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Noncooperative National Environmental Policies and International Capital Mobility

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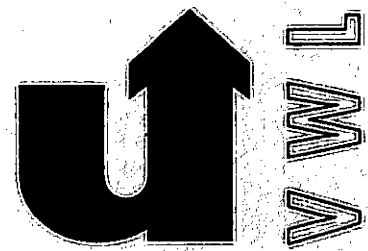
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**VOLKSWIRTSCHAFTLICHE
DISKUSSIONSBEITRÄGE**



**NONCOOPERATIVE NATIONAL
ENVIRONMENTAL POLICIES AND
INTERNATIONAL CAPITAL MOBILITY**

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DISCUSSION PAPER No. 49-94

**UNIVERSITÄT - GESAMTHOCHSCHULE - SIEGEN
FACHBEREICH WIRTSCHAFTSWISSENSCHAFTEN**

Abstract

This paper investigates the repercussions of noncooperative national environmental policies on international capital investments in the absence of transfrontier pollution with an emphasis on the consequences of removing the barriers to international capital transactions. Such repercussions are not insignificant among European countries which experience an 'oligopolistic interdependence' in various policy areas. The impact of national environmental controls on international (physical) capital flows is investigated not only under perfect information with strategic environmental policy formation but also in the absence of perfect information on pollution damage and abatement costs. Whatever pragmatic rule of pollution control is followed by individual countries in the latter case, it will lead to repercussions in the international capital market which should be well understood in the process of European economic integration.

The present paper addresses these issues in a simple one-sector model applying two different production-emissions technologies: production with integrated abatement technology and production on the basis of pollution-generating capital, but without abatement technology. In each of these two cases the consequences of capital mobility and international capital market liberalization are investigated when alternatively non-strategic, strategic or information-constrained environmental policies are pursued. It is shown that (under perfect information) non-cooperative behavior leads to allocative distortions with emission taxes deviating from their Pigouvian levels. But the analysis does not support some environmentalists's worries that if national environmental policies are uncoordinated, all national environmental quality standards will be 'competed down' in order to attract foreign capital in beggar-my-neighbor style.

Noncooperative National Environmental Policies and International Capital Mobility

Rüdiger Pethig¹, University of Siegen

1. Introduction

The emission of pollutants and its regulation by national environmental policies create international interdependence in a direct way through transfrontier pollution, and in an indirect way through international commodity trade (i.e. trade in final goods) and/or international factor markets. This interdependence is particularly obvious in the case of transfrontier pollution (e.g. OECD 1974, Pethig 1981) which leads to an inefficient allocation of resources in the absence of cooperation even if the countries involved are not engaged in any international economic interactions. But suppose the impact of domestic emissions of pollutants is purely domestic and the countries are interconnected by commodity trade or international factor mobility. Do we expect that 'institutional international competition' between national environmental policies is efficiency enhancing or distortion inducing?

The interaction between international commodity trade and national environmental policies (with or without transfrontier pollution) has been extensively discussed in the literature (e.g. by Markusen 1975, Pethig 1976, Gronych 1980, Siebert et al. 1980, Krutilla 1991, Ulph 1991, Conrad 1993, Kennedy 1993). Essentially, the (in-)efficiency implications of market-related indirect environmental interaction depend on the 'perfectness of competition' in the international markets and on the sophistication of national governments in choosing their environmental policies. As will be elaborated below, governments may either make (strategic) use of or ignore the impact of their environmental policy on trade flows and market-clearing prices in international markets.

The question, whether the interdependence of international factor transactions and national environmental policies is a potential problem of 'ecological dumping' in the course of establishing the internal European market, lead to a controversial discussion (Siebert 1991; Rauscher 1991, 1992a, 1992b). Environmentalists worry that if national environmental policies are uncoordinated, international capital will move to countries

¹ Helpful comments by Klaus Fiedler, Hildegard Müller, Matthias Prinzler and Michael Rauscher are gratefully acknowledged. All remaining errors are the author's responsibility.

with low environmental quality standards, and all countries' quality standards will be 'competed down' in order to attract capital in a beggar-my-neighbor style. However, this issue did not yet receive very much attention in the theory-oriented literature, in our view. Oates & Schwab (1988) and Long & Siebert (1991) reached the conclusion that with strictly domestic pollution and price taking firms on the international capital market "... competition among jurisdictions is .. conducive to efficient outcomes" because "... society's and the community's evaluation of the costs and benefits of environmental policy are identical" (Oates & Schwab 1988, p. 342). Therefore "... the competitive process and the international mobility of capital leads to an efficient allocation of resources" (Long and Siebert 1991, p. 299). In contrast, Rauscher (1991) shows that in the absence of cooperation it is not in the countries' self-interest to equate marginal pollution damage and marginal abatement costs.

To avoid intermingling of different international effects of national pollution controls the present paper ignores both transfrontier pollution and international commodity trade to focus exclusively on the interaction of pollution control and international factor mobility on perfectly competitive markets². The principal objective is to investigate interactions of noncooperative national environmental policies and international capital investments with a special emphasis on the consequences of removing the barriers to international capital transactions.

The efficiency claim of noncooperative environmental policies in the presence of mobile capital has been established, like the analogous conclusion in the literature on trade and the environment, by assuming

- that all governments have perfect information on domestic pollution damage and abatement costs, and
- that all governments' pollution controls are non-strategic in the sense that they ignore their impact on the market-clearing rate of return on capital in the international capital market.

These assumptions appear to be unsatisfactory since if it is argued that rational and benevolent governments implement the first best Pigouvian policy of internalizing domestic environmental externalities under perfect information, consistency requires to interpret non-strategic behavior as the government's deliberate neglect of international repercussions of its own actions. But unless the country is very small (causing only very small repercussions) deliberate neglect is not rational for a benevolent and omniscient government, since it turns out that Pigouvian taxation is not in the country's self-interest. The repercussions of national environmental policies on international

² Siebert et al. (1980) investigate a neoclassical two-country, two-commodity, two-factor model with both international commodity trade *and* capital transactions.

markets for production factors are not insignificant among the larger countries in Europe. Their 'oligopolistic interdependence' is obvious not only in the field of pollution control, but also in various other policy areas, such as monetary and fiscal policy³. Therefore, it is necessary to investigate – as Rauscher (1991) does – the non-market interdependence under perfect information *in a consistent way*, i.e. with strategic environmental policy formation.

Though it is important to know what the governments' options are in case of perfect information it is also clear that real-world environmental policies suffer from severe informational constraints. Without perfect information on pollution damage and abatement cost governments usually proceed with politically determined (second best) emissions standards and/or emissions tax rates – as had been suggested long ago by Baumol and Oates (1971) to avoid the Nirvana status of the Pigouvian approach. Whatever pragmatic rule of pollution control is followed by a country, it will lead to repercussions in international markets which should be well understood in the process of European economic integration which aims at reducing barriers to trade in the markets for capital investments among the member states of the European Community.

The present paper addresses these issues in a simple one-sector model applying two different production-emissions technologies: production with integrated abatement technology (Section 2) and production on the basis of pollution-generating capital, but without abatement technology (Section 3). In the former case, the emission of pollutants can be curbed by using less emission-intensive techniques, e. g. the SO₂ emissions of coal firing power plants can be reduced by implementing filters. The second production-emissions technology assumes that emissions are strictly proportional to a particular input (here: capital) independent of the level of outputs and other inputs. This assumption appears to be somewhat unrealistic, but it highlights the link between capital mobility and environmental issues in the simplest possible way: any import of (physical) capital is an import of pollution. In each of these two cases the consequences of capital mobility and international capital market liberalization are investigated when, alternatively, non-strategic, strategic or information-constrained environmental policies are pursued.

³ An illuminating example is a recent bill on taxation of firms in Germany. The official reason given for that amendment was to secure the competitiveness of Germany as 'location for industry' (Standortsicherungsgesetz) in view of trends of tax legislation in countries that are Germany's major trading partners.

2. Capital mobility in case of production with integrated abatement technology

2.1 The model

Consider a country that produces a single consumption good with the inputs *capital*, k , *labor*, ℓ , and nature's assimilative services that are equal to the total *emission of pollutants*, e . The production function, F , exhibits constant returns to scale, and the *per-capita output* is given by⁴

$$(1) \quad y = \underset{+ \quad + \quad +}{F(k, \ell, e)} / \ell =: \underset{+ \quad +}{Y(x, z)},$$

where $x := k/\ell$, $z := e/\ell$ and $Y_{xz} > 0$. The economy's aggregate *endowment of labor*, ℓ_0 , is constant and so is the *capital endowment*, k_0 . Consumers have identical preferences represented by the quasi-concave *utility function*

$$(2) \quad u = \underset{+ \quad -}{U(c, z)},$$

which satisfies $U_{cc} \leq 0$, $U_{zz} \leq 0$ and $U_{zc} \leq 0$. If each consumer has the same working time and receives the same share of capital income and tax revenue (in case an emissions tax is levied), the individual's *consumption*, c , is

$$(3) \quad c = Y(x, z).$$

Environmental policy may take the form of fixing an emissions standard per capita directly. In what follows, we choose to present the analysis in terms of an *emissions tax policy* which will turn out to highlight the interaction of national pollution controls and the international capital market in a particularly interesting way. Throughout the paper we assume that firms are price takers implying that they set the (per capita) *emissions tax rate*, t , equal to their marginal abatement cost, $Y_z(x, z)$.

For the purpose of later reference, we briefly recall that in the *closed economy* and under perfect information the emissions standard is efficiently set by maximizing an arbitrary consumer's utility (2) subject to (1), (3) and $\ell_0 \geq \ell$, $k_0 \geq k$. This yields

⁴ The plus or minus sign underneath an argument of a function indicates the sign of the respective partial derivative. Functions are generally represented by upper case letters, and subscripts to functions denote partial derivatives with respect to the argument that is used as subscript.

$$(4) \quad -\frac{U_z(c, z)}{U_c(c, z)} = Y_z(x, z).$$

Obviously, the maximum satisfies $x = x_0 := k_0/\ell_0$, so that equation (4) uniquely determines the emissions standard, z . In per capita terms the left side of (4) is the marginal damage of pollution and the right side is the marginal productivity of emissions which equals the marginal per capita abatement costs in terms of the consumption good. Suppose the government introduces an emission tax with rate t . Then it is profit maximizing for price taking firms to set $Y_z = t$. Therefore, the efficiency condition (4) will be achieved if the government fixes $t = (-U_z/U_c)$ which is known as the *Pigouvian tax*⁵.

On the other hand, if the information about abatement cost and pollution damage is insufficient, government may want to adopt a price-and-standard regime (Baumol & Oates 1972) where the political process determines "somehow" an aggregate emissions standard as the environmental policy goal which is then implemented by levying an appropriate emissions tax. The relationship between the standard, z , and the associated emissions tax rate, t , is very simple in the one-sector closed economy: Since $t = Y_z(x, z)$ and $x = x_0$, there is a function $Z : \mathbb{R}_+ \rightarrow \mathbb{R}_+$ such that $z = Z(t)$ satisfies $t = Y_z(x_0, z)$. The first derivative of Z is negative, as expected.

2.2 Non-strategic environmental policy

Suppose now, capital is internationally mobile, environmental information is perfect, and the country under consideration has no impact, or ignores its impact, on the *world rental rate of capital*, r . As a first step towards the investigation of a two-country model we consider a 'small open country' that takes the world price of capital as given. To analyze this case we replace the budget constraint (3) by

$$(5) \quad c = Y(x, z) - (x - x_0)r.$$

If the country imports capital [$x > x_0$] it pays $(x - x_0)r$ to the foreign capital owners out of its domestic output $Y(x, z)$ and consumes the rest determined by (5). Maximization of (2) under consideration of (1), (5) and $\ell \leq \ell_0$ results in (4) and

$$(6) \quad Y_x(x, z) = r.$$

⁵ Under perfect information one can also interpret such a policy as being implemented by majority voting — which is known to be Pareto-efficient when all individuals are identical.

As argued above, equation (4) means that the environmental externality is perfectly internalized, and equation (6) gives us the production efficiency condition that the domestic rate of return on capital be equal to the world price r . It is informative to see what the adjustments in t , x and z are when the world price of capital changes parametrically. The comparative static analysis (Appendix 1) yields the following major conclusions:

Result 1: Denote by $T(r)$, $X(r)$ and $Z(r)$ the values of t , x and z , respectively, that are determined as functions of the world price of capital, r , through the equations (4), (5) and (6). A small exogeneous change of r has the following consequences:

- (a) $T_r < 0$, $X_r < 0$ and $Z_r < 0$, if before the change in r the country's international capital transactions were zero or "sufficiently" small;
- (b) T_r ambiguous in sign, $X_r < 0$ and $Z_r < 0$, if the country exports capital ($x < x_0$);
- (c) $T_r < 0$, $X_r > 0$ and $Z_r > 0$, if the country's capital imports are 'sufficiently' large;
- (d) Under certain parameter constellations it is feasible that for (and only for) the capital-importing country the sign of Z_r is not equal to the sign of X_r .

Result 1 shows that the small country's optimal response to an increase in the world rate of return on capital is difficult to predict. The only 'unconditional' relationship seems to be that for a capital-exporting country a rise in the world price of capital always leads to increased capital exports and better environmental quality. Note also that $X(r)$ is the country's demand function for capital. One would expect that with an increase in the world rental rate of capital, the capital export [import] would increase [decrease] (i.e. $X_r < 0$). This seems to be the 'regular' reaction, indeed, but Result 1c shows that $X_r > 0$ in case of large capital imports.

– Figure 1 : Capital export and efficient pollution control response –

To understand the response $Z_r < 0$ consider Figure 1 where the autarky allocation is characterized by (r_0, x_0, z_0) and hence by the points A (upper part of Figure 1) and A' (lower part), hence by $r > r_0$. The necessary rise of $r_0 = Y_x(x_0, z_0)$ to r can be accomplished by allowing for various combinations of capital exports and changes in the emissions standard.

(a) Keep x_0 fixed and shift z_0 to $z_1 > z_0$. This implies a move from A' to B' and yields $r = Y_x(x_0, z_1)$ by construction. But the upper part of Figure 1 reveals that the difference BB" between the marginal damage of pollution, $MD(z_1)$, and the marginal abatement cost, $Y_z(x_0, z_1)$, is positive. Hence this strategy is not optimal.

(b) The opposite polar case is to keep z_0 fixed and shift x_0 to $x_1 < x_0$ so that $Y_x(x_1,$

$z_0) = r$ as illustrated by the move from A' to C' in Figure 1. But the upper part of Figure 1 shows that the marginal damage still exceeds the marginal abatement costs: $MD(z_0) - Y_z(x_1, z_0) = AC > 0$.

(c) Consequently, to achieve efficiency the capital imports must be increased beyond $x_1 - x_0$. But by doing so the condition $r = Y_x(x, z)$ can only be maintained if z is simultaneously reduced below z_0 . Eventually, one finds $\hat{x} < x_0$ and $\hat{z} < z_0$ satisfying both efficiency conditions, as illustrated by the points D and D' in Figure 1.

Observe finally that there are parameter constellations such as that of Result 1a where it is optimal to react to an increase in the capital price by reducing both the emissions tax rate and the level of emissions. This effect appears to be an important feature of capital mobility as the subsequent analysis will show.

We now turn to the two-country model. The country considered so far is called the home country. The foreign country is also characterized by the equations (1) and (2), but it is notationally distinguished from the home country by starred variables. As before, labor is assumed to be immobile. Perfect capital mobility between both countries is characterized by the condition that capital use in both countries, $k + k^* = \ell_0 x + \ell_0^* x^*$, must not exceed the world endowment with capital, $k_0 + k_0^*$. In formal terms,

$$(7) \quad k_0 + k_0^* \geq \ell_0 x + \ell_0^* x^* \quad \text{or} \quad \sigma_0 \geq \sigma x + x^*,$$

where $\sigma_0 := (k_0 + k_0^*)/\ell_0^*$ and $\sigma := \ell_0/\ell_0^*$. If both countries pursue non-strategic environmental policies, it is straightforward that the foreign country, like the home country, is characterized by the equations (4), (5) and (6). Denote by $X(r)$ the home country's per-capita demand for capital when the price of capital is r . The world market for capital clears when total capital endowment equals aggregate capital demand. In view of (7) the equilibrium condition can be written as $\sigma_0 = \sigma X(r) + X^*(r)$ which implicitly determines the equilibrium rental rate of capital. In equilibrium, the equations

$$(8) \quad Y_x(x, z) = Y_x^*(x^*, z^*),$$

$$(9) \quad c = Y(x, z) - (x - x_0) \cdot Y_x(x, z) \quad \text{and} \quad c^* = Y^*(x^*, z^*) - (x^* - x_0^*) \cdot Y_x^*(x^*, z^*)$$

hold⁶. The relationship between efficiency and equilibrium is summarized as

Result 2 (Oates & Schwab 1988): *In the two-country model, an efficient international allocation of resources is characterized by (4) (for both countries) and (8).*

⁶ In view of (7) (as an equality) and (9) it is easy to check that total consumption equals total production, i.e. $\ell_0 c + \ell_0^* c^* = \ell_0 y + \ell_0^* y^*$.

It can be attained by a perfectly competitive capital market and by noncooperative non-strategic national environmental tax policies with rates

$$t = Y_z = (-U_z/U_c) \quad \text{and} \quad t^* = Y_z^* = (-U_z^*/U_c^*).$$

2.3 Strategic environmental policy

In this section we wish to show for the two-country model, that the efficient allocation will not be brought about by decentralized noncooperative action, when the countries take into account the impacts on the international capital market of their own and the other country's environmental policy. The first step is to focus on the interdependence of the countries through their noncooperative environmental policies as given by (7), (8) and

$$(10) \quad t = Y_z(x, z) \quad \text{and} \quad t^* = Y_z^*(x^*, z^*).$$

+ - + -

These equations uniquely determine the variables x , x^* , z and z^* for each tuple (t, t^*) . In other words, there are four functions X , X^* , Z and Z^* whose derivatives exhibit the following signs (Appendix 2):

$$(11) \quad x = X(t, t^*), \quad x^* = X^*(t, t^*), \quad z = Z(t, t^*), \quad z^* = Z^*(t, t^*).$$

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Owing to (11) the equilibrium rate of return on capital is uniquely determined by the emissions tax rates:

$$(12) \quad r = R(t, t^*) := Y_x[X(t, t^*), Z(t, t^*)]$$

with $R_t = Y_{xx}X_t + Y_{xz}Z_t < 0$ and $R_{t^*} = Y_{xx}X_{t^*} + Y_{xz}Z_{t^*} < 0$. We now combine (4), (8) and the equations (11) to define the home country's payoff function as

$$(13) \quad P(t, t^*) := U\{Y[X(t, t^*), Z(t, t^*)] - [X(t, t^*) - x_0] \cdot R(t, t^*), Z(t, t^*)\}.$$

The foreign country's payoff function $P^*(t, t^*)$ is determined in a symmetric way. The tuple (\hat{t}, \hat{t}^*) constitutes a Cournot-Nash equilibrium, if $P(\hat{t}, \hat{t}^*) \geq P(t, \hat{t}^*)$, all t , and $P^*(\hat{t}, \hat{t}^*) \geq P^*(\hat{t}, t^*)$, all t^* . To characterize an equilibrium allocation $\hat{x} = X(\hat{t}, \hat{t}^*)$, \hat{x}^*

$= X^*(\hat{t}, \hat{t}^*)$, $\hat{z} = Z(\hat{t}, \hat{t}^*)$, and $\hat{z}^* = Z^*(\hat{t}, \hat{t}^*)$ we maximize⁷ $P(t, \hat{t}^*)$ with respect to t and $P^*(\hat{t}, t^*)$ with respect to t^* . An interior solution satisfies (Rauscher 1991)

$$(14) \quad t = Y_z = -\frac{U_z}{U_c} + (x - x_0) \cdot \frac{dr}{dz} \text{ and } t^* = Y_z^* = -\frac{U_z^*}{U_c^*} + (x^* - x_0^*) \cdot \frac{dr^*}{dz^*},$$

where

$$\frac{dr}{dz} := \frac{U_t}{Z_t} = \frac{\sigma Y_{yz}(Y_{xx}^* Y_{zz}^* - Y_{xz}^{*2})}{Y_{xx} Y_{zz}^* + \sigma(Y_{xx}^* Y_{zz} - Y_{xz}^2)} > 0 \text{ and}$$

$$\frac{dr^*}{dz^*} := \frac{R_{t^*}^*}{Z_{t^*}^*} = \frac{Y_{xt}^*(Y_{xx} Y_{zz} - Y_{xz}^2)}{\sigma Y_{xx}^* Y_{zz} + (Y_{xx} Y_{zz} - Y_{xz}^2)} > 0.$$

The equations (14) differ from (4) because now each unit of emissions has an additional (beneficial or detrimental) effect: it raises domestic capital income from foreign investment ($= (x - x_0) \cdot (dr/dz) > 0$) in case that $x < x_0$ or it reduces domestic income by increasing the bill for imported capital in case of $x > x_0$. An analogous argument applies to the foreign country.

Result 3: Suppose, the production–emissions technology is given by (1); capital is mobile between both countries; and each country considers its impact on the rental rate of capital as non-negligible.

(a) The capital–exporting country sets its emissions tax rate at an inefficiently low level and the capital–importing country sets it at an inefficiently high level. In view of (11), the capital–exporting [importing] country's emissions level is higher [lower] and its capital export [import] is lower [higher] than in case of non-strategic behavior⁸.

(b) A country's strategic potential of advantageous distortions as measured by the distortive effects $(x - x_0) \cdot (dr/dz)$ and $(x^* - x_0^*) \cdot (dr^*/dz^*)$ in equations (14) is c.p. the smaller, the smaller is the home country in terms of labor endowment relative to the other country.

Result 3a does not reflect the popular argument of ecological dumping according to which a country chooses an inefficiently lax environmental policy in order to attract foreign capital. On the contrary, it is advantageous for the capital–exporting country to raise its pollution above the Pigouvian level because relaxing the emissions standard

⁷ In general, the functions P and P^* are not concave in t and t^* , respectively. Rauscher (1991) shows that if emissions standards are taken as environmental policy instruments (rather than tax rates) concavity can be established if all third–order derivatives of production functions vanish.

⁸For more details and economic interpretations see Rauscher (1991).

increases the return on its capital working abroad. Conversely, the capital-importing country strengthens its environmental policy in an effort to reduce the bill to be paid on imported capital. As a result, the volume of international capital transaction is less than optimal, whereas the intuitive idea of ecological dumping seems to imply excessive international capital flows into 'pollution heavens'.

Result 3b shows that small countries tend to apply Pigouvian emissions tax rates while (very) large countries tend to assume the role of Stackelberg leaders. It is our conjecture that if, in a multi-country setting, all countries are relatively small with respect to the rest of the world, then the corresponding Cournot–Nash equilibrium of strategic environmental policies will be close to the solution where all countries pursue nonstrategic Pigouvian policies.

– **Figure 2:** Environmental policy distortions in the Cournot–Nash equilibrium –

Result 3a is illustrated in Figure 2 for the case that in autarky $r_0 < r_0^*$ and $z_0 > z_0^*$. It is also assumed that the marginal damage of pollution [$MD(z) = -U_z/U_c$] is the same in both countries and depends only on the level of emissions – as is the case when the utility functions are quasi-linear. In Figure 2 this initial situation is represented by the points A and A' for the home country and by B and B' for the foreign country. The allocation of the Cournot–Nash equilibrium $(\hat{x}, \hat{x}^*, \hat{z}, \hat{z}^*)$ satisfies $\hat{x} < x_0$, $\hat{x}^* > x_0^*$, $\hat{z} < z_0$ and $\hat{z}^* > z_0^*$. It is characterized by the points E and F for the home country and by E* and D for the foreign country. Observe also that $GF = MD(\hat{z}) - Y_z(\hat{x}, \hat{z}) > 0$ and $DC = Y_z^*(\hat{x}^*, \hat{z}^*) - MD(\hat{z}^*) > 0$ in conformity with (14).

Figure 2 depicts a situation that is compatible with the Cournot–Nash equilibrium conditions. But it cannot be concluded from this illustration that the equilibrium always satisfies $\hat{z} < \hat{z}_0$ and $z_0^* < \hat{z}^*$ if $(\hat{x}, \hat{x}^*, \hat{z}, \hat{z}^*)$ is the Cournot–Nash equilibrium with $\hat{x} < x_0$, $\hat{x}^* > x_0^*$, $r_0 < r_0^*$ and $z_0 > z_0^*$. Note however, that with the help of Figure 2 it is possible to establish the following proposition:

Result 4: Suppose that $(-U_z/U_c) = MD(z)$ and $(-U_z^*/U_c^*) = MD^*(z^*)$ with $MD_z > 0$ and $MD_z^* > 0$, as in Figure 2. Assume also that the home country exports capital in the Cournot–Nash equilibrium $(\hat{x}, \hat{x}^*, \hat{z}, \hat{z}^*)$. Then the home country's emissions tax rate is higher than in the autarkic situation.

To see this, observe first that $Y_z(x_0, \cdot) > Y_z(\hat{x}, \cdot)$ and $Y_z^*(x_0^*, \cdot) < Y_z^*(\hat{x}^*, \cdot)$. Moreover, owing to (14) the equilibrium fulfills $MD(\hat{z}) > Y_z(\hat{x}, \hat{z})$ and $MD^*(\hat{z}^*) < Y_z^*(\hat{x}^*, \hat{z}^*)$. In view of $MD_z > 0$, $MD_z^* > 0$ these properties yield the Result 4. Note,

however, that the tax rate reduction of the capital-exporting country does not necessarily imply a lower environmental quality. Figure 2 illustrates the possibility of an increase in environmental quality.

Unfortunately, it is very difficult to elicit additional properties of the Cournot–Nash equilibrium, because these depend on many second and third order effects of production technologies. Rauscher (1991) offers some additional important insights, but in general, neither the slopes of the reaction curves can be determined nor can we exclude multiple equilibria. It is very important to better understand what the strategic distortions of the Cournot–Nash equilibrium are like, in particular how environmental quality differs from that in autarky or from its welfare–maximal level when capital is mobile. Therefore, these issues are taken up again in Section 3 on the basis of a different production–emissions technology that lends itself more readily to simplifying parameterizations.

2.4 Information–constrained tax or standard policies

After having investigated the optimal noncooperative environmental control under full information we now turn to the price–and–standard approach. Here we do not intend to offer a systematic descriptive or normative analysis of how countries determine their tax rates or emissions standards. We are rather interested in the repercussions through the international capital market of some simple ad hoc environmental policy strategies either when international capital transactions are liberalized or when the initial situation is already characterized by a perfectly competitive international market⁹.

Consider first the case of a small open economy that reacts as a price taker to both the emissions tax rate and the world rental rate of capital by setting $t = Y_z(x, z)$ and $r = Y_x(x, z)$.

Result 5: *Suppose the real price of capital increases parametrically.*

(a) *If the country keeps its emissions tax rate constant, then its capital exports expands or its capital imports shrink, and its environmental quality improves. The change in welfare is ambiguous.*

(b) *If the country keeps its emissions standard constant by appropriate adjustments of the emissions tax rate, then its capital export increase or its capital imports diminish as described in Result 5a, but by a smaller amount. This policy is welfare–enhancing if the country invests abroad, but it reduces welfare otherwise.*

In the two–country world, the capital market interdependence is given by (11) and

⁹ Similar considerations can be found in Rauscher (1992a, 226 – 231).

(12) as shown in Section 2.3. Based on (11) it is possible to assess the consequences of different environmental strategies in the process of transition from autarky to full international capital mobility.

Result 6: *Let the autarkic equilibrium be given by (r_0, t_0, x_0, z_0) in the home country and by $(r_0^*, t_0^*, x_0^*, z_0^*)$ in the foreign country, and let $r_0 > r_0^*$ hold.*

(a) *Suppose that after capital market liberalization both countries stick to their emissions tax rates t_0 and t_0^* , respectively. Then*

- $X(t_0, t_0^*) > x_0$ and $X^*(t_0, t_0^*) < x_0^*$;
- $Z(t_0, t_0^*) > z_0$ and $Z^*(t_0, t_0^*) < z_0^*$;
- *The change in welfare of both countries is ambiguous;*

(b) *Suppose that after capital market liberalization both countries stick to their emissions standards z_0 and z_0^* , respectively, by adapting their emissions tax rates appropriately. Denote by t_1 and t_1^* the emissions tax rates at the new equilibrium. Then*

- $t_1 > t_0$ and $t_1^* < t_0^*$;
- $X(t_1, t_1^*) > x_0$ and $X^*(t_1, t_1^*) < x_0^*$;
- *The home country's welfare increases, and the foreign country's welfare deteriorates;*

(c) *Suppose that after capital market liberalization the home country sticks to its emissions tax rate t_0 and the foreign country maintains its emissions standard z_0^* . Then*

- $X(t_0, t_1^*) > x_0$ and $X^*(t_0, t_1^*) < x_0^*$;
- $Z(t_0, t_1^*) > z_0$ and $t_1^* < t_0^*$;
- *The home country's change in welfare is ambiguous, and the foreign country's welfare deteriorates;*

To prove the welfare implications of Result 6 we use (9) and determine the home country's change in consumption as

$$c - c_0 = \Delta C(x, z) := Y(x, z) - Y(x_0, z_0) - (x - x_0)Y_x(x, z).$$

Clearly, one has $\Delta C(x_0, z) > 0$ for all $z > z_0$ and $\Delta C(x, z_1) > 0$ for all $x > x_0$ and for all $z_1 \geq z_0$. Hence $\Delta C(x_1, z_1) > 0$ whenever $x_1 > x_0$ and $z_1 \geq z_0$. A similar argument applies with respect to the foreign country.

– **Figure 3:** Capital market liberalizations with constant emissions standards –

The striking feature of all these policies is that one of the countries or even both may incur a welfare loss after capital market liberalization. The 'risk' of becoming worse

off seems to be greater for the capital exporting country. The intuition for that is not clear, in particular not for the situation in which both countries stick to their autarkic emissions standards (Result 6b). This case is illustrated in Figure 3 where the autarkic situation is given by A_0 and A'_0 for the home country and by A_0^* and A'^*_0 for the foreign country (implying $r_0 > r_0^*$ and $t_0 < t_0^*$). The new equilibrium with mobile capital is characterized by the equilibrium price r_1 and by the new tax rates t_1 and t_1^* satisfying $t_1 > t_1^*$, $t_1 > t_0$ and $t_1^* < t_0^*$.

Suppose finally, capital is already perfectly mobile in the initial situation, each country chooses its emissions tax rate, and the international capital market is in equilibrium. In such a situation, one of the countries may want to change its tax rate. The consequences of that policy can be easily inferred from (11) and (12):

Result 7: *Suppose the international capital market is in equilibrium and the foreign country keeps its emissions tax rate constant while the home country increases its own emissions tax rate. Then¹⁰*

- (a) *the environmental quality improves in the home country, and it deteriorates in the foreign country;*
- (b) *the home country's capital import is reduced or its capital export expanded;*
- (c) *the world rental rate on capital decreases.*

These observations conform with intuition: If in a world with perfectly mobile capital a country wants to improve its environment, it has to increase its emissions tax rate. In contrast to the case of a closed economy, this induces capital to leave the country thus deteriorating the foreign country's environmental quality if this country sticks to its initial emissions tax rate (i. e. if it does not "retaliate").

3. Capital mobility in case of pollution-generating capital without abatement technology

3.1 The model

We now consider an alternative production-emissions technology which has been used, e.g., by Gronych (1980) and Long & Siebert (1991):

$$(15) \quad y = \underset{+}{F}(\underset{+}{k}, \underset{+}{\ell}) / \underset{+}{\ell} =: \underset{+}{Y}(\underset{+}{x}) \quad \text{and} \quad z = \underset{+}{E}(\underset{+}{x}) \quad \text{with } E_{xx} \geq 0.$$

¹⁰ All subsequent results are symmetric with respect to reductions rather than increases of the home country's emissions tax rate and with respect to interchanging the role of both countries.

As in the previous section, the (home) country produces a single consumption good with the inputs labor, ℓ , and capital, k . Per-capita output, $Y(x)$, and per-capita emissions, $E(x)$, depend on the capital-labor ratio, x , and pollutants are generated and discharged in strict correlation with the use of capital. Input-determined pollutants, often even in fixed relation ($E_{xx} = 0$), are typical for chemical processes, but in many cases the input use does not determine the amount of pollutants *emitted* when emissions can be reduced or avoided by technical devices such as end-of-pipe abatement technologies or integrated emissions reduction technologies¹¹. But there is a meaningful (aggregate) interpretation of the technology (15) if one considers the variable z as that part of the total natural environment which is destroyed in the process of industrialization or capitalization by turning natural resources such as wild life habitats, forests etc. into industrial sites.

In the closed economy the efficient allocation is easily determined by maximizing (2) under consideration of (15), $\ell \leq \ell_0$, $k \leq k_0$, and $c \leq Y(x)$. Since emissions cannot be abated, any reduction of the emissions standard (at full employment of labor) requires to reduce the use of capital. If the damaging effect of pollution is very severe, it may be even optimal not to use the entire capital stock. But idle capital and a rental rate of zero appears to be an unrealistic scenario. Therefore we restrict our attention to those solutions of the constrained maximization problem for which the marginal damage of pollution, $(-U_z/U_c)$, is less than the implicit marginal productivity of emissions, (Y_x/E_x) . This implies, in turn, that the efficient real rental rate (shadow price) of capital is positive¹²:

$$(16) \quad r = Y_x - \left[-\frac{U_z}{U_c} \right] \cdot E_x > 0.$$

The efficient allocation is implemented by levying the Pigouvian emissions tax at the (per-capita) rate $t = (-U_z/U_c)$.

¹¹ An example where abatement devices are not available appears to be CO₂-emissions from burning fossile fuels. But this case is inappropriate for the purpose of the present paper for two reasons: First, there is no clear link between CO₂-emissions and international capital investments and, second, the pollution emerging from CO₂-releases is global (warming) while we focus on strictly 'national' pollution in order not to mix different causes of international environmental interdependence.

¹² In formal terms, one maximizes the unconstrained function $V(x) := U[Y(x), E(x)]$ and assumes that $V_x(x) > 0$ for $x = x_0$. Economically speaking, the assumption $V_x(x_0) > 0$ means that the country suffers from an under-supply of capital.

3.2 Non-strategic environmental policy

Consider first the home country as a "small open economy". If this country pursues a non-strategic environmental policy under perfect information, it maximizes (2) subject to $\ell \leq \ell_0$, (15) and

$$(17) \quad c = Y(x) - (x - x_0) \cdot r$$

which yields the condition (16), as expected. The comparative statics (Appendix 4) give rise to the following major conclusions:

Result 8: Denote by $T(r)$, $X(r)$ and $Z(r)$ the values of t , x and z , respectively, that are determined as functions of the world price of capital, r , through the equations (15), (16) and (17). A small exogeneous change of r has the following consequences:

- (a) $T_r < 0$ and $X_r < 0$ (and hence $Z_r < 0$)
 - (α) if before the change in r the country's international capital transaction is zero or 'sufficiently' small;
 - (β) if the utility function U is quasi-concave (i. e. $U_{cc} = U_{cz} = 0$).
- (b) T_r ambiguous in sign and $X_r < 0$ (and hence $Z_r < 0$), if the country exports capital and U is not quasi-concave;
- (c) T_r and X_r (and hence Z_r) ambiguous in sign, if the country imports capital and U is not quasi-concave.

The comparison of the Results 1 and 8 shows a few divergences and, on the whole, many similarities. In both cases, the ambiguities are more pronounced for the capital-importing than for the capital-exporting country. With technology (15) the directions of change of the tax rate and the emissions standard are hardly more predictable than with (1) except in case of quasi-linear preferences. Under technology (1) it is not always optimal to change the capital use and total emissions (standards) in the same direction as is trivially the case with technology (15).

It is instructive to illustrate Result 8 with the following parametric version of the model (used by Long & Siebert (1991) in a different context):

$$(18) \quad U(c, z) = -\frac{e}{2} \cdot z^2 + c, \quad Y(x) = ax - \frac{1}{2} \cdot x^2, \quad E(x) = x.$$

With these simplifications it is straightforward that equation (16) is turned into r_0

$\equiv a - (1 + e) \cdot x_0$ for the closed economy¹³. If capital is mobile and the country under consideration is small, equation (18) implies that the representative consumer's utility is $U(c, z) = U(x) = -[(1 + e)/2] \cdot x^2 + (a - r) \cdot x + x_0 r$, and the country chooses its capital-labor ratio in such a way that $r = a - (1 + e) \cdot x$. Subtract $r_0 = a - (1 + e) \cdot x_0$ from the last equation to obtain

$$(19) \quad x - x_0 = \frac{r_0 - r}{1 + e} \quad \text{and} \quad t - t_0 = \frac{(r_0 - r) \cdot e}{1 + e}.$$

The equations (19) are related to Result 8a β telling us that efficiency requires to lower the tax rate relative to its autarkic level in the capital-exporting country and to increase it in the other country. Though Result 8 refers to *marginal* exogenous changes in r only and hence relates to the country's adjustments when capital was already mobile in the initial situation, the more restrictive parametric model also allows to assess the *non-marginal* impacts of the transition from autarky to international capital mobility.

In the two-country model, capital mobility is given by the constraint (7), and the market-clearing rate of return on capital is determined by $\sigma_0 = \sigma X(r) + X^*(r)$ with X and X^* as defined in Result 8. The analog to Result 2 is

Result 9 (Long & Siebert 1991): *In the two-country model, an efficient international allocation of resources is characterized by*

$$(20) \quad r = Y_x + \left[\frac{U_z}{U_c} \right] \cdot E_x = Y_x^* + \left[\frac{U_z^*}{U_c^*} \right] \cdot E_x^*.$$

It can be attained by a perfectly competitive capital market and by noncooperative non-strategic national environmental tax policies with rates

$$(21) \quad t = -\frac{U_z}{U_c} \quad \text{and} \quad t^* = -\frac{U_z^*}{U_c^*}.$$

To obtain more specific information about the efficient allocation (and for later reference in the next section) we employ again the parametric model (18). To keep the analysis simple, we also set $\ell_0 = \ell_0^*$ implying $x_0 + x_0^* = x + x^*$ in view of (7). Thus it is possible, after some rearrangement of terms, to rewrite equation (20) as:

¹³ As before we assume that $r_0 > 0$ so that the parameters a , e , and x_0 are restricted to the half space $a > (1 + e) \cdot x_0$.

$$(22) \quad \Delta x = \frac{\Delta a + (1 + e^*) \cdot x_0^* - (1 + e) \cdot x_0}{2 + e + e^*} \quad \text{and} \quad \Delta t = e \cdot \Delta x,$$

where $\Delta a := a - a^*$, $\Delta x := x - x_0$ and $\Delta t := t - t_0 = ex - ex_0$. It is easy to see from (22) that if the countries are identical ($\Delta a = 0$, $e = e^*$, $x_0^* = x_0$) the autarky position with zero capital transactions is efficient. With the help of equation (22) the influence of pollution damage on international capital flows can be clarified. If technologies do not differ ($\Delta a = 0$) and the home country is capital-poor ($x_0 < x_0^*$), this country would import capital if emissions were harmless ($e = e^* = 0$). But with harmful pollution the home country may well export capital if the preferences of its citizens are sufficiently greener than those of the other country's citizens.¹⁴

shock → response ↓	$\Delta(a-a^*)$	Δx_0	Δx_0^*	Δe	Δe^*
$\Delta z = \Delta x$	+	−	+	−	+
$\Delta t = -\Delta t^*$	+	−	+	−	+

Table 1: Comparative statics

Suppose now, the countries are identically initially and then one (and only one) parameter for either country changes. The resultant efficient displacement effects are shown in Table 1. It is worth emphasizing that the efficient response is always to move both emissions standards and emissions tax rates into the same direction.

Next we show that the transition from autarky to the efficient international allocation of capital is advantageous for both countries. To see that we consider $P(t, t^*)$ from (26) which is derived below for a different purpose. In (26) we replace $X(t, t^*)$ simply by x , and we set t at its efficient level $t = ex$. This gives us, after some rearrangement of terms, $W(x) := a \cdot x_0 - (1 + e) \cdot x_0 \cdot x + [(1 + e)/2] \cdot x^2$. On the other hand, in autarky the utility of a domestic citizen is $u_0 := ax_0 - [(1 + e)/2] x_0^2$. The difference turns out to be $W(x) - u_0 = [(1 + e)/2] \cdot (x - x_0)^2 > 0$ independent of whether the country under consideration is importing or exporting capital.

¹⁴ More specifically, if the home country is capital-poor ($x_0 < x_0^*$) and productivities are the same ($\Delta a = 0$) it will export capital if and only if $(1+e)/(1+e^*) > (x_0^*/x_0) > 1$.

3.3 Strategic environmental policy

In what follows we want to show that the rule (21) is not incentive compatible. As in Section 2.3 we proceed by allowing the countries to fix their tax rates at arbitrary levels to find out whether their self-interest lead them to choose the rate according to rule (21). Again, the two countries play a noncooperative game with emissions tax rates as their strategies. To see the impacts of these policies on the international capital market notice that the capital market equilibrium is characterized by

$$(23) \quad Y_x(x) - tE_x(x) = Y_x^*(x^*) - t^*E_x^*(x^*).$$

The equations (7) and (23) determine the variables x and x^* for each tuple (t, t^*) :

$$(24) \quad \underset{-}{x} = \underset{+}{X}(t, \underset{+}{t^*}), \quad \underset{+}{x^*} = \underset{-}{X^*}(t, \underset{-}{t^*}) \quad \text{and} \quad r = R(t, t^*) := Y_x[X(t, t^*)] - tE_x[X(t, t^*)].$$

? ?

If $x = X(t, t^*)$ is considered in (15) and in

$$(25) \quad c = Y(x) - (x - x_0)[Y_x(x) - t \cdot E_x(x)],$$

the utility function (2) is turned into the home country's payoff function

$$(26) \quad P(t, t^*) = U\{Y[X(t, t^*)] - [X(t, t^*) - x_0] \cdot R(t, t^*), E[X(t, t^*)]\}.$$

In a symmetric way, the payoff function $P^*(t, t^*)$ of the foreign country can be derived. The "best reply" first order conditions $P_t(t, t^*) = 0$ and $P_{t^*}^*(t, t^*) = 0$ yield at an interior solution (Appendix 5)

$$(27) \quad t = -\frac{U_z}{U_c} + (x - x_0) \cdot \frac{dr}{dz} \quad \text{and} \quad t^* = -\frac{U_z^*}{U_c^*} + (x^* - x_0^*) \cdot \frac{dr^*}{dz^*}$$

$$\text{where } \frac{dr}{dz} := \frac{R_t}{Z_t} = \frac{t^*E_{xx}^* - \sigma Y_{xx}}{E_x} > 0 \quad \text{and} \quad \frac{dr^*}{dz^*} := \frac{R_t^*}{Z_t^*} = \frac{tE_{xx} - \sigma Y_{xx}^*}{E_x^*} > 0$$

Result 10: Suppose, the production-emissions technology (15) applies and capital is mobile between two countries each of which considers its impact on the international capital market as non-negligible.

(a) Then the capital-exporting country sets its emissions tax rate at an inefficiently low

level and the capital-importing country sets it at an inefficiently high level¹⁵. In view of (24), the capital-exporting [importing] emissions level is higher [lower] and its capital export [import] is lower [higher] than in case of non-strategic behavior.

(b) The strategic potential of advantageous distortions, $(x - x_0) \cdot (dr/dz)$, is c.p. the smaller, the smaller is the home country's labor endowment relative to that of the other country and the greater is the number of countries among which capital is mobile. It tends to zero only if ℓ_0/ℓ_0^* tends to zero and E_{xx}^* or t^* is zero.

To obtain more specific information on the allocation reached by using environmental policies strategically, we wish to solve the noncooperative game for the parametric model (18). For notational simplicity we assume $\ell_0 = \ell_0^*$ which implies $\sigma = 1$ and $\sigma_0 = x_0 + x_0^*$ (with σ and σ_0 as defined in (7)). To derive the home country's reaction function $t = T(t^*)$ that is implicitly given by the condition $P_t(t, t^*) = 0$ we rewrite (24) with the help of (18) as

$$(28) \quad X(t, t^*) := \frac{x_0^* + x_0 + \Delta a}{2} - \frac{1}{2} \cdot t + \frac{1}{2} \cdot t^*,$$

where $\Delta a := a - a^*$. The payoff function (26) is turned into

$$(29) \quad P(t, t^*) := \frac{1-e}{2} \cdot [X(t, t^*)]^2 - (x_0 - t) \cdot X(t, t^*) - x_0 t + a x_0.$$

The derivatives of this function are

$$(30) \quad P_t = \frac{1+e}{2} \cdot X(t, t^*) - \frac{t+x_0}{2}, \quad \text{and} \quad P_{tt} = -\frac{3+e}{4} < 0,$$

$$P_{t^*} = \frac{1-e}{2} \cdot X(t, t^*) + \frac{t-x_0}{2}, \quad P_{t^*t^*} = \frac{1-e}{4} \begin{matrix} \leq \\ \geq \end{matrix} 0 \Leftrightarrow e \begin{matrix} \geq \\ \leq \end{matrix} 1.$$

In view of (28) and (30a) the home country's best reply function is

$$(31) \quad T(t^*) := \frac{(1+e)(x_0^* + \Delta a) - (1-e)x_0}{3+e} + \frac{1+e}{3+e} \cdot t^*.$$

The foreign country's best reply function $t^* = T^*(t)$ follows from analogous

¹⁵ Long & Siebert reach this conclusion in a similar model in which environmental protection agencies maximize real domestic income and are free to choose emissions tax rates as a fraction of the (true) marginal damage costs.

calculations. The Cournot–Nash equilibrium $\{t = T[T^*(t)], t^* = T^*[T(t^*)]\}$ turns out to be

$$(32) \quad \begin{aligned} t &= \frac{(1 + e)[(1 + e^*)x_0^* + \Delta a] + (2e + ee^* - 1)x_0}{4 + e^* + e}, \\ t^* &= \frac{(1 + e^*)[(1 + e)x_0 + \Delta a^*] + (2e^* + ee^* - 1)x_0^*}{4 + e^* + e}. \end{aligned}$$

As before, we use $\Delta x := x - x_0$ and $\Delta t := t - t_0$ with $t_0 = ex_0$ (autarky) to rewrite (28) and (32):

$$(33) \quad \Delta x = \frac{\Delta a + (1 + e^*)x_0^* - (1 + e)x_0}{4 + e + e^*} \quad \text{and} \quad \Delta t = (1 + e) \cdot \Delta x,$$

The comparison of the equations (22) and (33) gives rise to the following observations (Appendix 6):

Result 11: *Under perfect information, the lack of international environmental policy coordination has the following effects:*

- (a) *The direction of change in capital use, emissions standards and emissions tax rates, following exogeneous parameter shifts, is always efficient (as given by Table 1);*
- (b) *The international capital investment is inefficiently low;*
- (c) *The emissions tax rates are inefficiently high in both countries, if and only if $(e - e^*) \in (-2, 2)$, i.e. if the international differences in 'greenness' of preferences are not too large;*
- (d) *The welfare of the capital–importing country decreases and that of the other country improves.*

To see the rationale of Result 11d observe first that (26) and (31) imply

$$(34) \quad \frac{\partial P[T(t^*), t^*]}{\partial t^*} = \frac{(2 + e)(x - x_0) + (t - ex)}{(3 + e)} = \geq 0 \Leftrightarrow x \geq x_0.$$

The corresponding property holds for the foreign country. To determine the point on the best–reply curves where no capital is traded recall that in view of (28)

$$x \geq x_0 \quad \text{and} \quad x^* \leq x_0^* \Leftrightarrow t \leq \Delta a - x_0 + x_0^* + t^*.$$

Suppose, without loss of generality, the Cournot–Nash equilibrium (t_{CN}, t_{CN}^*) satisfies $t_{CN} < \Delta a - x_0 + x_0^* + t_{CN}^*$, i.e. the point of intersection of the best-reply curves is located below the line $t = \Delta a - x_0 + x_0^* + t^*$. This situation is drawn in Figure 4 where the graphs of the functions $t = T(t^*)$, $t^* = T^*(t)$ and $t = \Delta a - x_0 + x_0^* + t^*$, respectively, are given by CF, GL, and AB. If the line AB intersects CF in point D, as shown in Figure 4, the allocation in D is characterized by $x = x_0$ and $t = (-U_z/U_c)$ owing to (27). Hence the home country's payoff in D is that of the Pareto-efficient allocation in autarky. Owing to condition (34) the home country's payoff decreases along CF in the direction of F so that the payoff in E is less than in D. If AB does not intersect CF the home country's autarkic welfare is even higher than its payoff in point A. Therefore we conclude that the capital-importing country's welfare decreases.

– Figure 4: Cournot–Nash equilibrium in the parametric model –

Consider now the situation of the foreign country. Since the slope of AB is steeper than that of GL ($\tan \alpha = 1 > \tan \beta$) these two straight lines always intersect at a point to the left of E such as point K. The foreign country's payoff in K represents its maximum welfare in autarky. But along GL from K towards G the foreign country's welfare increases. Hence its payoff in E is greater than in K.

The payoff indifference curves are difficult to characterize. But if $(e - e^*) \in (-2, 2)$, Result 11c implies that they are shaped as drawn in Figure 4, because then the equilibrium tax rates (in point E) are too high as compared with an efficient allocation, such as point R in Figure 4.

Result 11 presents us with several surprises: Even though the tax rates are too high in both countries, the capital-exporting country pollutes too much and its foreign investment is too small. It appears to be counter-intuitive that the capital-importing country gets worse off after trade liberalization because the technology is such that with its foreign investment it also exports pollution. But apparently, the welfare gain from a cleaner environment is overcompensated by the reduction in welfare from real domestic income.

3.4 Information-constrained tax policies

Suppose now, information is imperfect and the countries follow the rule of maintaining their emissions tax rates after capital market liberalization¹⁶. To fix our ideas let $t = t_0 = ex_0$ and $t^* = t_0^* = e^*x_0^*$ (ad hoc). Then equation (28) is turned into

¹⁶ In view of technology (15) the strategy of maintaining the autarkic emissions standards or introducing other standards, as discussed in Section 2.3, would amount to introducing direct capital market controls.

$$(35) \quad \Delta x = \frac{\Delta a + (1 + e^*)x_0^* - (1 + e)x_0}{2}$$

With $t = t_0 = ex_0$ the utility of a home country's citizen is $u = x_0(a - ex_0) - x_0(1 - e)x + (1 - e)x^2/2$. Therefore $U_x = (x - x_0)(1 - e)$ and, via symmetric arguments, $U_x^* = (x - x_0^*)(1 - e^*)$. This leads us to conclude:

Result 12: *Let the autarkic equilibria be characterized by $t_0 = ex_0$ and $t_0^* = e^*x_0^*$ and suppose that after capital market liberalization both countries stick to their emissions tax rates t_0 and t_0^* , respectively.*

- (a) *Then the international capital flows are inefficiently high.*
- (b) *Assume without loss of generality that the home country exports capital. Then the home country's welfare is reduced at the new equilibrium, if and only if $e < 1$; the foreign country's welfare is reduced if and only if $e^* > 1$.*

It is interesting to observe that in Result 12b the direction of welfare change does not depend on the assumption that both countries stick to their autarkic tax rates. Consequently, if the home country expects to export capital after capital liberalization and suffers heavily from pollution ($e > 1$) it should be advised not to play its Cournot–Nash strategy but rather the strategy $t = ex_0$.

Suppose, as in Section 2.4, that capital is already perfectly mobile in the initial situation, that each country has chosen its emissions tax rate, and that the international capital market is in equilibrium. What happens if one of the countries changes its tax rate?

Result 13: *Suppose the production–emissions technology is given by (15), the international capital market is in equilibrium and the foreign country keeps its emissions tax rate constant while the home country increases its own emissions tax rate. Then*

- (a) *the environmental quality improves in the home country, and deteriorates in the foreign country;*
- (b) *the home country's capital export is reduced or its capital import expanded;*
- (c) *the impact on the world rental rate of capital is ambiguous.*

5. Concluding remarks

It has been shown that, in case of mobile capital, internationally uncoordinated national environmental policies induce allocative distortions when countries are self-interested under perfect information. Long & Siebert (1991, p. 307) may be right "... that the possibility of manipulating environmental policy instruments is an interesting case for the theoretician but not of practical relevance". However, the existence of strategic potential means that benevolent governments do have an incentive to behave strategically. Whether they have sufficient information to take advantage of this potential or whether their "... environmental policy should not be overloaded with strategic non-environmental targets" (Long & Siebert 1991, p. 307) are quite different issues.

In the 'strategic' noncooperative equilibrium at least one country may be worse off after market liberalization than in autarky as demonstrated in Section 3. Hence there is scope for international coordination of national environmental policies which reintroduces the question, of course, how the supra-national agency gets all the necessary information on national environmental damages and abatement costs and on the operation of the international capital market to do a better job than the noncooperating countries.

Our analysis also showed that even if the countries under consideration do not have at their disposal all information necessary for successful strategic manipulation, the countries' interdependence via noncooperative national environmental policies has important international repercussions. This is true in case of adjusting environmental policy when capital becomes (more) mobile, but also when one country makes a change in its policy while capital is already perfectly mobile.

All these issues have been scrutinized for two different types of production-emissions technologies. The principal motivation for that double-track procedure was that both technologies capture relevant aspects of the complex reality, and therefore it is important to know how the implications differ. It turned out that the conclusions are fairly robust with respect to the alternative modeling approaches. The phenomenon of 'ecological dumping', if interpreted as advantageous distortive use of environmental policy, is qualitatively the same under both production-emissions technologies. Moreover, regarding the noncooperative game of strategic environmental policies under perfect information the parametric version of the model in Section 3 produced much more specific results than the model of Section 2.

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Appendix

1. **Proof of Result 1:** The variables x and z are determined by the equations

$$(a) \quad S(x, z, r) = Y_z(x, z) \quad \text{and} \quad r = Y_x(x, z),$$

where $s = S(x, z, r) := -\frac{U_z[Y(x, z) - (x - x_0)r, z]}{U_c[Y(x, z) - (x - x_0)r, z]}$. Total differentiation of (a) yields

$$(b) \quad \begin{bmatrix} U_c Y_{zx} & U_c(Y_{zz} - S_z) \\ Y_{xx} & Y_{xz} \end{bmatrix} \cdot \begin{bmatrix} dx \\ dz \end{bmatrix} = \begin{bmatrix} (x - x_0)(U_{zc} + sU_{cc}) \cdot dr \\ dr \end{bmatrix},$$

where $S_z = -[2sU_{zc} + U_{zz} + s^2U_{cc}]/U_c > 0$. The determinant of the above matrix is

$$D = U_c[Y_{zx}^2 - Y_{xx}U_c(Y_{zz} - S_z)] = V_{xz}^2 - V_{xx}V_{zz},$$

where the function $V: \mathbb{R}_+^2 \rightarrow \mathbb{R}$ is defined by $V(x, z) := U[Y(x, z) - (x - x_0)r, z]$. D is assumed to be negative because $V_{xx}V_{zz} - V_{xz}^2 > 0$ must be satisfied for V to be (locally) concave which is in turn necessary for the equations (a) to represent a (local) maximum. We solve the equations (b) to obtain

$$(c) \quad \frac{dx}{dr} = [(x - x_0)Y_{xz}(U_{zc} + sU_{cc}) - U_c(Y_{zz} - S_z)]/D,$$

$$(d) \quad \frac{dz}{dr} = -[(x - x_0)Y_{xx}(U_{zc} + sU_{cc}) - U_c Y_{zx}]/D,$$

$$(e) \quad \frac{dx}{dr} = Y_{zx} \cdot \frac{dx}{dr} + Y_{zz} \cdot \frac{dz}{dr} = [(x - x_0)(U_{zc} + sU_{cc})(Y_{zx}^2 - Y_{xx}Y_{zz}) + S_z U_c Y_{xz}]/D.$$

In order to demonstrate that the combined reactions $dz/dr > 0$ and $dx/dr < 0$ may be

optimal we observe that (c) and (d) imply

$$\frac{dz}{dr} > 0 \Leftrightarrow (x - x_0) > \frac{U_c Y_{zx}}{Y_{xx}(U_{zc} + sU_{cc})} =: H > 0,$$

$$\frac{dx}{dr} < 0 \Leftrightarrow (x - x_0) < \frac{U_c (Y_{zz} - S_z)}{Y_{zx}(U_{zc} + sU_{cc})} =: K > 0.$$

Since K is greater than H, the interval [H, K] is non-empty. Consequently,

$$\frac{dz}{dr} > 0 \text{ and } \frac{dx}{dr} < 0 \Leftrightarrow (x - x_0) \in [H, K].$$

Suppose now, contrary to the assertion, that $dz/dr < 0$ and $dx/dr > 0$. Then $(x - x_0) < H$ and $(x - x_0) > K$. But $H < K$. Contradiction.

2. Partial derivatives in equation (11): Consider the three equations $Y_x(x, z) = Y_x^*(\sigma_0 - \sigma x, z^*)$, $Y_z(x, z) = t$ and $Y_z^*(\sigma_0 - \sigma x, z^*) = t^*$. Total differentiation yields

$$\begin{bmatrix} Y_{zx} & Y_{zz} & 0 \\ -\sigma Y_{zx}^* & 0 & Y_{zz}^* \\ Y_{xx} + \sigma Y_{xx}^* & Y_{xz} & -Y_{xz}^* \end{bmatrix} \cdot \begin{bmatrix} dx \\ dz \\ dz^* \end{bmatrix} = \begin{bmatrix} dt \\ dt^* \\ 0 \end{bmatrix}$$

The determinant is $D := Y_{zz}^*(Y_{xx}Y_{zz} - Y_{xz}^2) + \sigma Y_{zz}(Y_{xx}^*Y_{zz}^* - Y_{xz}^{*2}) < 0$. Moreover,

$dx = D^x/D$ with $D^x := -Y_{xz}Y_{zz}^*dt + Y_{xz}^*Y_{zz}dt^*$; $dx^* = -\sigma dx$;

$dz = D^z/D$ with $D^z := -Y_{zx}Y_{zx}^*dt^* + [Y_{xx}Y_{zz}^* + \sigma(Y_{xx}^*Y_{zz}^* - Y_{xz}^{*2})]dt$;

$dz^* = D^{z^*}/D$ with $D^{z^*} := -\sigma Y_{zx}^*Y_{zx}dt + (Y_{xx}Y_{zz} - Y_{xz}^2 + \sigma Y_{xx}^*Y_{zz}^*)dt^*$.

3. Proof of Result 5: The equations $t = Y_z(x, z)$ and $r = Y_x(x, z)$ imply the 'factor demand functions' $z = Z(r, t)$ and $x = X(r, t)$. The partial derivatives of these functions are found by total differentiation of $t = Y_z(x, z)$ and $r = Y_x(x, z)$. Defining $N := Y_{xx}Y_{zz} - Y_{xz}^2 > 0$ one obtains:

$$(a) \quad \begin{aligned} X_t &= -Y_{zx}/N \quad \text{and} \quad X_r = Y_{zz}/N, \\ Z_t &= -Y_{xx}/N \quad \text{and} \quad Z_r = -Y_{zx}/N. \end{aligned}$$

The policy of Result 5a (policy A) has the effects $\frac{dx}{dr}\Big|_A = X_r < 0$ and $\frac{dz}{dr}\Big|_A = Z_r < 0$. The effect $Z_r < 0$ is (partially) welfare improving. Under policy A the impact of dr on

real consumption is

$$\left. \frac{dc}{dr} \right|_A = t \cdot Z_r - (x - x_0)$$

which is negative for $x > x_0$ and ambiguous in sign otherwise. The policy of Result 5b (policy B) requires to choose dt so that $dz = Z_t dt + Z_r dr = 0$. Hence

$$dx = X_t dt + X_r dr = -\frac{X_t Z_r}{Z_t} \cdot dr + X_r \cdot dr = \frac{1}{Y_{xx}} \cdot dr < 0.$$

The last line can be rewritten as $\left. \frac{dx}{dr} \right|_B = \left. \frac{dx}{dr} \right|_A - X_t Z_r / Z_t$. Hence $\left. \frac{dx}{dr} \right|_B < \left. \frac{dx}{dr} \right|_A$. Under policy B the impact of dr on real consumption is $\left. \frac{dc}{dr} \right|_B = -(x - x_0)$.

4. Proof of Result 8: Maximizing (2) subject to $\ell \leq \ell_0$, (15) and (17) yields

$$(a) \quad r = Y_x(x) - S(r, x) \cdot E_x(x) \quad \text{with} \quad S(r, x) := -\frac{U_z[Y(x) - (x - x_0)r, E(x)]}{U_c[Y(x) - (x - x_0)r, E(x)]}$$

Total differentiation of (a) results in

$$(b) \quad \frac{dx}{dr} = \frac{1 + S_r E_x}{Y_{xx} - S_x E_x - t E_{xx}} \quad \text{with}$$

$$(c) \quad S_x = -[(U_{zc} + t U_{cc})(Y_x - r) + (U_{zz} + t U_{cz})E_x] / U_c \quad \text{and} \quad S_r = -(x - x_0)(U_{zc} + t U_{cc}) / U_c,$$

where $S_x > 0$ and $S_r \geq 0 \Leftrightarrow x_0 \geq x$. Consider (c) in (b) to obtain

$$(b') \quad \frac{dx}{dr} = \frac{U_c + (x - x_0)(U_{zc} + t U_{cc})E_x}{(Y_{xx} - t E_{xx})U_c + (U_{zc} + t U_{cc})(Y_x - r)E_x + (U_{zz} + t U_{zc})E_x^2}$$

Total differentiation of $S(r, x)$ leads to

$$(d) \quad \frac{dt}{dr} = S_r + S_x \cdot \frac{dx}{dr} = \frac{S_x + S_r(Y_{xx} - t E_{xx})}{Y_{xx} - S_x E_x - t E_{xx}}.$$

5. Derivation of equation (27): With $P(t, t^*)$ as defined in (26) one obtains

$$P_t(t, t^*) = U_c[Y_x X_t - r X_t - (x - x_0)R_t] + U_z Z_t = 0$$

and therefore $-\frac{U_z}{U_c} = \frac{tZ_x X_t}{Z_t} - (x - x_0) \frac{R_t}{Z_t}$, because $Y_x - r = tZ_x$. By definition of R and

Z , one has $Z_t = Z_x X_t$ and $R_t = (Y_{xx} - tZ_{xx})X_t - Z_x$ and therefore

$$\frac{dr}{dz} = \frac{R_t}{Z_t} = \frac{t^* Z_{xx}^* - \sigma Y_{xx}^*}{Z_x} > 0.$$

6. Proof of Result 11: Define $\Delta x := x - x_0$ and consider (27) to obtain

$$(a) \quad 2\Delta x = \Delta a + x_0^* - x_0 + t^* - t.$$

With the help of (29) the difference $t^* - t$ is transformed to read

$$t^* - t = \frac{(2-e+e^*)x_0 - (2-e^*+e)x_0^* - (2+e+e^*)\Delta a}{4 + e + e^*}. \text{ Substitution into (a) yields}$$

$$\Delta x = \frac{\Delta a + (1+e^*)x_0^* - (1+e)x_0}{4 + e + e^*}. \text{ Small changes of } e \text{ and } e^* \text{ have the effects}$$

$$\frac{d\Delta x}{de} = -\frac{(1+e^*)x_0^* + (3+e^*)x_0 + \Delta a}{(4 + e + e^*)^2}, \quad \text{and} \quad \frac{d\Delta x}{de^*} = \frac{(3+e)x_0^* + (1+e)x_0 - \Delta a}{(4 + e + e^*)^2}.$$

Define $\Delta t := t - t_0 = t - ex_0$ and consider (29) to find, after some rearrangement of terms, that $\Delta t = (1 + e)\Delta x$. Hence

$$\frac{d\Delta t}{de^*} = (1 + e) \frac{d\Delta x}{de^*} \quad \text{and} \quad \frac{d\Delta t}{de} = \Delta x + (1 + e) \frac{d\Delta x}{de}.$$

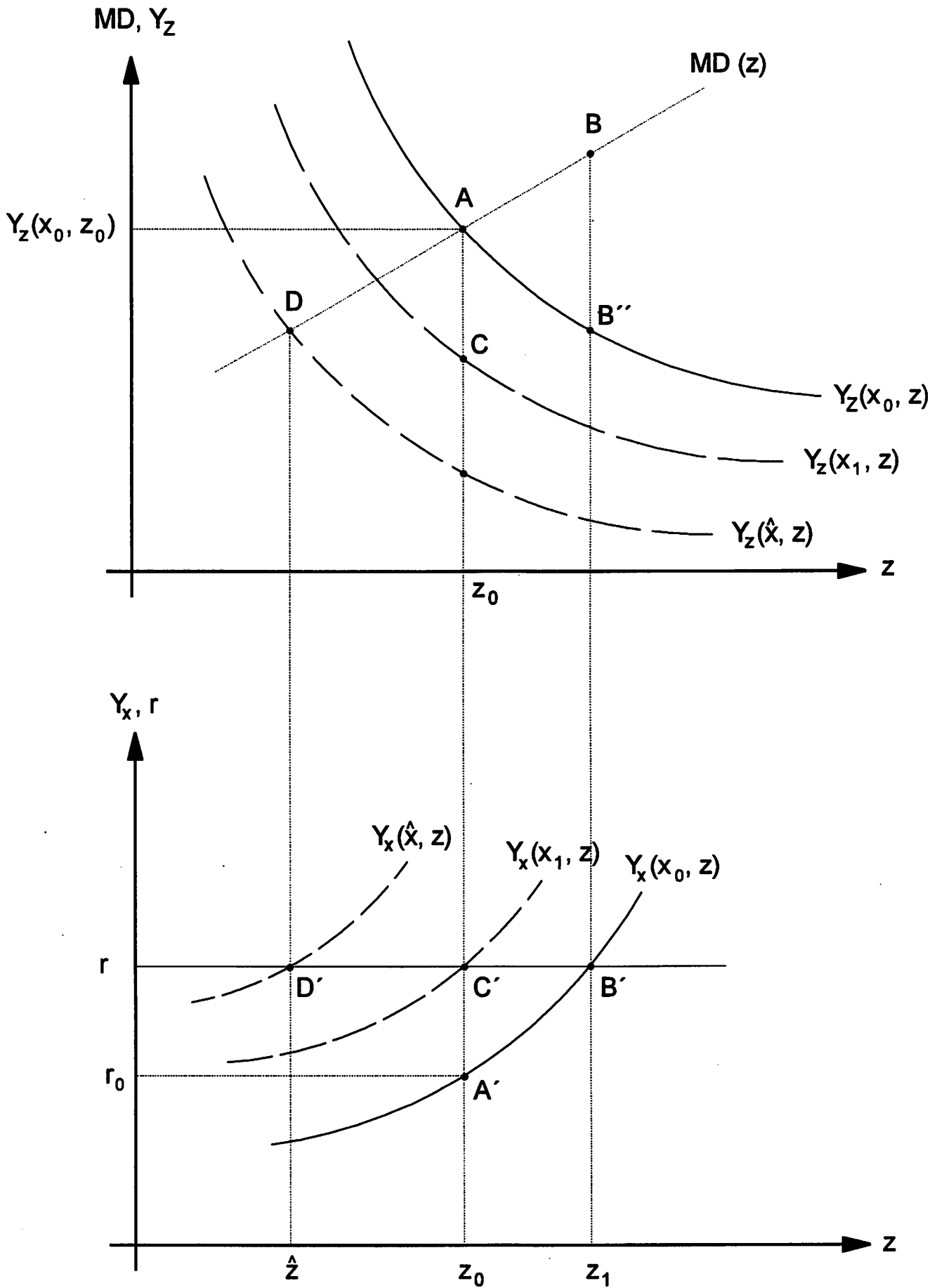


Figure 1: Capital export and efficient environmental policy response

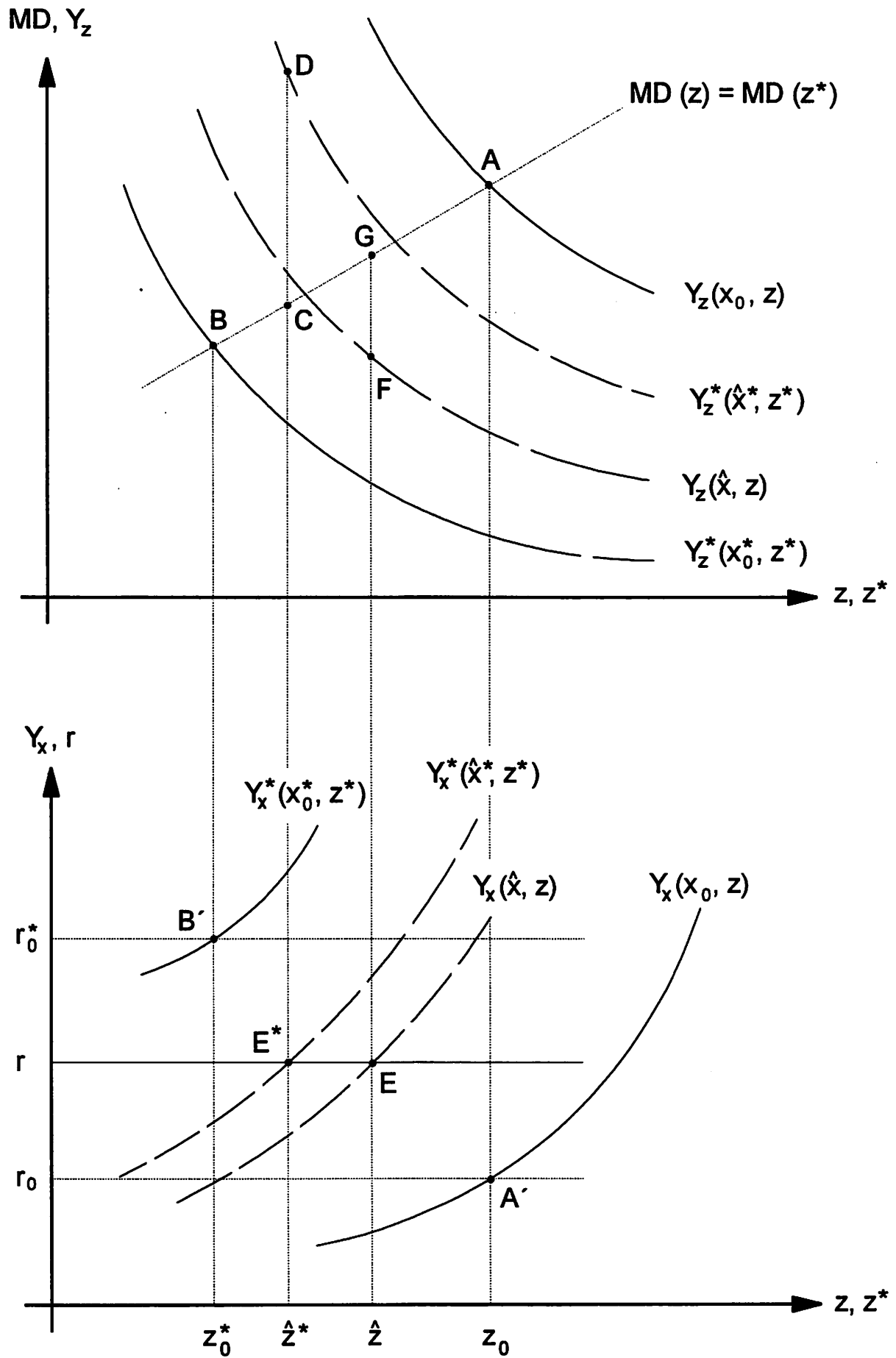


Figure 2: Environmental policy distortions in the Cournot-Nash equilibrium

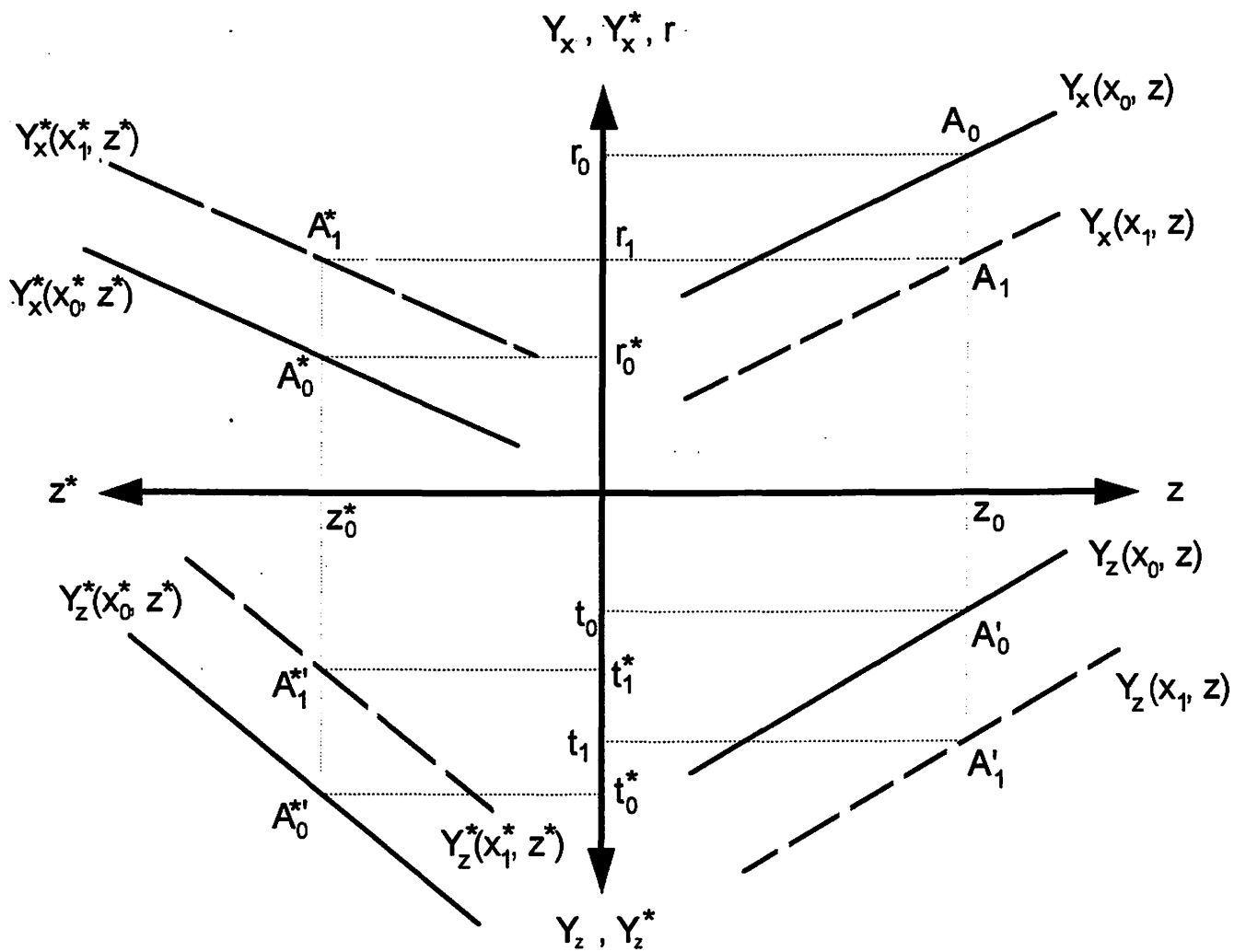


Figure 3: Capital market liberalization with constant emissions standards

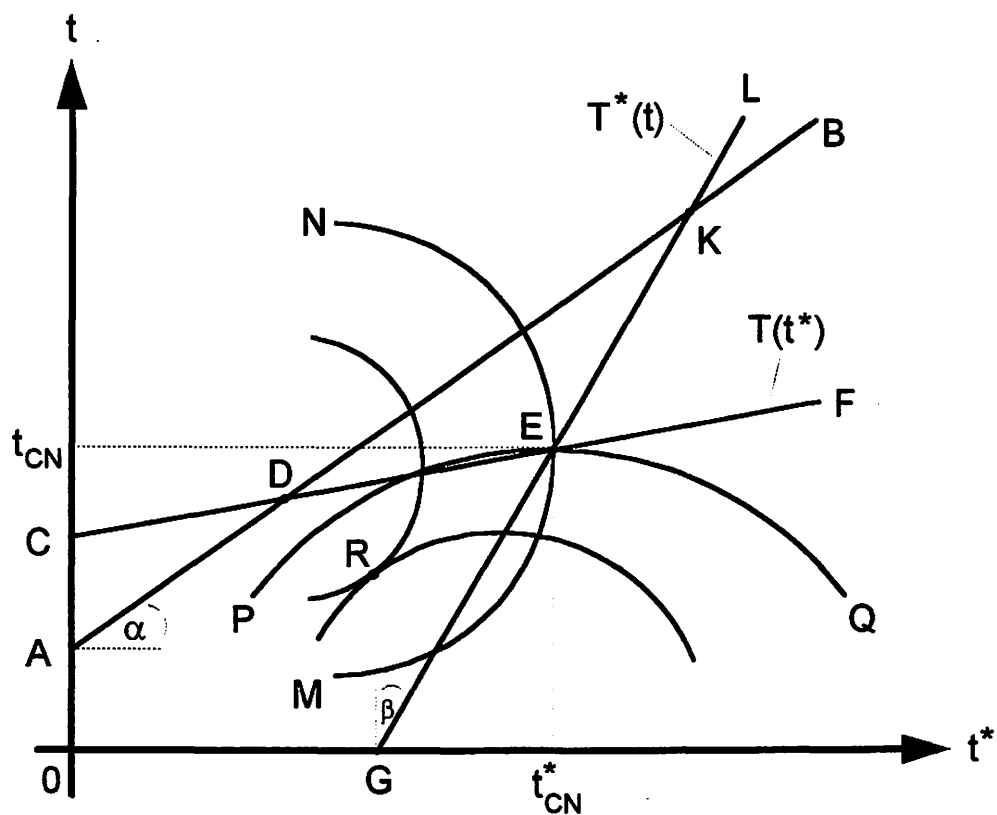


Figure 4: Cournot-Nash equilibrium in the parametric model

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