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Can Environmental Regulation of X-Inefficient Firms Create a “Double Dividend”?

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Can Environmental Regulation of X-Inefficient Firms Create a “Double Dividend”?

Abstract

This paper investigates the impact of environmental policies on environmental quality and on economic welfare. Its point of departure is Michael Porter’s hypothesis that environmental regulation may actually raise enterprises’ productivity through “innovation offsets”. We first review Porter’s arguments and the ensuing discussion with his critics. Then we develop a variation of Porter’s theme by investigating environmental policies in a model with “rationally X-inefficient” firms. The term “rationally” X-inefficient is used to designate a setup where X-inefficiency does not necessarily arise out of irrationality or “human weakness”. Rather, it arises out of the institutional separation of firms’ ownership and management, where managers act as agents for the owners, who are the principals. Under this setting managers will pursue at least partially their personal objectives which cannot be expected to be perfectly congruent with the principals’ objectives of profit maximization or cost minimization. This conflict between agents and principals is the source of X-inefficiencies in our model. We proceed with investigating the impact of government regulation. For this, we integrate the X-inefficiency in a model with imperfect competition in the product market. The “green” perspective enters through the assumption that one of the factors of production generates pollution. We investigate two types of policies, (i) regulatory policy of the “command-and-control” type, where the government directly requires the firms to use a certain environmentally friendlier technology and (ii) tax policy, where the government imposes a tax on the polluting production factor thus attempting to diminish its use. We show that environmental regulation of the command-and-control type can raise the efficiency of the allocation by putting pressure on firms to improve X-efficiency. The same policy can also be expected to improve environmental quality, thus generating a “double dividend”. We also show that a traditional tax policy generates the same “double dividend”. However, it may be less effective in improving welfare.

JEL-Classification: Q 20, L 1, D 2

1. Introduction

This paper investigates the impact of environmental policies on environmental quality and on economic welfare. The point of departure is Michael Porter's (1991) conjecture that environmental regulation could raise enterprises' productivity through "innovation offsets". Porter claimed that government policies which either directly required enterprises to cut back pollution or which made pollution financially unpalatable could induce enterprises to develop new technologies with higher resource productivity and that this in turn could more than offset the costs imposed on them by the government policies. The objective of this paper is to investigate this conjecture in the context of a formal economic model with imperfect competition. In fact, the paper presents a slight variation of Porter's theme, his focus being on technological efficiency, ours on X-efficiency (on the level of individual firms) and on market efficiency (on the aggregate level).

The paper proceeds as follows. In the following section Porter's arguments and the ensuing discussion with his critics are reviewed. We also discuss the connection between his conjecture and the theory of X-inefficiency. In section 3, a model with imperfect competition in the product market and "rationally X-inefficient" firms is developed which serves as the vehicle for investigating Porter's hypothesis. The term "rationally" X-inefficient is used to designate a setup where X-inefficiency does not necessarily arise out of irrationality or "human weakness". Rather, it arises out of the institutional separation of firms' ownership and management, where managers act as agents for the owners, who are the principals. In such a setup managers will pursue at least in part their personal objectives which cannot be expected to be perfectly congruent with the principals' objectives of profit maximization or cost minimization (Kamecke, 1993). This conflict between agents and principals is the source of X-inefficiencies. As it was already pointed out above, the arguments in this section are somewhat different from Porter's. Whereas he focuses on improvements in technological efficiency, the focus of this paper lies on reductions of X-inefficiency inside individual firms and on the resulting improvements in market efficiency. In the following section, however, the thrust of the arguments coincides again with Porter's, the common theme being that by putting pressure on firms the government can "compel" them to become more efficient.

In section 4 the impact of government regulation is analysed. The "green" perspective enters through the assumption that one of the factors of production generates pollution. Government policies which affect the number of firms in the market, their output or their factor input will therefore impact both on aggregate emissions and on market efficiency. Starting from a benchmark case where market entry is deterred through X-inefficiency we investigate two types of policies, (i) regulatory policy of the "command-and-control" type, where the government directly requires the firms to use a certain environmentally friendlier technology and (ii) tax policy, where the government imposes a tax on the polluting production factor thus attempting to diminish its use. It is shown that a command-and-control policy may – under certain conditions – improve both environmental quality *and* market efficiency, the key reason being that it puts pressure on firms and alters X-efficiency. We also show that a traditional tax policy generates the same "double dividend". However, it may be less effective in improving welfare.

2. Can environmental regulation improve competitiveness?

a. The Porter hypothesis

Porter was the first to raise the question whether environmental policy could be beneficial for the performance of domestic enterprises. In his 1991 article 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 be not 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".

In their 1995 paper, Porter and van der Linde went on to illustrate this idea in greater detail and to underpin it with empirical examples. Their central message is that competition between enterprises is not a static phenomenon but a dynamic one. New technological production possibilities constantly arise over time of which firms are not completely aware because of incomplete information, deficiencies in organizational structure or because of internal control problems. They also argue that, from the point of view of individual firms, the benefits from environmental innovation are uncertain. For this reason firms hesitate to innovate in this direction. In this context, tough environmental regulation could provide firms with the incentive to search for new technologies.

Innovations could regard production processes as well as product properties. Porter and van der Linde expect innovation offsets especially from the first type of innovations because the resulting increases in productivity and/or resource efficiency could lead to cost savings and enhanced performance of the firms compared to international competitors. Additional positive effects on international competitiveness could result from first mover advantages.

Critical for the innovation offsets claimed by Porter and van der Linde is the design of the policy instruments. Authorities should use instruments based on market incentives and instruments which stress pollution prevention rather than the abatement of pollution. Essential in this regard is that the instruments do not act as a constraint on technological development and that a maximum degree of freedom remains for firms to implement new technologies by innovation. However, regulation has to be stringent enough to induce innovation and innovation offsets. If regulation is too lax, it can be dealt with incrementally or only through abatement in the context of the existing technologies.

Porter's hypothesis induced a lively debate. Its validity was questioned in several ways. Among others, Palmer, Oates and Portney (1995) criticize Porter and van der Linde for implicitly assuming that the private sector systematically overlooks profitable opportunities for innovation and that the regulatory authority is in a position to correct this "market failure", thus helping firms increasing their profits. They find this unconvincing and, as a counter-argument, present a simple static model with incentive-based regulation. A representative firm operates in perfectly competitive markets. There is neither slack nor X-inefficiency nor strategic interaction between the polluting firms and the regulating authority. Tighter regulation in this case always leads to reduced profits, which contradicts the Porter hypothesis. Additionally, Palmer et al.

contrast the real-world firm-specific examples on innovation offsets presented by Porter and van der Linde with aggregated US data. Estimates by the U.S. Commerce Department's Bureau of Economic Analysis show that, in 1992, expenditures by U.S. firms on environmental protection, net of offsets, have amounted to at least $ 100 billion. This suggests innovation offsets are a long way from compensating for the costs of regulation. Other critics have arrived at similar conclusions. Positive effects of environmental regulation on profits could be obtained only as very special cases.[1]

However, in a different theoretical setting than the one used by Palmer et al. it is possible to derive other conclusions, namely that environmental regulation may indeed raise domestic firms' competitiveness in the world market. Some recent contributions which are best summarized under the heading of "strategic environmental policy" allow for imperfectly competitive markets with strategic behavior of the agents. Under specific 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) act as means to shift profits from foreign to domestic enterprises.[2] For instance, this occurs in an international duopoly when enterprises compete by setting prices (Bertrand competition). Strong emission standards raise marginal costs and hence the price of the commodity. In response, the foreign firm raises its price as well, resulting in higher demand for the domestically produced good and in higher profits for the domestic firm. Unfortunately, this conclusion is not robust to changes in the nature of the game. If Cournot competition is assumed, the result could be reversed. Various models have been formulated in which "environmental dumping", i.e. a lower-than-social-cost regulation, appears to be optimal in the sense that profit shifting becomes possible.[3] This serves as an indirect subsidy to the domestic firms. But again, this result critically depends on the underlying assumptions. Thus an equal-to-social-cost regulation appears to be optimal if industry size is treated as endogenous, demand is approximately linear, no severe entry barriers exist, and pollution cannot be abated (as is the case for CO_2).[4]

b. The role of X-inefficiency

The idea that innovation offsets could result from a reduction of X-inefficiency has already been mentioned in the literature[5], albeit without formal proof. Indeed, it provides one possible explanation for Porter's claim that regulatory pressure by the government could induce firms to realize hitherto unexploited opportunities for innovation and productivity increases. The term X-efficiency – the converse of X-inefficiency – was coined by Leibenstein (1966) who also discussed various reasons for X-inefficiencies to arise. From the beginning, the notion of X-

1 See e.g. Simpson/Bradford (1996), Ulph (1997).

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

3 See e.g. Barrett (1994), Kennedy (1994), Ulph (1996), Rauscher (1997).

4 See Requate (1997).

5 See Oates/Palmer/Portney (1994), p. 16ff., Rauscher (1997), p. 191, Gabel and Sinclair-Desgagné (1998).

efficiency or X-inefficiency has been subject to a controversial discussion. Its underlying assumptions are – as critics have put it – inconsistent: On the one hand, maximization is rejected as a tool to predict individual behavior, on the other hand agents are assumed to maximize some objective.[6]

A new view was introduced by Kamecke (1993) who showed that X-inefficient behavior could arise under "neoclassical" assumptions. He uses a principal-agent model where a manager acts as the agent for the firms's owner, the principal. He shows that the manager may rationally decide not to minimize long-run costs and thus act "inefficiently" from the point of view of an outside observer. The reason for this behavior lies in the employment contract of the manager (an insider with relatively high productivity) which is binding only for one period. In the second period he could be replaced by a rival (an outsider with lower productivity). Through overinvestment in the first period the incumbent manager eliminates the chances of the rival to replace him and run the firm profitably. Only intensifying competition in the output market can force the manager to reduce overinvestment. A larger number of competitors reduces profits and the remaining scope for overinvestment. In complete markets all the profits are competed away and the firms are organized efficiently.

Kamecke's model is a key component of our own model in the following section. We construct a model with an X-inefficient monopolistic firm and endogenous market entry of an efficient rival. Both firms are subject to environmental regulation which raises their production costs. Thus the incentive of the manager of the monopolistic firm to overinvest is reduced. This answers one criticism levelled against Porter's hypothesis, namely, why should the government be able to push firms to exploit hitherto unexploited opportunities for productivity increases? Our answer is that government policies effectively "stiffen" cost pressure and thus diminishes the scope to behave inefficiently.

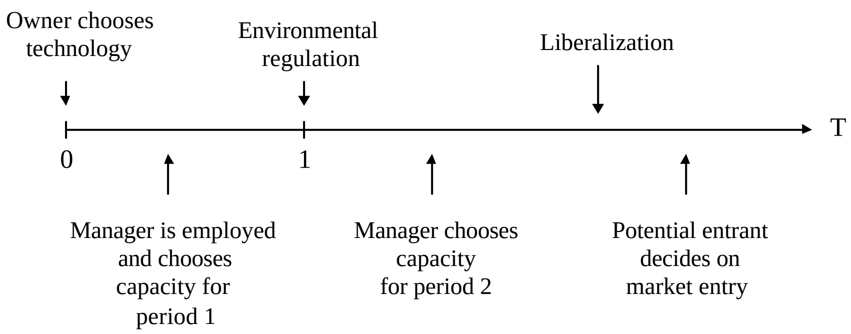
3. The model

a. Basic structure of the model

The temporal setup of the analysis is as follows (c.f. Figure 1): In period 0 the owner of a firm with a monopolistic position in an entry-resticted market chooses the production technology of his firm and hires a manager who consequently decides on the production capacity.

Figure 1: Time structure of the model

6 See Kamecke (1993), p. 391.



Production takes place with two production factors. One, say capital, determines the capacity of the next period. Given the amount of this factor, the other production factor is chosen in the next period in an optimal fashion. In every period the manager chooses the capacity for the next production period, i.e. in period 0 for period 1. We assume that capacity equals output.
In period 1 the government implements an environmental policy instrument and thus changes the production costs of the firm. We investigate the impact of two different environmental instruments, a production standard and a tax. After their implementation the market is liberalized.
The benchmark case of the analysis is given by the market equilibrium after liberalization, i.e. a situation without any policy measure. In the benchmark case we assume that market entry of a rival firm is deterred through the X-inefficient behaviour of the incumbent. The rival is assumed to be organized in an X-efficient way, producing a perfect substitute and behaving as a Stackelberg-follower. This allows to analyse the impact of environmental regulation on X-inefficiency, market strucure, and welfare. The game proceeds until period T.

b. Production and costs

The monopolistic firm uses capital K – at interest rate r – and the environmentally harmful resource E (say, energy) – at price e – to provide capacity Z which is sold at the market price P. Its production function is

$$Z = E^{a} K^{1-a} . \tag{1}$$

Capital has a delivery time of one period and must therefore be chosen one period before production is supposed to take place. Environmental damage per unit of capacity is characterized by the energy intensity e:

$$e = \frac{E}{Z} . \tag{2}$$

Additionally to the costs for the variable production factors, the provision of capacity Z causes fixed costs F. Efficient factor combination results in the cost function

$$C = F + gZ , \quad \text{with} \quad g = \left(\frac{e}{a}\right)^{a} \left(\frac{r}{1-a}\right)^{1-a} . \tag{3}$$

An environmentally friendlier technology (with a lower e) is assumed to go along with higher fixed costs F and lower marginal costs g. The market demand function has the form

$$P = 1 - Z . \tag{4}$$

The profit function for the case of two periods and for an unthreatened monopoly is

$$p = P\,Z - C = (1-Z)Z - g\;Z - F\;. \tag{5}$$

We assume that the technology of the incumbent and the potential entrant and (thus) the cost functions are identical. If the potential entrant decides to enter the market the profit function of the incumbent becomes

$$p = P\,Z - C = (1 - Z_i - Z_p)Z_i - g\;Z_i - F \tag{6}$$

where Z_i and Z_p stand for the capacity provided by the incumbent and the entrant respectively.

c. Principal-Agent problem

If firms are managed not by their owners but by managers who are employees and receive only a partial share in profits, then the managers' personal utility maximization may dominate profit maximization. This could give rise to a non-optimal resource utilization and, possibly, X-inefficiency. In the present section we introduce this type of behavior. Essentially, we use Kamecke's (1993) principal-agent model of X-inefficiency: The monopolistic firm's management is the agent acting on behalf of the firm's owner, who is the principal. The reason for the manager's inefficient behavior lies in his employment contract. The contract is incomplete in that it is binding only for one period, thus in the second period he could possibly be replaced by a rival.[7]

In period 0, the owner of the monopolistic firm hires a manager who we will afterwards call the insider-manager, whereas the other potential managers which are not hired in period 0 are called outsiders. In the same period the manager chooses the capital stock which determines the capacity of the next period. In period 1, the other factor of production, E, is ordered which can be employed instantenously. The manager receives the wage w and the profit share α of the firm's net profit $(\hat{p} - w)$, where $\hat{p}$ indicates the profit under X-inefficiency.[8] The manager's pay-off is determined in every period anew.

While employed the insider-manager i reaches a higher productivity level than an outsider which expresses itself in lower marginal costs under the insider's management. The insider runs the firm with the production function $Z_i = f(K_t, E_t)$, while an outsider o produces $Z_o = f(K_t, E_t)$ with $g_o = g_i + f$ and $f > 0$. However, the higher productivity level of the insider vanishes if he has to leave the firm (which will not happen in equilibrium).

Under these assumptions, it is rational for the manager *not* to maximize the long run profit. To keep his position inside the firm, he orders a larger than optimal capital stock which results in the X-inefficient capacity.

Figure 2: Profit functions of insider- and outsider-manager

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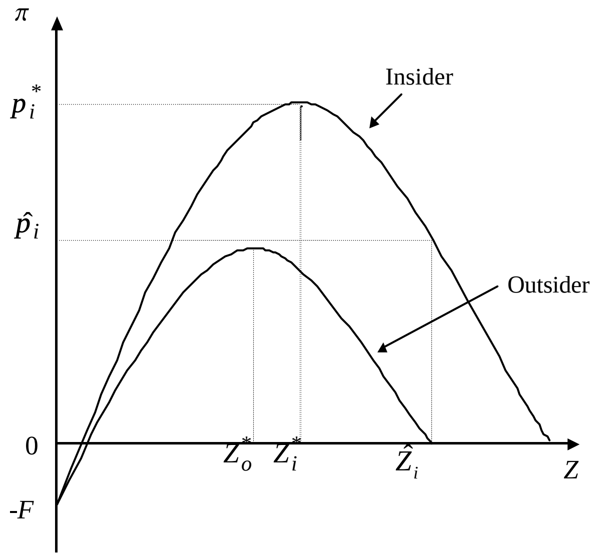
7 Therefore, two kinds of competitive situations exist in this model: On the one hand, the incumbent competes on the output market with a potential entrant and, on the other hand, the insider-manager competes on the job market with another kind of manager (an outsider).

8 The sign ^ characterizes the variables under X-inefficiency.



The behaviour of the insider leads to overinvestment $\hat{Z}_i$, as can be seen in Figure 2.[9] The shown profit curves of insider- and outsider-manager depend on the capacity in place. The insider's curve lies above the outsider's due to the lower productivity of the latter. The factor allocation is optimal since the manager maximizes short-run profits. But in order to protect his position the insider chooses a capacity $\hat{Z}_i$ which is larger than the optimal capacity Z_i^*. $\hat{Z}_i$ is exactly the value that maximizes the difference between the profits of the insider and an outsider. For the outsider, this capacity is too large to allow for profit making (for the analytical proof see Appendix 2a).[10]

The capacity which yields a zero profit of the outsider can be derived from equation (5) with $g = g_o$ and $p = 0$. We get

$$Z_o = \frac{1}{2}\left(1 - g_o + \sqrt{(1-g_o)^2 - 4F}\right) = \hat{Z}_i . \qquad (7)$$

The resulting profit of the monopolistic firm is

$$\hat{p}_i = (1-\hat{Z}_i)\hat{Z}_i - g_i\hat{Z}_i - F . \qquad (8)$$

This is less than the maximum profit p_i^* which means that the insider uses part of the potential profits to protect his position.[11] $\hat{p}_i$ is the highest profit the firm can gain in this setting, and we

9 This diagram shows the case of two periods.

10 The profit-maximizing capital stock Z_i^* would be selected only if the maxima of the two short-run profit functions coincided. This case is ruled out since we assumed that the insider's and the outsider's productivities differ.

11 Naturally, the question arises whether the owner of the firm has to tolerate the X-inefficient behaviour of the manager. However, the assumed "rules of the game" do not allow negotiation between owner and manager about a reduction of overinvestment, because this would imply a commitment for two periods, which is by assumption not possible.

If the assumption of X-inefficient behaviour of the management is abandoned, it can be shown that monetary incentives can be used to induce an environmentally friendlier behaviour of the management. See Gabel and Sinclair-Desgagné (1993).

have $\hat{p}_i = gp_i^*$ with $g \in [0,1]$. The ratio g can be interpreted as a measure of the "degree" of X-efficiency.[12] The larger g, the smaller is the distortion resulting from the manager's behaviour.

d. Market equilibrium

As a benchmark case for the analysis in the following sections we now consider the welfare implications for the market equilibrium, i.e. after the liberalization of the product market has taken place in period 1, but without environmental regulation. We construct the benchmark case in such a way that entry of the rival firm on the output market is deterred. This allows an analysis of the impact of environmental regulation on the market structure later on.

The policy-maker's objective function – the welfare function Ω – is the sum of the consumer surplus U and aggregate profit Π of all firms minus a monetary measure of the damage D arising from the use of the environmental harmful production factor E. Thus we have the function for welfare:

$$W = U + P - D(C) \tag{9}$$

with

$$D = \frac{d}{2}E^2 = \frac{d}{2}(e\,Z)^2,$$

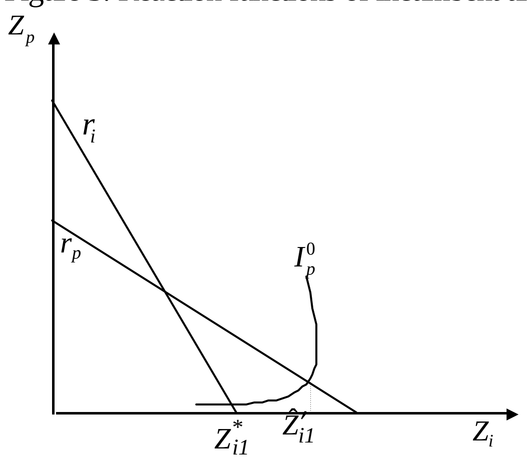
$d > 0$ and

$$C = \sum_i C_i, \quad P = \sum_i P_i, \quad U = \frac{1}{2}Z^2.$$

Z denotes the sum of provided capacities.

The profit component of the welfare function depends on the market structure after liberalization. In order to secure that entry of the potential rival firm is deterred in market equilibrium we have to investigate its entry decision. It would decide to enter the market after liberalization has taken place if it can gain a non-negative profit.

Figure 3: Reaction functions of incumbent and rival firm



12 Its inverse is then a measure of the degree of X-*in*efficiency.

Figure 3 shows the reaction functions of the incumbent (r_i) and of the rival firm (r_p) and the potential entrant's isoprofit-curve of zero profit (I_p^0). Since it is assumed to behave X-efficient and as a Stackelberg-follower, the relevant output combination has to be on r_p. Its profit is given by the function

$$p_p = (1 - \hat{Z}_i - Z_p)Z_p - g_p Z_p - F_p \qquad (10)$$

$$\text{with } \hat{Z}_i = \frac{1}{2}\left(1 - g_o + \sqrt{(1-g_o)^2 - 4F_i}\right).$$

For the benchmark case we assume that the incumbent's cost parameter yield - according to equation (7) - the capacity $\hat{Z}_i'$ in Figure 3, i.e. entry of the rival is deterred through X-inefficiency. Therefore, X-inefficiency reduces the number of market participants because it results in an X-inefficiently high capacity.

The resulting effects of X-inefficiency on welfare are ambivalent. Without X-inefficiency market entry would occur in period 1 because the capacity of the incumbent would be smaller and would therefore allow for a positive profit of the rival firm. Whether the capacity in the monopolistic, X-inefficient case is larger or smaller than in the dyopolistic case without any X-inefficiency depends on the cost parameters (c.f. equation (7)). Should it be larger, higher consumer surplus than in the efficient case results. A further positive effect on welfare arises from larger profits in the monopolistic case. However, the larger capacity also results in a higher environmental damage which in turn reduces welfare. The direction of the net effect is ex-ante unclear and depends on the weight of the environmental damage in the welfare function, i.e. on parameter d.

We now investigate the effects of environmental policies on market structure, environmental damage, and welfare.

4. Environmental policies

We consider two kinds of environmental policies:

- *Regulation*: The government requires all firms in the market to fulfill a production standard e_R that restricts the energy intensity of their production process. For the monopolistic firm this necessitates a change in its production technology, i.e. to a new equipment with lower energy intensity $e \leq e_R$.
- *Taxation*: The government taxes the use of the emission-generating resource E.

We begin with the first policy, which is essentially of the command-and-control type.

a. Command-and-control regulation

Proposition 1: *Environmental command-and-control type regulation of an X-inefficiently organized industry can increase the number of firms in the market and thus increase economic efficiency.*

The proof is outlined via the impact of the policy measure on the degree of X- inefficiency of the monopolistic firm. Afterwards, its effect on the market structure will be investigated.

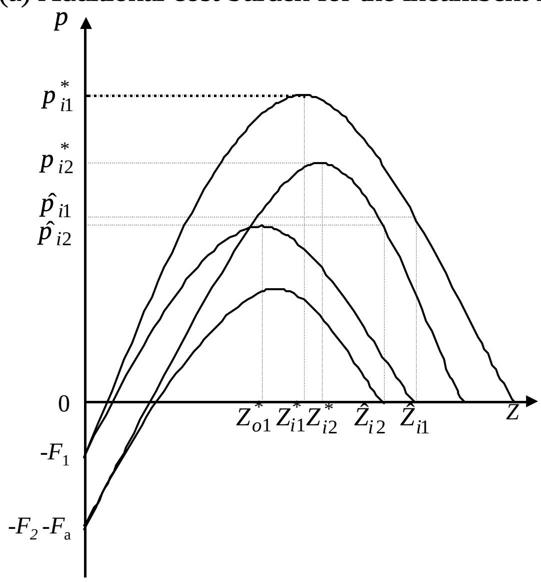
By assumption, the reduced energy intensity e_R can only be achieved with a new production technology. This entails a rise in fixed costs F because the new technology is either embodied in capital goods which have to be bought or rented or requires expenditures on R&D.[13] Energy intensity decreases with rising fixed costs, thus we have $e = e(F)$ with $\frac{\partial e}{\partial F} < 0$. However, the new technology uses a smaller amount of energy per unit capacity and therefore marginal costs are lower. Moreover, firms acquiring the new technology have to bear adaptation costs F_a.

Figure 4 shows the profit curves and resulting X-inefficiencies both with and without the imposition of the technological requirement. The index “1” stands for the situation without environmental policy (i.e. under the old technology) and “2” for the policy-induced situation (i.e. the new, environmentally friendlier technology).

The fixed costs the incumbent has to bear under a regulation policy (F_2+F_a) are larger than in the previous state without regulation (F_1). Therefore, the profit curves of both types of managers lie below the profit curves without policy. Dependent on the changes of variable and fixed costs, two cases can be distinguished. In case (a) the higher fixed costs reduce the outsider-manager’s profit over the whole range of possible capacities, while the reduction in variable costs is not large enough to compensate the higher fixed costs and adaptation costs. Therefore, from the viewpoint of the insider the optimal capacity is reduced.

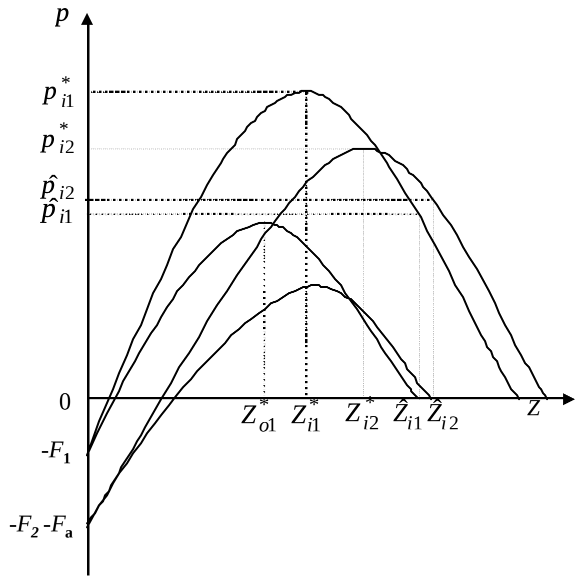
Figure 4: Monopolistic and X-inefficient capacity under regulation policy

(a) Additional cost burden for the incumbent firm



(b) Cost savings for the incumbent firm in case of large capacities

[13] For this reason the new technology implies a smaller profit in the monopolistic case and is therefore not implemented by the owner of the monopolistic firm in period 0.



A different situation arises in case (b). Here, the reduction in variable costs compensates for large capacities the adaptation costs and the increase in fixed costs. The X-inefficient capacity increases, since the profit making capabilities of the outsider-manager are enhanced and the insider has to implement a higher capacity than before to protect his position.

In both cases, $\frac{\hat{p}_{1i}}{p^*_{1i}} = g_1 < g_2 = \frac{p_{2i}}{p^*_{2i}}$ holds. The degree of X-inefficiency is less under the new technology.

The change of the incumbent's capacity influences the incentives of a rival firm to enter the market. Its entry decision can be analyzed on the basis of Figure 5.

Figure 5: Fixed costs and adaptation costs and the market entry decision of the rival firm

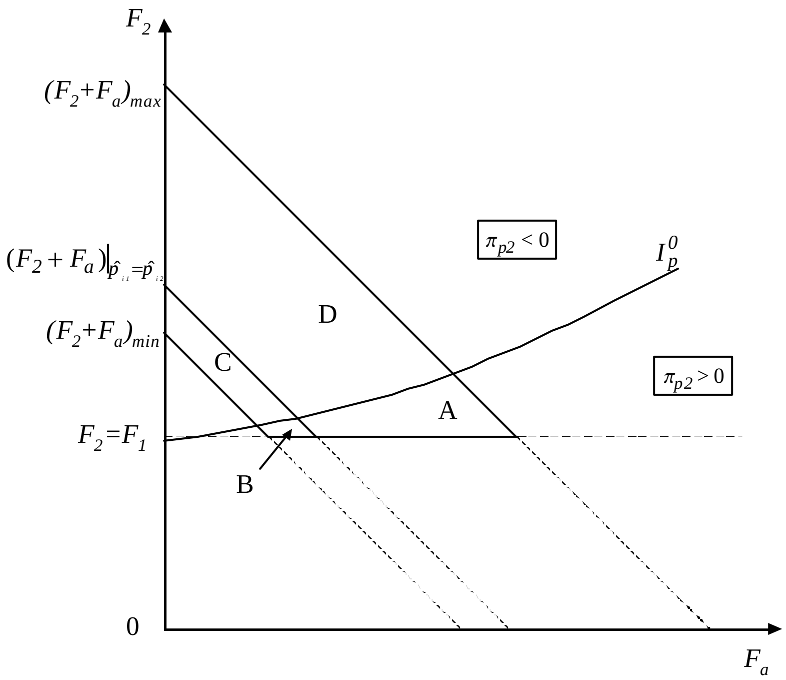


Figure 5 depicts different combinations of fixed costs (F_2) and the adaptation costs (F_a) resulting from regulation with a given reduction in variable costs from g_1 to g_2. The reasonable cost combinations are restricted to certain areas of the diagram. The lower bound of F_2 is given by the assumption that the fixed costs of the technology 2 are larger than those of technology 1 (F_1). In addition, all reasonable cost combinations have to lie above of the negatively sloped line indicated by $(F_2 + F_a)_{min}$. This line results from the condition that the monopolistic profit is smaller under the new technology than under the old one. Further, the sum of fixed and adaptation costs must be lower than $(F_2 + F_a)_{max}$ which is given by the assumption that the outsider-manager can not make any positive profit at all. Values of $(F_2 + F_a)$ larger than $(F_2 + F_a)_{max}$ would imply that X-inefficiency would not exist within the framework of this model.

These restrictions together define the area of relevant cost combiantions (A+B+C+D). The area can be further subdivided into the parts (A+D) and (B+C): The negatively sloped line in the middle is defined by the assumption that the profit of the monopolistic firm in an X-inefficient situation is identical regardless of the technologies. Should the cost components exceed $(F_2 + F_a)\big|_{\hat{p}_{i1}=\hat{p}_{i2}}$ a situation as shown in Figure 4(a) arises and the capacity of the incumbent firm will be downsized as a response to the new regulation (areas A+D). If costs do not surpass $(F_2 + F_a)\big|_{\hat{p}_{i1}=\hat{p}_{i2}}$ Figure 4(b) pictures the relevant situation with a rise in the incumbent's capacity (areas C+D).

Figure 5 shows that the decision on market entry of the rival firm depends on the ratio of fixed costs F_2 to adaptation costs F_a. Cost combinations resulting in indifference on behalf of the rival firm between entrance and non entrance are given by the isoprofitcurve I_p^0. This curve is defined by

$$p_p = (1 - \hat{Z}_{i2} - Z_{p2})Z_{p2} - g_{p2}Z_{p2} - F_2 = 0\,, \tag{11}$$

where Z_{p2} is the maximum of the potential entrant's profit function (equation (12)) as a Stackelberg-follower:

$$Z_{p2} = \frac{1 - \hat{Z}_{i2} - g_{p2}}{2}\,. \tag{12}$$

In the area (A+B) below I_p^0 the profit of the rival firm in case of market entry is positive, in the area above it is negative (C+D). The curve is positively sloped due to the asymmetric cost burdens on the incumbent and the rival firm: Whereas the fixed costs are borne by both competitors, the adaptation costs are borne only by the incumbent firm. With rising adaptation costs, the capacity of the incumbent firm decreases (c.f. equation (7)) and the rival firm is now able to obtain a positive profit. It will thus decide to enter the market even if the fixed costs F_2 are slightly larger. Therefore, a technological production standard can induce market entrance of the rival firm. The sum of the provided capacities rise and the economic efficiency enhances. A necessary condition is that fixed costs are not too large compared to the adaptation costs.[14]

[14] Rothfels (1999) shows that welfare can also increase should the enter be still deterred under a regulatory scheme. The necessary condition for this result is an increase in the capacity of the incumbent. This can come about when the cost combination lies in area C of figure 5, which

Next, we have to investigate whether this kind of regulation will also reduce emissions and therefore produce a "double dividend". The problem is obvious: On the one hand, the regulation policy reduces the energy intensity per unit of capacity, while on the other hand, it raises the number of firms and the sum of the provided capacities, which in turn will increase the total use of the environmentally harmful resource *E*. Ex-ante it is therefore unclear whether environmental quality will improve or even deteriorate. A similar problem arises regarding the welfare implications. On the one hand, the increase in capacity has a positive effect on welfare. On the other hand regulation will go along with lower profits with a corresponding negative impact. The results of the following analysis are summarized in

Proposition 2: *Environmental regulation of an X-inefficiently organized industry can simultaneously improve environmental quality and raise welfare.*

First we discuss the impact of regulation on environmental quality. A sufficient condition for regulation to enhance environmental quality is that its impact on the energy intensity is large enough so that the condition

$$e_1 \hat{Z}_{i1} \geq e_R (\hat{Z}_{i2} + Z_{p2}) \tag{13}$$

is satisfied. In other words, the reduction of ϵ to ϵ_R has to be sufficiently large. This will depend on the characteristics of the environmentally friendlier technology and is a question that can actually only be dealt with on the basis of empirical information about the costs involved with the reduction of energy intensity. Nevertheless, our model does allow a more precise statement since the fixed costs have a twofold influence which guarantees that condition (13) can be satisfied. Higher fixed costs on the one hand result in a larger reduction of energy intensity, and on the other hand induce a smaller increase in capacity. Therefore condition (13) will be fulfilled if the fixed costs are relatively large.[15]

Taken together the results so far show that the fixed costs of the new technology display diverging influences in the context of our model. As proposition 1 stated the new fixed costs must not be too high for market entry to occur. On the other hand, they must not be too low either, otherwise a reduction in the energy intensity will be not large enough to secure a healthier environment. Numerical simulations produce evidence that reasonable parameter constellations exist where market entry occurs *and* environmental quality enhances. Thus, regulation can create a "double dividend".

Now we turn to the impact of regulation on welfare. As we have just shown, the aggregate use of energy will drop if the reduction in energy intensity is strong enough. The effect on the consumer surplus depends on aggregate output. Under the conditions of proposition 1 we know that the number of firms in the market will increase. This goes hand in hand with an increase in the provided capacity, thus consumer surplus will rise. However, a negative impact

corresponds with Figure 4(b). Since the profit of the incumbent increases and, if the new technology is clean enough, environmental quality improves, a "win-win" situation arises. For this see also Gabel and Sinclair-Desgagné (1998).

In area *D*, welfare decreases because of shrinking capacity. However, in this case an improvement in environmental quality occurs.

[15] The numerical simulations given in the Appendix show different cost combinations and the corresponding reduction of energy intensity resulting in a constant environmental quality.

on welfare arises out of the third determinant, i.e. the profit component. Since the incumbent firm will lose its monopolistic position, its profit will be reduced. This loss can not be compensated by the profit of the entrant as the sum of profits in the dyopoly case is lower than the monopolistic profit. It remains to be shown that the positive effects are not outweighted by the loss in profit. Again, our numerical simulations show that this can be the case and that environmental regulation can result in welfare increases if the fixed costs F_2 are not too high.[16]

b. Taxation

We now turn to the impact of the second possible policy measure mentioned above, i.e. taxation of the environmental harmful resource. We assume that the tax policy consists of a tax rate t which raises the factor price of E from e to $e + t$.[17] This will induce firms to shift away from the use of E. Taxation results in an increase of marginal costs from g_i to $g_{i\tau}$ with

$$g_{it} = (1+t)^{b_1} g_i . \qquad (14)$$

The results of our analysis are summerized in

Proposition 3: *A "green" tax policy which taxes the use of the emission-generating resource E (and thus raises marginal production costs g) increases the number of firms in the market.*

First, we have to ask about the impacts of taxation on X-inefficiency. As for the command-and-control type of regulation, the tax on E reduces the insider's and the outsider's profit (c.f. Figure 6). The monopolistic output of the incumbent is reduced and consequently X-inefficiency is also reduced, i.e. one can show that

$$\frac{\partial g_t}{\partial t} > 0 .$$

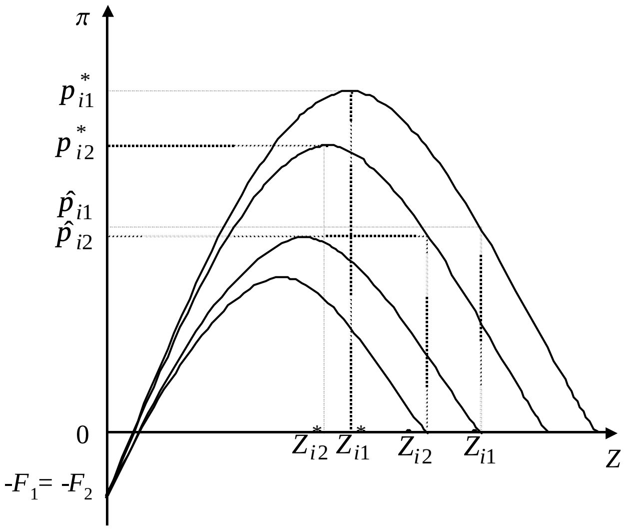
This depends on fixed costs and the productivity disadvantage of the outsider being not too large.[18] However, the reduction could be smaller than under command-and-control regulation. The reason for this lies in the lesser pressure felt by the incumbent. Therefore, the insider's possibilities to reduce X-inefficiency are less than under a regulatory policy.

Figure 6: Monopolistic and X-inefficient capacity under taxation

[16] In the different simulations in the Appendix the environmental quality remains unchanged. This allows us to compare the impact of the policy measure on the other welfare components. However, it has to be kept in mind that the requirements for the reduction of energy intensity are different for the different cost combinations. This can be seen by a comparison of ΔF and $\Delta\epsilon$ in the last two rows of Table 2a in the Appendix.

[17] In what follows, variables after taxation are characterized by index t.

[18] For the proof see Rothfels (1999).



Second, we have to turn to the effects of taxation on the entry decision of the rival firm. Taxation will induce market entry if the profit of the rival firm

$$p_{pt} = (1 - \hat{Z}_{it} - Z_{pt})Z_{pt} - g_{pt}Z_{pt} - F \qquad (15)$$

is positive. The marginal costs of the potential entrant (g_{pt}) equal the marginal costs of the incumbent firm (g_{it}). The first order condition for profit maximizing yields the capacity

$$Z_{pt} = \frac{1 - \hat{Z}_{it} - g_{pt}}{2}. \qquad (16)$$

Taxation has two conflicting impacts on the market entry decision. On the one hand, the capacity of the incumbent shrinks. Market entry therefore becomes more attractive. On the other hand, the entrant's marginal costs rise which has a negative impact. It can be shown that the positive effect always dominates (see Appendix 2b).

To summarize: Taxation can reduce X-inefficiency and increase the number of market participants. It yet remains to be discussed whether a green tax policy can also create a ”double dividend” by simultaneously improving the quality of the environment and whether it results in welfare improvements.

Proposition 4 *An environmental tax policy can increase environmental quality and welfare. However, the welfare gain may be smaller than under regulation, depending on the cost increase of a regulatory scheme.*

Again, the influences on environmental quality are divergent. Since the number of market participants increases the total use of the harmful production factor E grows, too. Environmental quality is only enhanced if the condition

$$\hat{E}_i \geq \hat{E}_{it} + E_{pt} \qquad (17)$$

is satisfied. The quantities of E can be derived from the constrained factor demands which in turn can be derived from the production function in equation (1). Before taxation factor demand is given by

$$\hat{E}_i = \hat{Z}_i^{\frac{1}{b_1+b_2}} \left(\frac{r}{e} \frac{b_1}{b_2} \right)^{\frac{b_2}{b_1+b_2}} . \tag{18}$$

Afterwards it is for the incumbent

$$\hat{E}_{it} = \hat{Z}_{it}^{\frac{1}{b_1+b_2}} \left(\frac{r}{e(1+t)} \frac{b_1}{b_2} \right)^{\frac{b_2}{b_1+b_2}} = \left(\frac{1}{1+t} \right)^{\frac{b_2}{b_1+b_2}} \hat{E}_i \tag{19}$$

and for the entrant

$$E_{pt} = Z_{pt}^{\frac{1}{b_1+b_2}} \left(\frac{r}{e(1+t)} \frac{b_1}{b_2} \right)^{\frac{b_2}{b_1+b_2}} . \tag{20}$$

These relations allow for the derivation of a minimum tax rate dependent on the assumed production function assuring that environmental quality does not deteriorate.[19] Taxing the resource E will improve the quality of the environment, if the tax rate exceeds this minimum level.

Taking the results together, we obtained two positive effects on welfare under the condition of a certain minimal tax rate. Capacity and consumer surplus increase while environmental damage decreases. However, analogous to the before examined command-and-control regulation we also obtain a negative effect on the sum of the firms' profits. For this reason the tax rate can not exceed a certain upper limit if a welfare increase is to result. Again, numerical simulations show that a range of values of the tax rate exist which allow for a welfare increase. However, depending on the cost parameters of the new technology, the welfare gain might be larger if a command-and-control policy is implemented.[20]

5. Conclusions

The aim of this paper has been to show that in the case of X-inefficient organized firms environmental policy measures can enhance environmental quality and equally raise the efficiency of domestic firms and of the market outcome. This we call a "double dividend".

For this purpose we developed a model that allows the investigation of the impact of environmental policy measures on X-inefficient firms. The driving force for the double dividend is reduced X-inefficiency and stronger competition on the output market. Positive welfare effects arise, as aggregate output increases with benefits to consumers. These positive effects can occur under a tax policy as well as under a command-and-control policy.

A further implication of our model concerns the relation of the welfare effects of taxation and of a command-and-control policy. In other models that deal only with allocative inefficiencies, command-and-control policies are usually shown to be inferior if compared to incentive-based policies, e.g. taxation. However, we showed that this evaluation may differ if one allows for additional inefficiencies such as X-inefficiency. The outcome depends on the fixed and adaptation costs of an environmental friendlier technology under the command-and-control

[19] The necessary tax rate t_{min} under which environmental quality remains unchanged is given in Table 2b in the Appendix.

[20] See the ranking list in Tables 1, 2a and 2b in the Appendix.

policy. Under special circumstances, i.e. when the fixed costs and the adaptation costs of the new technology are not too large and the ratio of fixed to adaptation costs is relatively small, a command-and-control policy can result in a higher welfare gain.

Appendix 1: Results of numerical simulations

Table 1: Benchmark case

g_{i1}	0,1
g_{i2}	0,09
g_{o1}	0,3
g_{o2}	0,29
g_{p1}	0,1
g_{p2}	0,09
F_1	0,01180371

$\hat{Z}_{i1}$	0,682711
$\hat{p}_{i1}$	0,136542
p^*_{i1}	0,190696
γ_1	0,7160192
CS	0,233047
D	0,233047 $d\,e_1^2$
W	0,369589 - 0,233047 $d\,e_1^2$
$(F_2+F_a)_{min}$	0,0163287
$(F_2+F_a)_{max}$	0,0186308
Ranking	**VII**

The parameter values of the benchmark case are determined as follows: The values for the marginal costs of technology 1 are given exogenously. This allows the derivation of the fixed costs under which the potential entrant receives zero profit. For this, the equations

$$\hat{Z}_i = \frac{1}{2}\left(1 - g_o + \sqrt{(1-g_o)^2 - 4F}\right),$$

$$p_p = (1 - \hat{Z}_i - Z_p)Z_p - g_p Z_p - F_p = 0$$

and

$$Z_p = \frac{1 - \hat{Z}_i - g_p}{2}$$

are solved simultaneously. Then the values of the other variables can be determined according to the equations given in the text. The energy intensity in the benchmark case is

$$e_1 = \left(\frac{r}{e}\frac{b_1}{b_2}\right)^{\frac{b_2}{b_1+b_2}}.$$

Figure A.5: Fixed costs and adaptation costs and the market entry decision of the rival firm

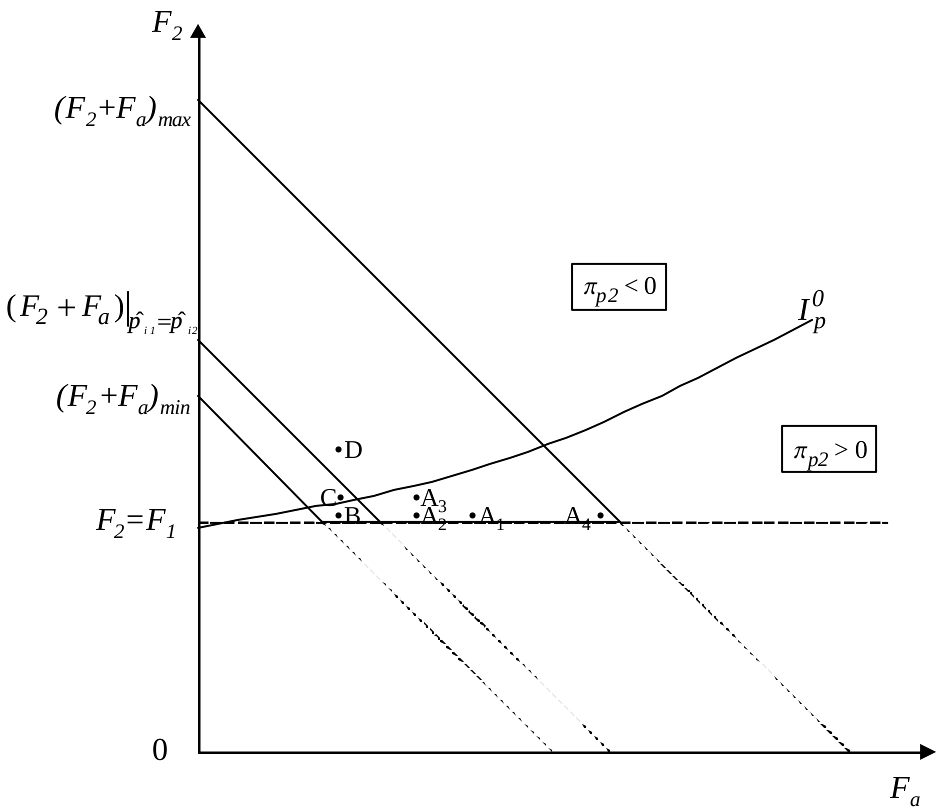


Table 2a: Impact of command-and-control regulation assuming that environmental damage remains unchanged (the columns indicate the different cost combinations in Figure A.5)

Parameter	B	A_2	A_3	A_1	C	D	A_4
F_2	0,012	0,012	0,013	0,012	0,013	0,015	0,012
F_a	0,005	0,008	0,008	F_1	0,005	0,005	0,02
$\hat{Z}_{i2}$	0,685189	0,680615	0,679076	0,674721	0,683672	0,680615	0,661635
Z_{p2}	0,112405	0,114693	0,115462	0,11764	-	-	0,124183
ΣZ	0,797594	0,795308	0,794538	0,792361	0,683672	0,680615	0,785818
p^*_{i2}	0,190025	0,187025	0,186025	0,183221	0,189025	0,187025	0,175025
$\hat{p}_{i2}$ (Mon.)	0,137038	0,136123	0,135815	0,134944	0,136734	0,136123	0,132327
γ_2	0,721158	0,727833	0,73009	0,7365	0,723364	0,72783	0,756046
$\hat{p}_{i2}$ (Dyo.)	0,060019	0,058062	0,057408	0,05557	-	-	0,050164
π_{p2}	0,000635	0,001154	0,000332	0,001839	-	-	0,003421
Σp	0,060654	0,059216	0,057739	0,057409	0,136734	0,136123	0,053585
CS	0,318078	0,316257	0,315645	0,313918	0,233704	0,231618	0,305477
$\bar{e}_{\min}$	0,855963 e_1	0,858423 e_1	0,859255e_1	0,861616 e_1	0,998594 e_1	1,003079 e_1	0,87344 e_1
D	0,233047 $d e_1^2$	0,233047 $d e_1^2$	0,233047 $d e_1^2$	0,233047 $d e_1^2$	0,233047 $d e_1^2$	0,233047 $d e_1^2$	0,23305 $d e_1^2$
W	0,378732 - 0,233047 $d e_1^2$	0,375473 - 0,233047 $d e_1^2$	0,373384 - 0,233047 $d e_1^2$	0,371327 - 0,233047 $d e_1^2$	0,370438 - 0,233047 $d e_1^2$	0,367741 - 0,233047 $d e_1^2$	0,359061 - 0,233047 $d e_1^2$
Ranking	**I**	**II**	**IV**	**V**	**VI**	**VIII**	**IX**
ΔF (in vH)	1,66	1,66	10,13	1,66	10,13	27,08	1,66
Δe (in vH)	-14,4	-14,2	-14,1	-13,8	-0,14	+0,003	-12,7

Compared to the benchmark case welfare increased in points A_1, A_2, A_3, B, and C. In B and A_2 the welfare increase is larger under a regulatory command-and-control policy than under taxation.

Table 2b: Impact of taxation

	$\beta_1 = 0{,}1$ und $\beta_2 = 0{,}9$
$\hat{Z}_{it}$	0,681037
Z_{pt}	0,108666
ΣZ	0,789703
ΔZ	15,67 vH
τ_{min}	0,175579
$g_{i\tau} = g_{p\tau}$	0,101631
$\epsilon_{i\tau}$	0,864517 ϵ_i
$p_{i\tau}$	0,062202
$p_{p\tau}$	0,00000459
Σp	0,06220649
γ_τ	0,717021
CS	0,311815
D	0,233047 $d e_i^2$
W	0,374022 - 0,233047 $d e_i^2$
Ranking	**III**

Appendix 2: Analytical proofs

a. Principal-Agent problem

To derive the X-inefficient capacity we solve the manager's decision problem backwards, thus starting in the last period *T* (see also Kamecke (1993)).
In *T* the firm operates with the capacity Z_T which was ordered in period *T-1*. The owner continues to employ the manager of the previous period (the insider) if the insider offers him a contract $(\alpha_{i,T}, w_{i,T})$ which satisfies

$$w_{i,T} + \alpha_{i,T}\left(\pi_i(Z_T) - w_{i,T}\right) \leq \pi_i(Z_T) - \pi_o(Z_T).$$

This means that the insider's wage w and profit share α are equal to or smaller than the additional profit the firm receives if the insider is employed instead of an outsider.
In equilibrium the insider will receive exactly the difference between the firm's profit under his management and the profit under the outsider's management:

$$w_{i,T} + \alpha_{i,T}\left(\pi_i(Z_T) - w_{i,T}\right) = \pi_i(Z_T) - \max\{0; \pi_o(Z_T)\}. \tag{i}$$

In *T-1* the insider tries to maximize his next period pay-off, given in equation (i). Thus, he orders the capital stock $\hat{Z}_T$ to maximize the right hand side of equation (i):

$$D(Z) := \pi_i(Z) - \max\{0; \pi_o(Z)\}.$$

Since in *T-1* the insider could be undercut by an outsider we have to take the outsider's offer into account. This can consist of a side payment to the owner. The outsider will be willing to work at $(\alpha_{o,T-1}, w_{o,T-1})$ if this side payment to the owner is not larger than the pay-off he receives as an insider in period *T* (i.e. if the owner hires him instead of the insider). Therefore we can derive the following condition for the outsider's offer:

$$w_{o,T-1} + \alpha_{o,T-1}\left(\pi_o(Z_{T-1}) - w_{o,T-1}\right) \geq -D\hat{Z}_{i,T}.$$

The insider will be rehired in period *T-1* if he proposes a profit share and wage $(\alpha_{i,T-1}, w_{i,T-1})$ such that the pay-off the owner will receive if he rehires the insider is larger than if he hires an outsider. This yields the following condition for the insider's salary in *T-1*:

$$(1 - \alpha_{i,T-1})\left(\pi_i(Z_{i,T-1}) - w_{i,T-1}\right) \geq \pi_o(Z_{i,T-1}) + D(\hat{Z}_{i,T}).$$

In equilibrium equality holds, and the condition can be transformed into

$$w_{i,T-1} + \alpha_{i,T-1}\left(\pi_i(Z_{i,T-1}) - w_{i,T-1}\right) = D(Z_{i,T-1}) - D(\hat{Z}_{i,T}).$$

This expression is again maximal for $\hat{Z}_{i,T-1} = \hat{Z}_{i,T}$. The same applies for all remaining periods save the first one: In the first period all potential managers bid to become the insider for the remaining periods. We assume that they are willing to offer their first period salary and their last period pay-off in order to be hired. One of them is chosen by the owner in a random fashion.

b. Impact of taxation on the market entry decision of the potential rival

We differentiate equation (17) and get

$$\frac{\partial p_{pt}}{\partial t}=\frac{\partial g_{it}}{\partial t}\left[\left(-\frac{\partial \hat{Z}_{it}}{\partial g_{it}}-\frac{\partial Z_{pt}}{\partial g_{it}}\right)Z_{pt}+(1-\hat{Z}_{it}-Z_{pt})\frac{\partial Z_{pt}}{\partial g_{it}}-\left(Z_{pt}+g_{it}\frac{\partial Z_{pt}}{\partial g_{it}}\right)\right]. \quad \text{(ii)}$$

Market entry occurs if expression (19) has a positive sign. Proving this requires several steps: The impact of the taxation on the capacities of the incumbent and the potential entrant is

$$\frac{\partial \hat{Z}_{it}}{\partial t}=\frac{\partial \hat{Z}_{it}}{\partial g_{it}}\frac{\partial g_{it}}{\partial t}=\frac{\partial g_{it}}{\partial t}\frac{1}{2}\left(-1-\frac{1-g_{ot}}{\sqrt{(1-g_{ot})^2-4F}}\right)<0 \quad \text{(iii)}$$

and

$$\frac{\partial Z_{pt}}{\partial t}=\frac{\partial g_{pt}}{\partial t}\frac{1}{2}\left(-1-\frac{\partial \hat{Z}_{it}}{\partial g_{it}}\right). \quad \text{(iv)}$$

Since we have $\frac{\partial g}{\partial t}>0$ expression (iv) has a positive sign if the condition

$$\frac{\partial \hat{Z}_{it}}{\partial g_{it}}<-1$$

holds. With equation (iii) one can show that this is true. Equation (ii) simplifies to

$$\frac{\partial p_{pt}}{\partial t}=\frac{\partial g_{it}}{\partial t}\frac{1}{2}\left(-\frac{\partial \hat{Z}_{it}}{\partial g_{it}}-1\right)(1-\hat{Z}_{it}-g_{it}),$$

and one can show that this condition is positive if

$$(g_{ot}-g_{it})(1-g_{it})>-F$$

holds. This condition is always satisfied.

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