for the case of symmetric costs.

Figure 6: Reaction curves and equilibria under cost disadvantage and subsidy



If the competitor does not react to the leapfrogging activities of the domestic firm situation A′ would result where the quality differences are relatively small. In a situation like this the foreign firm could increase its profits with larger differences in the quality. Thus A′ can not be a stable equilibrium and the game ultimately ends at point E with the foreign firm supplying the low quality.
It remains to be shown that this subsidy can be self-financing. The larger the cost disadvantage, the higher the necessary subsidy will be to induce leapfrogging of the domestic firm. However, since rising subsidies imply increasing expenses of the goverment, we expect that a maximal cost disadvantage a'_{max} exists. If this threshold is crossed, the subsidy will not be self-financing.

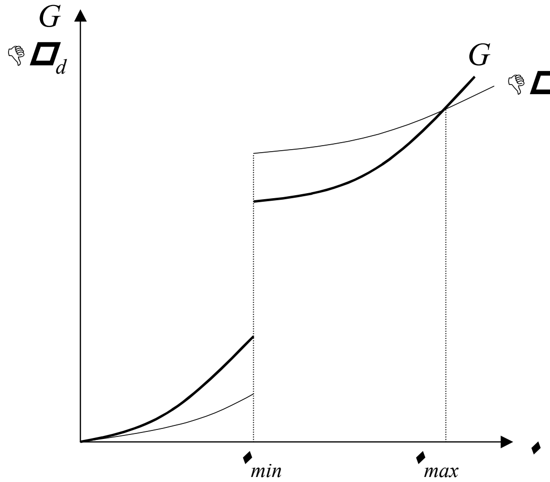
Proposition 4: *Subsidizing the quality dependend costs can both enhance environmental quality and raise welfare, even if the domestic firm suffers from a cost disadvantage compared to the foreign supplier.*
The welfare function now takes the form

$$W_d(\omega_i) = \pi_i - G + CS - D, \tag{10}$$

$$\text{with } G = \sigma\, b_d \omega_i^2 = \sigma\, a'\, b_f \omega_i^2 \tag{11}$$

for the government expenditures necessary for the subsidy and $i = l, h$ for the produced low and high quality, respectively. The term $(\pi_i - G)$ reacts positively to environmental policy should it induce leapfrogging and if the subsidy is self-financing. A necessary condition for this to occur is the cost disadvantage does not rise beyond a certain point. This can be seen in Figure 7. At the point of the lowest leapfrogging inducing subsidy σ_{min}, the profit jumps upwards. This profit increase exceeds than the total subsidy expenditures G, since the profit of the high quality supplier always surpasses the possible profits of the low quality supplier and furthermore the subsidy reduces the production costs.[16]

Figure 7: Subsidy expenditures and profit increase



With further increasing subsidy rates σ, the subsidy expenditures G rise more strongly than the profit of the domestic firm. This ensures the existence of a maximal self-financing subsidy σ_{max} where the increase in profits equals the amount spent by the government on subsidization.
The size of the interval $[\sigma_{min}, \sigma_{max}]$ depends on the cost disadvantage: The higher a', the larger must be the subsidy σ_{min} in order to induce leapfrogging and thus the lower will be the self-financable subsidy rate. It is possible to derive a maximum cost disadvantage a'_{max} such that for larger a' no self-financing subsidy exists.

Regarding the third term of the welfare function, the consumer surplus, subsidization of the domestic firm results in a positive quality effect but also a negative quantity effect. The positive quality effects is due to the fact that both qualities are higher than in the previous market equilibrium: The foreign firm faces lower costs and will therefore as the low-quality supplier produce a higher quality than the domestic firm has done before regulation. And the quality supplied by the domestic firm after regulation is higher than the one offered before by the foreign competitor, as well. A counterveiling influence is present through the negative effect on the supplied quantity. Increasing qualities go hand in hand with lower quantities actually consumed. It can be shown that under reasonable assumptions the positive quality effect will outweight the negative quantity effect. The rising qualities also exert a positive influence on the environmental quality, which is the fourth term in the welfare function.
To sum up, should the cost disadvantage of the domestic firm not exceed a'_{max}, then a subsidy in the range $[\sigma_{min}, \sigma_{max}]$ can increase both the domestic firm's profits and the environmental quality. Additionally, the subsidy can also serve to increase welfare.

[16] For the analytical proof see the Appendix.

6 Conclusions

This paper studied the influence of environmental policies on environmental quality, domestic firms, and welfare. In using a partial-equilibrium model of vertical product differentiation where the consumption of a product causes environmental harm, the domestic industry will either be market leader or lag behind in terms of the environmental quality of the produced product. Assuming that the domestic industry lags behind in the benchmark case, we analysed the possibilities of the government to induce leapfrogging of the domestic firm.

It was shown that in the case of a cost advantage for the domestic firm the imposition of a binding minimum quality standard can serve as a tool to induce leapfrogging. In case of a cost disadvantage for the domestic firm the same result can be achieved through adequate subsidization of the quality dependend production costs. In both scenarios the domestic firm can better its competitive position against foreign competitors and earn larger profits after regulation. Additionally, environmental quality and welfare can be enhanced.

Thus we have shown that environmental policies must not necessarily harm the international competitiveness of domestic industries, an often heard claim voiced by the opponents of the Porter hypothesis. However, we explicitely do not recommend the adoption of a ”strategic environmental policy“ since the informational requirements are too high for governments to be able to carry out this demanding task.

Appendix

Derivation of the profit function (3)

Maximizing of the profit function of the supplier for the high quality and the low quality,

$$\pi_h = p_h q_h - c_h = p_h(\overline{\theta} - \theta_h) - b_j \omega_h^2$$

and

$$\pi_l = p_l q_l - c_l = p_l(\theta_h - \theta_l) - b_j \omega_l^2,$$

with respect to the prices for given qualities under consideration of $\theta_h = \dfrac{p_h - p_l}{\omega_h - \omega_l}$ and $\theta_l = \dfrac{p_l}{\omega_l}$ yields the Nash equilibrium price for the high quality product

$$p_h = \frac{2\overline{\theta}\omega_h(\omega_h - \omega_l)}{4\omega_h - \omega_l}$$

and for the low quality product

$$p_n = \frac{\overline{\theta}(\omega_h - \omega_l)\omega_l}{4\omega_h - \omega_l}.$$

Consumed quanities of the product with high quality and low quality are then

$$q_h = \frac{2\overline{\theta}\omega_h}{4\omega_h - \omega_l}$$

and

$$q_l = \frac{\overline{\theta}\omega_h}{4\omega_h - \omega_l} = 0{,}5\, q_h.$$

Inserting these results in the original profit function we obtain equation (3).

Derivation of the reaction functions

The reaction function of the domestic firm is determined by the first order conditions for the profit maximization, i.e. the derivation of (3) with respect to the high and the low qualities:

$$\frac{\partial \pi_d}{\partial \omega_h} = \frac{4\overline{\theta}^2\omega_h(4\omega_h^2 - 3\omega_h\omega_f + 2\omega_f^2)}{(4\omega_h - \omega_f)^3} - 2b_d\omega_h = 0$$

and

$$\frac{\partial \pi_d}{\partial \omega_l} = \frac{\overline{\theta}^2\omega_f^2(4\omega_f - 7\omega_l)}{(4\omega_f - \omega_l)^3} - 2b_d\omega_l = 0.$$

These conditions implicitely define the reaction function $r_d(\omega_f)$. The slope of the reaction function is given by the implicit derivation of the first order condition for profits maximization:

$$r_d' = \left.\frac{d\omega_d}{d\omega_f}\right|_i = -\frac{\partial(\partial\pi_d/\partial\,\omega_d)}{\partial\omega_f} \Bigg/ \frac{\partial(\partial\pi_d/\partial\,\omega_d)}{\partial\omega_d}.$$

This yields

$$r_d' = \frac{\overline{\theta}^2(20\omega_h^2\omega_l + 4\omega_h\omega_l^2)}{\overline{\theta}^2(20\omega_h\omega_l^2 + 4\omega_l^3) + b_d(4\omega_h^2 - \omega_l)^4} > 0$$

in the segment for the high quality and

$$r_d' = \frac{\overline{\theta}^2(8\omega_h^2\omega_l + 7\omega_h\omega_l^2)}{\overline{\theta}^2(8\omega_h^3 + 7\omega_h^2\omega_l) + b_d(4\omega_h^2 - \omega_l)^4} > 0$$

in the segment for the low quality. The slope is in both cases positive which reflects the fact that the qualities act as strategic complements to each other.

Combining the reaction curves of both competitors allows us to calculate the equilibrium qualities. The other parameter values can also be derived, depending on the cost parameter b and the maximal income parameter $\overline{\theta}$. This was done using *Mathematica* for the symmetric case $b_d = b_f$ and also for the cases of a cost advantage or a cost disadvantage for the home country (see Table 1).

Analytical outline of Proposition 1:

First, the leapfrogging inducing minimum quality standard has to be derived. For this we assume that the domestic firm can not make positive profits as a supplier of the low quality product ($\pi_l|_d = 0$), and that the foreign firm as a supplier of the high quality behaves in a profit maximizing fashion ($\left.\frac{\partial\pi_h}{\partial\omega_h}\right|_f = 0$). However, this results in a very low quality differential and it is therefore advantageous for the domestic firm to switch to a higher quality ω_M. Point E in Figure 4 is the only possible new equilibrium. To see this, we can check other quality combinations:

Suppose the foreign firm would supply a quality higher than ω_M. Then the conditions

$$\pi_h|_f(\omega_h, \omega_M) = 0 \text{ and } \omega_h = r_f(\omega_M) \text{ with } \omega_M = \frac{\overline{\theta}^2}{8b_d} \text{ and } b_f = a\,b_d$$

would have to be fulfilled. However, this can only happen if $a \le 2/3$ which contradicts the assumption of a cost advantage for the domestic firm ($a > 1$).

Suppose alternatively that the foreign firm profitably supplies the low quality and the domestic firm the high quality. Then the conditions

$$\pi_l|_f(\omega_M, \omega_l) = 0 \text{ with } \omega_M = \frac{\overline{\theta}^2}{8b_d} \text{ and } b_f = a\,b_d$$

would have to be met. This allows us to derive the quality ω_l as a decreasing function of the cost parameter b_f. For a > 1 we always have $\omega_{min} > \omega_l$. Therefore, the foreign firm can not make positive profits as supplier of the low quality.

Analytical outline of Proposition 3:
The minimal subsidy a'_{min} can be derived with the following considerations:
The leapfrogging inducing subsidy has to lead to a cost parameter $a'_{min} = (1-\sigma_{min})a'$, like point A in Figure 6, where the domestic firm produces ω'_l and the foreign firm supplies ω'_h and the first order conditions are met. We get

$$\frac{4(4\omega_h'^2 - 3\omega_h'\omega_l' + 2\omega_l'^2)}{\omega_h'(4\omega_h' - 7\omega_l')} = \frac{b_f\omega_h'}{b_d^\sigma\omega_l'} = \frac{\omega_h'}{a'_{min}\omega_l'} .$$

Additionally, the condition for indifference of the domestic firm

$$\frac{4\bar{\theta}^2\tilde{\omega}_h^2(\tilde{\omega}_h - \omega_h')}{(4\tilde{\omega}_h - \omega_h')^2} - a'_{min}b_f\tilde{\omega}_h^2 = \frac{\bar{\theta}^2\omega_h'(\omega_h' - \omega_l')\omega_l'}{(4\omega_h' - \omega_l')^2} - a'_{min}b_f\omega_l'^2$$

between supplying the high and the low quality has to be met. The term on the left hand side represents the profit of the domestic firm in point A‘ in Figure 6, whereas the right hand side shows its profit in point A. In this constellation, $\tilde{\omega}_h$ is the best answer of the domestic firm to the quality of its competitor. The first order condition for profit maximization with $\tilde{\omega}_h$ as the high quality and ω_l' as the low quality yields

$$\frac{4\bar{\theta}^2\tilde{\omega}_h(4\tilde{\omega}_h^2 - 3\tilde{\omega}_h\omega_h' + 2\omega_h'^2)}{(4\tilde{\omega}_h - \omega_h')^3} = 2a'_{min}b_f\tilde{\omega}_h .$$

Putting these conditions together we can derive the cost parameter a'_{min} and since $a'_{min} = (1-\sigma_{min})a'$ also the minimal subsiy $\sigma_{min} = 1 - \frac{a'_{min}}{a'}$.

The maximal self-financing subsidy can be derived with help of the condition

$$\sigma_{max}\, b_f\, \omega_h^2 = \pi_d[(1-\sigma_{max})\,a'b_f] - \pi_d(a'\,b_f),$$

i.e. the expenses for the subsidy have to equal the increase in profits resulting from leapfrogging. ω_h is determined by the first order conditions for profit maximization of both suppliers, which taken together yield

$$\frac{4(4\omega_h^2 - 3\omega_h\omega_l + 2\omega_l^2)}{\omega_h(4\omega_h - 7\omega_l)} = \frac{a'_{min}\omega_h}{\omega_l} .$$

With these conditions, the intervall $[\sigma_{\min}, \sigma_{\max}]$ can be derived, depending on a'.
The maximum self-financable cost disadvantage a'_{max} results from the condition

$$(a'_{max} - a'_{min})b_f\omega_h^2 = \pi(a'_{min}\, b_f) - \pi(a'_{max}\, b_f)$$
$$= \frac{4\bar{\theta}^2\omega_h^2(\omega_h - \omega_l)}{(4\omega_h - \omega_l)^2} - a'_{min}b_f\omega_h^2 - \left(\frac{\bar{\theta}^2\omega_h''(\omega_h'' - \omega_l'')\omega_l''}{(4\omega_h'' - \omega''_l)^2} - a'_{max}b_f\omega_l''^2\right)$$

where ω_h'' and ω_n'' are the qualities supplied in point A. They are again determined by the first order conditions, which can be expressed as

$$\frac{4(4\omega_h''^2 - 3\omega_h''\omega_l'' + 2\omega_l''^2)}{\omega_h''(4\omega_h'' - 7\omega_l'')} = \frac{b_f\omega_h''}{b_d\omega_l''} = \frac{\omega_h''}{a'_{max}\omega_l''} .$$

ω_h and ω_l are again given by

$$\frac{4(4\omega_h^2 - 3\omega_h\omega_l + 2\omega_l^2)}{\omega_h(4\omega_h - 7\omega_l)} = \frac{a'_{min}\omega_h}{\omega_l}.$$

These conditions together yield $a'_{max} = 1{,}14$. With a cost disadvantage larger than 14 % of the competitor's costs a subsidy can no longer be self-financing.

Table 1: Results for model parameters and of simulations*

Parameter	Symmetric cost structures	Cost advantage for the domestic firm	
		Market equilibrium (A)	Regulated equilibrium (E)
a	1	1,5	1,5
a^*	1,014	1,014	1,014
q_h	$0{,}524994\ \overline{\theta}$	$0{,}533329\,\overline{\theta}$	$0{,}5\,\overline{\theta}$
q_n	$0{,}262497\ \overline{\theta}$	$0{,}266665\,\overline{\theta}$	0
q_n+q_h	$0{,}787491\ \overline{\theta}$	$0{,}799994\,\overline{\theta}$	$0{,}5\,\overline{\theta}$
p_h	$0{,}053831\frac{\overline{\theta}^3}{b}$	$0{,}034133\frac{\overline{\theta}^3}{b_d}$	$0{,}0625\frac{\overline{\theta}^3}{b_d}$
p_n	$0{,}005126\frac{\overline{\theta}^3}{b}$	$0{,}004266\frac{\overline{\theta}^3}{b_d}$	0
ν	5,25123	4	-
ω_h	$0{,}126655\frac{\overline{\theta}^2}{b}$	$0{,}08533\frac{\overline{\theta}^2}{b_d}$	$0{,}125\frac{\overline{\theta}^2}{b_d}$
ω_l	$0{,}024119\frac{\overline{\theta}^2}{b}$	$0{,}02133\frac{\overline{\theta}^2}{b_d}$	0
ω_{min}	-	-	$0{,}042753\frac{\overline{\theta}^2}{b_d}$
$\overline{\omega}_n$	-	-	$0{,}055\frac{\overline{\theta}^2}{b_d}$
π_f	$0{,}012219\frac{\overline{\theta}^4}{b}$	$0{,}00728\frac{\overline{\theta}^4}{b_d}$	0
π_d	$0{,}000764\frac{\overline{\theta}^4}{b}$	$0{,}00068\frac{\overline{\theta}^4}{b_d}$	$0{,}0156\frac{\overline{\theta}^4}{b_d}$
CS_d	$0{,}021609\frac{\overline{\theta}^4}{b}$	$0{,}0159\frac{\overline{\theta}^4}{b_d}$	$0{,}0156\frac{\overline{\theta}^4}{b_d}$
D_d	$15{,}0284\frac{b}{\overline{\theta}}$	$18{,}7521\frac{b_d}{\overline{\theta}}$	$4\frac{b_d}{\overline{\theta}}$
W_d	$0{,}022373\frac{\overline{\theta}^4}{b}-15{,}0284\frac{b}{\overline{\theta}}$	$0{,}01658\frac{\overline{\theta}^4}{b_d}-18{,}7521\frac{b_d}{\overline{\theta}}$	$0{,}0312\frac{\overline{\theta}^4}{b_d}-4\frac{b_d}{\overline{\theta}}$

Table 1 (continued)

Parameter	Cost disadvantage for the domestic firm		
	Market equilibrium (A)	Regulated Equilibrium (E)	Regulated Equilibrium (E)
a'	1,1	1,1	1,1
$a'_{\max}$	1,143	1,143	1,143
σ	-	σ_{min}	0,446
q_h	$0,523219\,\overline{\theta}$	$0,517169\,\overline{\theta}$	$0,51672\,\overline{\theta}$
q_n	$0,261609\,\overline{\theta}$	$0,258585\,\overline{\theta}$	$0,25836\,\overline{\theta}$
q_n+q_h	$0,784828\,\overline{\theta}$	$0,775754\,\overline{\theta}$	$0,77508\,\overline{\theta}$
p_h	$0,054405\,\frac{\overline{\theta}^3}{b_f}$	$0,08965\,\frac{\overline{\theta}^3}{b_f}$	$0,09271\,\frac{\overline{\theta}^3}{b_f}$
p_n	$0,004829\,\frac{\overline{\theta}^3}{b_f}$	$0,005952\,\frac{\overline{\theta}^3}{b_f}$	$0,006\,\frac{\overline{\theta}^3}{b_f}$
ν	5,63354	7,53041	7,72572
ω_h	$0,126423\,\frac{\overline{\theta}^2}{b_f}$	$0,199892\,\frac{\overline{\theta}^2}{b_f}$	$0,20611\,\frac{\overline{\theta}^2}{b_f}$
ω_l	$0,022441\,\frac{\overline{\theta}^2}{b_f}$	$0,026545\,\frac{\overline{\theta}^2}{b_f}$	$0,026678\,\frac{\overline{\theta}^2}{b_f}$
σ_{min}	0,428024	0,428024	0,428024
σ_{max}	0,451537	-	-
b'_d	-	$0,629174\ b_f$	$0,61\ b_f$
π_f	$0,012483\,\frac{\overline{\theta}^4}{b_f}$	$0,008346\,\frac{\overline{\theta}^4}{b_f}$	$0,000839\,\frac{\overline{\theta}^4}{b_f}$
π_d	$0,000709\,\frac{\overline{\theta}^4}{b_f}$	$0,021224\,\frac{\overline{\theta}^4}{b_f}$	$0,021995\,\frac{\overline{\theta}^4}{b_f}$
CS_d	$0,021144\,\frac{\overline{\theta}^4}{b_f}$	$0,031169\,\frac{\overline{\theta}^4}{b_f}$	$0,031968\,\frac{\overline{\theta}^4}{b_f}$
D_d	$15,7962\,\frac{b_f}{\overline{\theta}}$	$12,3287\,\frac{b_f}{\overline{\theta}}$	$12,1913\,\frac{b_f}{\overline{\theta}}$
G	-	$0,018812\,\frac{\overline{\theta}^4}{b_f}$	$0,020816\,\frac{\overline{\theta}^4}{b_f}$
W_d	$0,021854\,\frac{\overline{\theta}^4}{b_f}-15,7962\,\frac{b_f}{\overline{\theta}}$	$0,033582\,\frac{\overline{\theta}^4}{b_f}-12,3287\,\frac{b_f}{\overline{\theta}}$	$0,033146\,\frac{\overline{\theta}^4}{b_f}-12,1913\,\frac{b_f}{\overline{\theta}}$

*While the choice of the assumed degrees of asymmetry (a = 1,5 and a' = 1,1) was carried out in an ad-hoc fashion, other calculations with different values have shown only neglectable variations in the above results.

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