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GROWTH, THE ENVIRONMENT AND ENVIRONMENTAL AID IN THE INTERNATIONAL ECONOMY*

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ABSTRACT: The paper studies the relationship between growth and the environment in a two-country neoclassical growth model with transboundary deposition of pollution and its abatement. The model is also extended to cover environmental aid given by one country to the other. The dynamic solution gives new insight into the interaction between growth and the environment in an international context. If the domestic environment can be protected more efficiently through international aid, this leads to a cut in domestic environmental measures, such as pollution taxes, in the donor country. The recipient country directs its resources to consumption needs, but in total more is invested in pollution abatement in the recipient country. The paper and its results are formulated with emphasis on the current situation in the Baltic region.

Kari Alho

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1. Introduction

Reconciliation of economic growth and environmental protection is a pressing current problem on a global scale. In Europe the Eastern European countries are undergoing a difficult adjustment process of restructuring their countries into market economies, and simultaneously have to cope with their unfortunate endowment of an ill-managed environment.

The Western countries have a clear selfish rationale behind their environmental aid to the former socialist countries. First, there is a marked transboundary air and sea pollution from the East to the West. Secondly, in Western Europe environmental investments already have to face diminishing returns, while in Eastern Europe virtually nothing has been invested into the environment and therefore the marginal return is high. Accordingly, a unit of resources invested into Eastern Europe often gives a higher return in terms of gains to Western environment than when invested at home. Thirdly, in the former Soviet region the environment and technology even involves at some places such sizable risks that outright environmental catastrophes leading to uncontrollable emigration of people cannot be excluded. And last, we should also admit that the unselfish equality motives of building a more harmonious and peaceful Europe are also behind Western aid.

The basic result that a donor nation can also increase its own welfare by financing some of its neighbour's environmental investment with transfers has recently been reached in the context of the Baltic region environment, using partial equilibrium analysis, by Kaitala, Pohjola and Tahvonen (1990,1991a,b,1992). In a general equilibrium framework Alho (1992), using numerical calibrations of the previous studies, also gives support for positive welfare effects produced by this kind of environmental financing operations. On the other hand, it is shown therein that the terms on this subsidized financing may be in quite an essential position in influencing the outcome of these environmental policies to the partner countries.

Environmental economics has intensively focused upon the interplay between the scarcity of natural resources and economic growth and, more recently, has also considered pollution and its abatement in a growth context. With respect to the current situation in Europe and around the Baltic Sea the latter approach is more relevant.

However, most of the analysis concerning environmental aid has so far omitted economic growth and the literature on growth and pollution has operated in the context of a single closed economy. In the present paper the aim is to consider the relationship between growth and the environment and the role of international environmental aid in a two-country general equilibrium framework using a standard neoclassical growth model supplemented with relationships regarding pollution, its international spillovers and its abatement. This kind of framework has become fairly widely used in a single country case by e.g. Musu (1990, 1991), Tahvonen and Kuuluvainen (1991) and van der Ploeg and Withagen (1991). Our analysis sheds new insight into the dynamics of economic growth and pollution in an international perspective, and the interdependence of national environmental policies.

The standard question intensively analyzed in the literature on international environmental problems is the comparison of international cooperative and noncooperative pollution abatement. The general outcome, which is intuitively appealing, is that cooperation leads to less pollution than isolated national policies not internalizing the spillover of pollution across borders. Recently, van der Ploeg and de Zeeuw (1992) have also demonstrated that noncooperation may lead to too much investment in clean technology, i.e pollution abatement. Here we tackle this question in the connection of international environmental aid and are able to show that international environmental aid from one country to the other normally leads to a more efficient pollution abatement and therefore implies a smaller need for abatement in the home country.

We are also able to respond to the doubt, whether the environmental aid leads the recipient country to adopt lax environmental policies. We find that this is indeed the case, but that the total abatement capital in the recipient country is going to rise, but by less than the amount of aid. However, in a corner situation of no abatement investment by the recipient the environmental aid leads to no offset of domestic environmental measures realized in the recipient country. Part of the environmental aid is also used to meet the needs of material consumption.

The structure of the paper is as follows. The basic model is presented in section 2. The social optimum under free international borrowing and noncooperative environmental policies is derived and illustrated in section 3. Section 4 turns to the behaviour of a market economy under national environmental policies and their optimal use. International environmental aid and its interdependence with national policies is studied in section 5. Section 6 concludes.

2. The model

There are several ways to describe the interaction between production, pollution, its abatement and the material consumption goals; see the presentation by van der Ploeg and Withagen (1991). A common way to link pollution and production is to use the joint production formulation, where the flow of pollution is an input in the production process, as is done by Becker (1982) and recently e.g. by Kuuluvainen and Tahvonen (1991). In the following we have preferred to use a two-sector specification, comprising of a production and a pollution-abatement sector as used by Musu (1989) and also discussed by van der Ploeg and Withagen (1991). However, we also want to emphasize the fact that pollution abatement usually requires large capital investment and therefore we distinguish in the model the allocation of capital into production and pollution abatement.

We describe both countries in similar aggregative terms and no attention is paid to their specialization in production. Direct trade flows between them do not differ from their trade with other countries. In each country a single homogeneous product Q_i is produced with capital K_i and labour L_i. The labour force is constant over time in both countries. The production function F,

$$(1) \qquad Q_i = F_i(K_i, L_i), \text{ where } F_K > 0,\ F_L > 0,$$

is a normal concave production function in K and L. For simplicity, let us also disregard technical change. Production gives rise to a flow of pollution emissions E_i, which can be reduced by investing in pollution abatement technology, the installed capital stock of which is denoted by Z_i. So we have

$$(2) \qquad E_i = G_i(Q_i, Z_i), \text{ where } G_Q>0,\ G_Z<0,\ G_{QQ}\geq 0,\ G_{ZZ}>0 \text{ and } G_{QZ}<0.$$

For simplicity, no depreciation of capital is considered. Over time, pollution leads to a stock of deposition D_i of the pollutant in an international spillover process which is assumed to be linear in the standard manner,

$$(3) \qquad \dot{D}_i = a_{ii}E_i + a_{ji}E_j - d_iD_i \ .$$

Here the a_{ij}'s are the spillover parameters which lie between zero and unity and reflect how emissions in country i are transferred to depositions in country j, and d_i is the speed of assimilation of emissions by the environment in country i. For simplicity, this speed is taken to be a constant independent of the cumulated deposition of pollution. A dot over the variable indicates the time derivative.

The homogeneous good is used for investment in material production, pollution abatement or material consumption. The countries also have trade with the rest of the world (and so potentially with each other, too) in the homogeneous commodity they both produce. We consider the foreign and domestic good to be perfect substitutes for each other, which simplifies the exposition. The national income identity for material production is as follows,

$$(4) \qquad Q_i = \dot{K}_i + \dot{Z}_i + \dot{Z}_{ij} + C_i + X_i,$$

where as new items Z_{ij} is the environmental abatement stock transferred by country i to country j, C is the flow of consumption and X net exports. In the following, the rich nation is denoted by subscript i. For country j, the receiver of environmental aid, Z_{ij} is negative in its budget constraint (4), i.e. $Z_{ji} = -Z_{ij}$.

Factors used in physical production, labour and capital are assumed to be internationally immobile, but environmental capital is internationally mobile through government aid operations. So we disregard here foreign direct investment in the productive capital, the role of which in environmental policies is analyzed by Rauscher (1991). Within each country capital can be moved without cost between its uses in material production and pollution abatement.

In the following we differentiate the countries with respect to their integration into the world capital markets. We assume that the rich country i can freely borrow and lend internationally at the going world real interest rate r. The poor country j does not (yet) have access to these markets and as an extreme case we assume that it has to keep its foreign debt at the initial value, which we take to be zero. Accordingly, its net imports are zero, too (see (7) below).

The national wealth, denoted by V_i, of the rich country consists of the capital stocks in the production sector and in the pollution abatement sector, less its foreign debt B,

$$(5) \qquad V_i = K_i + Z_i - B_i \ .$$

The national wealth of the less well-off country j also consists of the environmental aid stock Z_{ij},

$$(5)' \qquad V_j = K_j + Z_j + Z_{ij} \ .$$

The national wealth of country i accumulates via domestic saving, less the transfers of capital to its neighbour. Saving is income less consumption, and income is equal to domestic production less the interest payments on the foreign debt. So we have

$$(6) \qquad \mathring{V}_i = F_i(K_i, L_i) - rB_i - C_i - \mathring{Z}_{ij} \ .$$

For j this is similar but without interest payments abroad. By differentiating (5) and combining it with (4) and (6) we get the dynamics of the foreign debt,

$$(7) \qquad \mathring{B}_i = rB_i - X_i \ ,$$

i.e. the deficit in the current account. By further adding (7) and (6) we can derive the dynamics of the total capital stock K+Z, to be denoted by H in the sequel,

$$(8) \qquad \mathring{H}_i = F_i(K_i, L_i) - C_i - X_i - \mathring{Z}_{ij} \ .$$

Let us turn then to government policies. We assume that the government of country i (j) levies a tax t_{Ei} (t_{Ej}) on a unit of domestic emissions. In addition, the revenues of the government consist of taxes on labour income, the tax rate being t_{Wi} (t_{Wj}). The government expenditure is used to subsidize the environmental investment by the domestic firms and to buy some abatement capital and extend it as a gift to the neighbouring country j to be installed there. So we have as the government budget constraint,

$$(9) \qquad s_i Z_i + \dot{Z}_{ij} = t_{Ei}E_i + t_{Wi}L_i \ ,$$

where s is the rate of (permanent) subsidization of the domestic investment into pollution abatement. For country j the flow of Z_{ij} is a revenue to its government. Without any influence on the results, we disregard government deficit financing in specifying (9) as a balanced budget constraint.

The harm caused by pollution depends on either the flow or the stock of it, or both; see the discussion on this by van der Ploeg and Withagen (1991). In the case of transboundary air or sea pollution it is reasonable to concentrate on the stock aspect. Therefore we specify that the infinitely living consumer dynasty maximizes the intertemporal objective function,

$$(10) \qquad \int_0^\infty e^{-\delta t}\, U(C_{it},D_{it})dt \ .$$

This is also the society's welfare function. In (10) the instantaneous utility function U has the normal concavity properties and takes into account the fact that D is a "bad" so that $U_D < 0$, $U_{DD} < 0$ and $U_{CD} < 0$. The parameter δ is the constant subjective time preference which for both the countries is set equal to the international real rate of interest r. This analytical convenience guarantees a steady state solution for the economy. An important property of the model is the fact that the consumers do not by their own consumption-saving decisions influence the decumulation or accumulation of the stock of pollution. This is due to the assumption of continuous full employment (see next section) and that pollution is only a function of output.

3. Optimal growth and the environment under international borrowing

In the following we only consider open-loop strategies in decision-making; for a comparison to closed loop strategies, see van der Ploeg and de Zeeuw (1992). The goal of the social planner in each country is to maximize the welfare (10) of the representative citizen of its home nation subject to the production and environmental technology (1)-(3) and the national budget constraint (4).[1)] Under noncooperative environmental policies there are no such transfers and so $Z_{ij} = 0$ and E_j is a fixed parameter in country i's optimization.

The state variables are the total capital stock H, the foreign debt B and the stock of pollution D. The decision variables are the flow of consumption C, the labour input L, the share of the total capital invested in abatement capital Z and in productive capital K, and net exports X. The dynamics of the economy are described by equations (3), (7) and (8).

Substitute Z = H-K for Z in (2). The current value Hamiltonian of the optimization problem in the rich country i is the following (we omit the subscript i when unnecessary),

$$H = U(C,D) + \alpha(F(K,L)-C-X) + \beta(rB-X) + \mu(a_{ii}G(Q,H-K)+a_{ji}E_j-dD), \quad (11)$$

where α, β, and μ are the costate variables of the state variables H, B and D, respectively. The necessary and sufficient conditions for an inner point optimum with respect to C, X, for full employment, and K, and the dynamics of the costate variables are the following,

$$U_C - \alpha = 0 \quad (11a)$$

$$-\alpha - \beta = 0 \quad (11b)$$

$$(\alpha + \mu a_{ii}G_Q)F_L \geq 0 \quad (11c)$$

$$(\alpha + \mu a_{ii}G_Q)F_K - \mu a_{ii}G_Z = 0 \quad (11d)$$

$$\dot{\alpha} = -\mu a_{ii}G_Z + \delta\alpha \quad (11e)$$

$$\dot{\beta} = -\beta r + \delta\beta \quad (11f)$$

$$\dot{\mu} = -U_D + (\delta+d)\mu \ . \quad (11g)$$

Conditions (11b) and (11f) and the fact that δ is equal to r imply

$$\dot{\alpha} = \dot{\beta} = 0, \quad (12a)$$

i.e. β and α are constant over time. In the standard growth model, see Blanchard and Fischer (1989), ch. 2, the constant α would imply a constant level of consumption over time, which is made consistent with capital accumulation by foreign borrowing. In contrast, in our model we have a constant marginal utility U_c of consumption over time. (11a) gives C as a function D and α,

(12b) $C = C(\alpha,D),\ C_\alpha < 0,\ C_D < 0.$

In the optimal solution the consumption and the pollution stock go into reverse directions. The fact that α is constant over time, when combined with (11e) and further with (11d), produce the criteria for allocation of capital,

(12c) $[1 + (\mu/\alpha)a_{ii}G_Q]F_K = r$ and

(12d) $(\mu/\alpha)a_{ii}G_Z = r.$

In the optimum the marginal social return on material and environmental investment are equal, as is natural. The social return on material investment has to be downgraded by the environmental damage caused by it as the shadow price μ of the pollution stock is nonpositive. In the following we denote $-\mu$ by p and call it, for short, the price of environment. The labour input is assumed to be at the full employment level in the optimum.[2)]

The dynamic solution of the model is essentially simplified by the fact that there is free foreign borrowing, as the shadow price of the foreign debt is a constant. The dynamics can now be split into two recursive parts: those for the state variables H and D and their costate variables α and μ and those for the foreign debt B and its co-state variable ß. The first part is further simplified as α is constant over time.

The optimal stock of capital K* and the total capital stock H* can be solved from the capital allocation criteria (12c and d) as a function of p and r. The reactions are unambiguous with respect to the interest rate, but the reaction of H and K to the price of the environment p consists of two conflicting elements.[3] The rise in p directly lowers the social marginal rate of return on capizal, as can be seen from (12c), which leads to a cut in K. At the same time the marginal return on the abatement capital Z rises which also calls for more capital to be invested in material production as the two stocks K and Z are cooperative in pollution abatement in the sense that more pollution can be abated with a given stock Z when production Q is higher. In (12e) we have assumed that the direct effect dominates. So we have,

(12e) $K^* = K(p,r),\ K_p < 0,\ K_r < 0$ and

(12f) $H^* = H(p,r),\ H_p > 0,\ H_r < 0$.

Similarly, a rise in p increases the value of marginal productivity of Z and leads to higher investment in Z. However, the simultaneous decrease in K also calls for less total capital H. We assume in (12f) that the former effect dominates. Together these imply for the optimal abatement capital Z = H-K the plausible reactions,

(12g) $Z^* = Z(p,r),\ Z_p > 0,\ Z_r < 0.$

The dynamics now consist of only two equations for the pollution stock D and the price of the environment p, as α is constant,

(13a) $\dot{D}_i = a_{ii}G_i(K(p),Z(p)) + a_{ji}E_j - d_iD_i$ and

(13b) $\dot{p} = U_D(C(\alpha,D),D) + (d+\delta)p$.

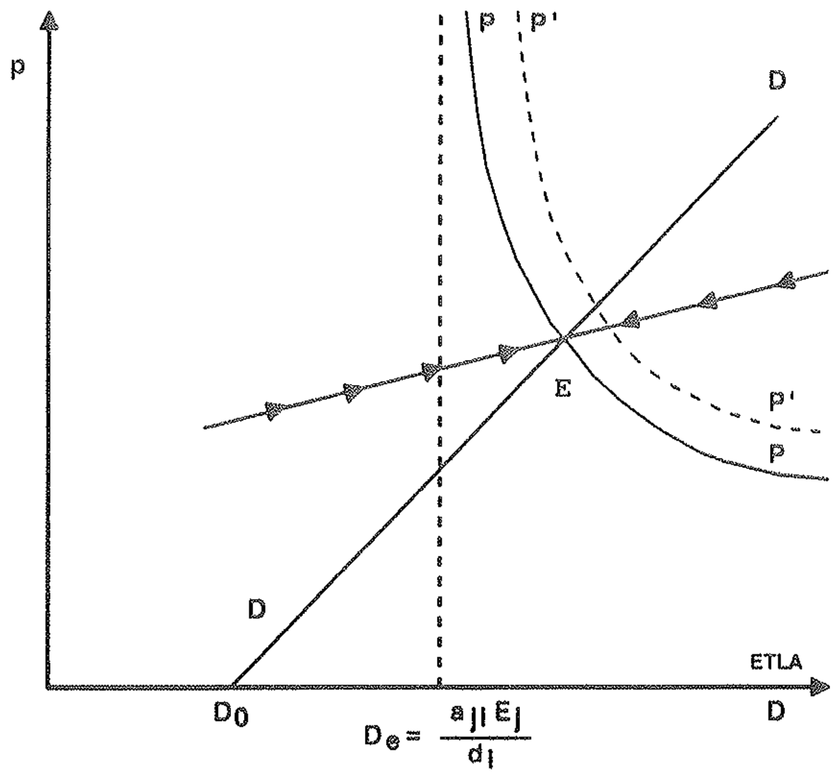
The dynamics are saddle point stable if the trace of the system is positive and the determinant is negative. This is so if the marginal disutility of pollution depends negatively on the stock of pollution, taking into account the consequent reduction in material consumption, which works in the opposite direction reducing the absolute value of disutility of pollution. This we assume to be the case. Under a separable utility function (10) between C and D this holds for certain.

The situation is depicted in figure 1. The equilibrium stock of pollution at the value $D_{ie} = a_{ji}E_j/d_i$ is the pollution stock cumulated solely from the pollution deposited in country i from its neighbour's constant flow of emissions. This can only be reached if there is no home country pollution, i.e. if the price of the environment rises to infinity. The DD curve from (13a) which shows the trade-off in pollution abatement between the equilibrium stock of pollution and the price of environment p is downward sloping, as lower values of p lead to a smaller abatement capital Z and thereby to larger emissions and to a higher stock of pollution.

The PP curve from (13b) shows how the equilibrium price of pollution is discounted from the marginal disutility of pollution and it is upward sloping given the above assumptions on the reactions of K and H with respect to p. The environment is a free good at the stock denoted by D_0, which is the stock prevailing under conditions of no man-made emissions in both countries. The saddle-path leading to the equilibrium at point E can be shown to be upward sloping.[4)]

Normally in Western countries we observe developments where the stock of pollution and the price of the environment, which is in a fixed relationship to the Pigouvian tax on pollution (see section 4) have both risen over time. In the former socialist countries, however, the reverse may at present be the case so that we can imagine the following case. In figure 1 they have a stock of pollution higher than is sustainable in the long-run and an artificial downgrading of the price of the environment. So, an immediate shift to an optimal growth path would mean a sharp rise in the environmental tax (see the next section) and then a diminishing environmental taxation.

Figure 1. The dynamic solution of the stock of pollution and the price of the environment in the international economy.



Let us turn to consider the time paths of the other variables. The country i accumulates capital and production and reaches its steady state at the modified golden rule optimum, now with two capital stocks. The steady state capital stock in materal production is definitely less than under no environmental considerations, as determined by (12e) at the equilibrium price of the environment. As was mentioned above, the material consumption declines as the stock of pollution rises. Furthermore, as p rises the material capital stock contracts and the pollution abatement stock expands. The material consumption is then solved by combining the dynamic equation (7) for the foreign debt with the national income identity (4) and by specifying the normal transversality condition for foreign borrowing,[5)]

$$\int_0^\infty e^{-\delta t} C(t)dt = \int_0^\infty e^{-\delta t} Q(t)dt - \delta\int_0^\infty e^{-\delta t} (Z(t)+K(t))dt \quad (14)$$

$$+ [Z(0)+K(0)-B(0)].$$

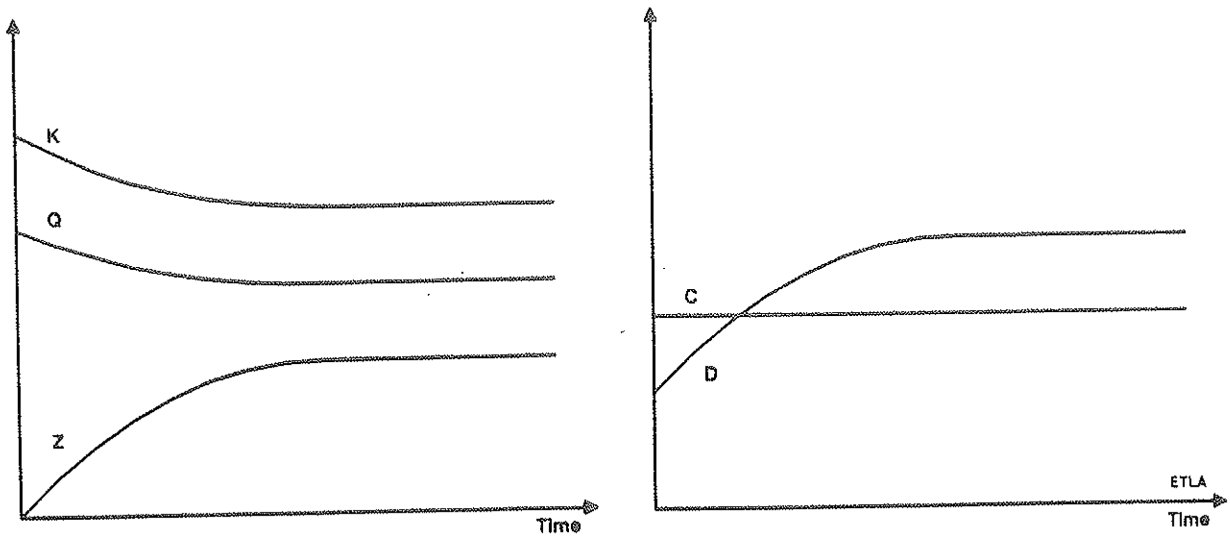
The country i only consumes its labour income, which consists of the first two terms on the right-hand side, and leaves its capital income intact. Additionally, the country consumes over time the net wealth at the initial moment, consisting of the three last terms in brackets. The optimal path of consumption (or marginal utility α) can now be solved as consumption is a function of α and D (see (12b) above). Furthermore, D, production Q and the capital stocks K and Z are a function of α. If the economy is near the steady state at the initial moment, (14) gives the solution,

$$C = Q - \delta B . \quad (14)'$$

This implies that the net exports is equal to the interest payments on foreign debt so that current account is in balance in equilibrium.

At the initial moment t=0 there is a stock adjustment in the economy so that the two capital stocks K and Z immediately reach their optimal values given V and D. This is achieved through raising foreign debt, which takes place instantaneously. The only dynamic force after this stage which leads to a change in the resource allocation of the economy is the growing pollution and the consequent need to invest the economy's resources in its abatement.

Figure 2. The dynamic solution of production (Q), consumption (C) and the stocks of abatement capital (Z) and the material capital stock (K).



For the closed economy j, which does not have access to the international capital market, the optimum problem is similar to that above but with no terms related to foreign borrowing. The optimum conditions consist of (11a, c, d, e and g). Again, the optimum resource allocation condition (11d) allows us to solve the capital stock K as a function of the total capital stock H and the relative price of the environment p/α. This can then be inserted into (11e). Now we have again a dynamic system for the two stocks H and D and their costate variables α and μ. This can be shown to have saddlepoint stability, analogous to the analysis by van der Ploeg and Withagen (1991).[6)]

4. National environmental policies in a market economy

Let us now turn to derive the firm and household behaviour in a market economy under environmental tax and subsidy instruments. The firms are assumed to operate under perfect competition in the output and input market. The representative firm maximizes the (real) profit

(15) $$\pi_i = Q_i - r(K_i + (1-s_i)Z_i) - w_iL_i - t_{Ei}E_i \ .$$

The necessary and sufficient conditions for firm behaviour are the following[7)],

(16a) $$F_K(1-t_{Ei}G_Q) = r$$

(16b) $$F_L(1-t_{Ei}G_Q) = w_i$$

(16c) $$G_Z = -(1-s_i)r/t_{Ei} \ .$$

From (16a) and (16b) we see that the pollution tax is neutral with respect to the choice of capital and labour input in material production, as is plausible. If the economy wants to maintain full employment and combine environmental goals with it by introducing a pollution tax, (16b) shows that the real wage has to fall to make these two goals compatible with each other. Accordingly, we assume throughout in the following a flexible real wage rate which guarantees full employment with L being the constant full employment level of employment.

Let us then turn to consumer optimization. The infinitely living consumer dynasty maximizes the utility function (10) subject to the flow budget constraint

$$(17) \qquad \dot{V}_i = (1-t_{Wi})w_i L_i + [Q_i - w_i L_i - t_{Ei} E_i + s_i Z_i] - C_i - rB_i \ .$$

The first term is the after-tax labour income and the term in brackets is the profit, i.e. dividends, of the firms. Using the budget constraint (9) of the government, (17) can be written in identical terms as the national wealth accumulation (6) above. Therefore the consumption and saving behaviour of the households are the same as in the social optimum. This is due to the fact that full employment prevails throughout and that consumers do not have a direct effect on the pollution stock prevailing in the equilibrium. They only adjust the consumption path as a reaction to the accumulation or decumulation of the pollution stock without any effect on it.

From the labour demand condition (16b) and the inelastic supply L of labour we can solve for the equilibrium wage rate. Given the international rate of interest and the demand for capital K and Z by firms, the wealth demand by households determines the foreign debt in equilibrium. The dynamics are the same as in the social optimum above if the government tax and subsidy measures are set optimally.

Equating the private and social optimal conditions for material investments in (12c) and (16a) gives the standard result in environmental economics for the optimal environmental tax rate,

$$(18) \qquad t_{Ei} = \frac{-\mu_i}{\alpha_i} a_{ii} \ .$$

This implies that the tax rate is nonnegative and zero if the domestic country only pollutes its neighbour and not at all itself, i.e. if a_{ii} is zero. Equating the return on environmental investment in (12d) and (16c) gives the same tax rate as in (18) and the condition that

$$(19) \qquad s_i = 0 \ .$$

So the government should only tax pollution but not subsidize abatement investment at all. The reason for this is that the return on material and environmental investment should be the same and the environmental tax is enough to do this. A subsidy on environmental investment would lead to overinvestment in the environment. The government budget constraint (9) implies that the revenues from a pollution tax are channelled to households through negative taxes on labour income, i.e. transfers. In this model of no disutility of working and the consequent fixed labour supply, taxes on labour are nondistortionary and irrelevant as to operation of the economy, as could be seen already above in the previous section.

In a standard neoclassical one-sector growth model, see e.g.

Blanchard and Fischer (1989), ch. 2, government expenditure has no effect on the steady state capital stock and only consumption is crowded out in a one-to-one relationship. Here we do not have any government expenditure, as there are no subsidies in the optimum, but a pollution tax is levied on production and therefore the equilibrium output is less than under environmental laissez fair. However, even if there were government expenditure in the form of subsidies, these would not influence the household decision-making, as they, in contrast to the treatment of government expenditure in the standard model, are here reimbursed to the private sector.

For country j the conditions in (16) are similar to those of country i with the exception that instead of the international rate of interest r the interest rate r_j is internal and endogenous. From (16b) we again solve w to maintain full employment and then r_j is solved from the equality of the demand for capital (K and Z) as given by (16a and b) and the supply of capital through the net wealth in (5)'. This interest rate is equal to the marginal social return on capital and equal to $r-(\dot{\alpha}/\alpha)$. As α declines over time, this rate of interest is typically higher than the international rate of interest. Country j should also impose an environmental tax of the kind in (19) but again no subsidy.

If the countries have access to the same constant returns to scale technology, i.e. the same F-function, the standard aggregative growth model would predict that they would reach an identical golden rule steady state equilibrium, where they would have in the end the same level of material welfare and real income per capita. Environmental considerations, however, may lead to a deviation between the countries.

This is caused by two factors. First, they may have different preferences and value the environment in a different way. Note in contrast that in the standard growth model preferences only have an influence on the steady state equilibrium through the time preference. If country i values the environment more than j, i.e. i has a higher value for the real price of environment p/α than j, country i would like to impose a higher tax rate on pollution than country j. Condition (16a) would then imply a lower level of capital in equilibrium in country i than in j and therefore also a lower level of real income and material consumption.

Secondly, the geographical conditions may cause the countries to differ with respect to the a_{ii} parameter and so to tax pollution in a different way, which leads to a difference in material production.

The foreign flow of pollution has a direct effect on the optimum in each country through the $a_{ji}E_j$ term in (13a). A larger E_j raises the stock of pollution in country i through transboundary spillovers of pollution which raise the equilibrium values of D and p. In figure 1 the PP curve shifts now to the right to the dotted position. An immediate reaction by country i is to raise its pollution tax. There is a rise in the abatement stock Z and a reduction in the capital stock K. So, also consumption C declines to restore the equilibrium.

An unbearable situation for country i would arise if $a_{ji}E_j$ were higher than d_iD_i, see (13a), for all relevant D_i, i.e. if the spillover pollution would be higher than the assimilation capacity of nature in the victim country. No environmental policy by country i would produce a sustainable situation for it in the long run. It should also be recognized that the open-loop strategy analyzed here produces a result with less pollution than the closed loop strategy. Furthermore, the closed loop stategy takes into account the preferred reaction by the neighbour, which is not embodied in the open loop strategy; see on these issues van der Ploeg and de Zeeuw (1992).

Let us briefly consider the Nash equilibrium of the countries in their environmental policies. As shown above, larger emissions by the neighbour lead a country to tighten its environmental policies, which also benefits the neighbour. Note therefore that the countries internalize, through the price of environment, as victims international spillovers of pollution even though they do not coordinate their environmental policies. However, this may not be done in an efficient way, as both only take into account the pollution of the neighbour, but not its own spillovers. By solving the equilibrium conditions of (13a and b), the following reaction functions hold for the environmental tax rates,

$$(21) \qquad t_{Ei} = R_i(t_{Ej}), \; R_i' = - \frac{\alpha_j}{\alpha_i} \frac{a_{ji}}{a_{jj}} \frac{(G_j)_p}{(G_i)_p + d_i(\delta + d_i)/a_{ii}U_{DD}} < 0,$$

and similarly for the neighbouring country. Normally the absolute value of R' is less than unity. Consideration of efficient cooperative solutions lies outside this paper; see on this e.g. Alho (1992).

5. International environmental aid

We now enlargen the above case of noncooperative environmental policies to the case where the government in country i also collects taxes to finance pollution abatement in country j but operates unilaterally in the sense that it only considers its own welfare in extending this aid. To simplify the presentation, we assume that the donor i is in its steady state equilibrium. Further, as one case we also allow for the possibility that the recipient country j is in an initial situation where it starts environmental and material planning with no abatement capital of its own, $Z_j=0$. This should resemble the current situation in the Baltic region, where various kinds of environmental aid and financing are just being extended i.a. by the Nordic countries to the newly independent Baltic countries with virtually no inherited pollution abatement capital.

As was specified above in section 2, environmental aid here takes the form of shipments of environmental abatement capital from country i to j. However, as we shall see, the form in which the aid is extended only matters in the case where it imposes an effective constraint on the free allocation of resources by country j. As was also mentioned above, the national wealth of country i is reduced in this operation, while that of country j is increased by the same amount. Let A_{ij} be the flow of environmental aid from i to j so that the corresponding aid stock accumulates by

(22) $$\dot{Z}_{ij} = A_{ij} .$$

The Hamiltonian for country i's optimization is now transformed into the following,

$$H = U(C,D) + \alpha(F(K,L,D)-C-X-A_{ij}) + \beta(rB-X) + \tag{23}$$
$$\mu(a_{ii}G_i(Q_i,H_i-K_i)+a_{ji}G_j(Q_j,Z_j+Z_{ij})-d_iD_i) + hA_{ij} .$$

The optimal conditions are the same as above in (11) and (12) supplemented with those for A_{ij},

$$-\alpha + h = 0 \tag{11h}$$

$$\dot{h} = -\mu a_{ji}G_{zj} + \delta h . \tag{11i}$$

Combining (12d), (11h) and (11i) gives the condition that

$$a_{ji}G_{zj} = a_{ii}G_{zi} . \tag{24}$$

So we reach the conclusion that in an optimum a country would like to invest in all the environmental projects in its neighbour which give to itself at least the same environmental return as its own abatement investment. Location of the environmental capital does not have any effect on its decisions, which are solely determined by pure efficiency considerations. It should be noted that here the assumption of a homogeneous material production in the two countries leads to an exclusion of the effects arising in connection with the transfer problem.

Let us first study the consequences of environmental aid on country i. As can be seen from (14), without the aid the steady state rate of consumption $C_{i,e}$ depends on the steady state level of production in the following way,

$$dC_{i,e} = (F_{Ki}-\delta)dK_i . \tag{25}$$

The equilibrium stock of pollution in country i changes by

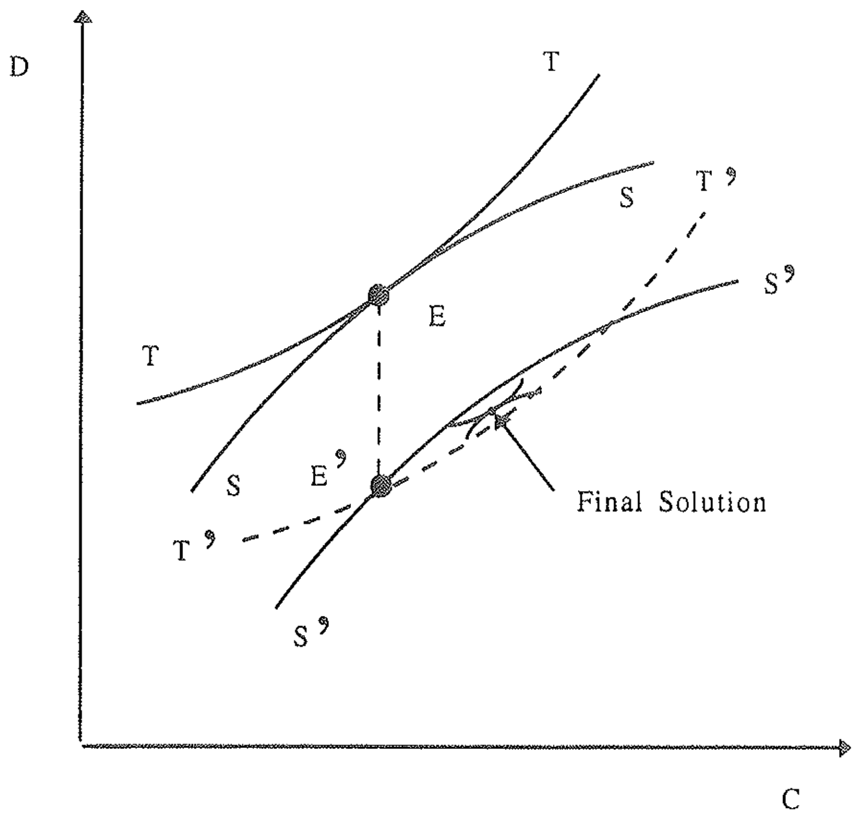
$$(26) \qquad dD_{i,e} = \frac{a_{ii}(G_Q F_K dK_i + G_{Zi} dZ_i)}{d_i} .$$

Since in the steady state the resource allocation is constrained by $dK_i+dZ_i=0$, the rate of transformation between C and D is,

$$(27) \qquad \frac{dD_{i,e}}{dC_{i,e}} = \frac{a_{ii}(G_{Qi}F_{Ki} - G_{Zi})}{d_i(F_{Ki}-\delta)} > 0.$$

In figure 3 we have depicted the transformation curve TT in production between material consumption C and the stock of pollution D and also the indifference curve SS in consumption and the equilibrium at point E.

Figure 3. The change in the steady state of the donor country after environmental aid extended to the neighbouring country.



When the opportunity to invest in the neighbour's environment becomes open to country i, this has clearcut effects on its situation. The equilibrium rate of consumption is now, corresponding to (25)[8)]

$$(25)' \qquad dC_{i,e} = F_{Ki}dK_i - rdZ_{ij} \; .$$

The equilibrium pollution stock changes by

$$(26)' \qquad dD_{i,e} = \frac{a_{ii}(G_{Qi}F_{Ki}dK_i + G_{Zi}dZ_i) + a_{ji}G_{Zj}dZ_{ij}}{d_i} \; .$$

Let us now assume that the return to country i on the first unit of environmental investment Z_{ij} to be financed by it in country j is higher than that on the last domestic unit in i, i.e. that $a_{ij}G_{Zj} > a_{ii}G_{Zi}$. This assures that the return on foreign environmental aid is higher than its marginal cost. The green national income of country i expands by investing in j as far as this condition is fulfilled. Accordingly, the transformation curve shifts downward in figure 1, but with a given price ratio p/α the domestic resource allocation between material capital stock K and pollution abatement capital Z is not changed. This can also be seen from the fact that the possibility of aid does not have an effect on the optimality conditions for the various investment allocations derived above. This means that in point E' the marginal rate of transformation is the same as in point E.

So, the new environmental investment opportunity works like a positive productivity shock to the donor country increasing its national income. In point E', however, the marginal rate of substitution in consumption between C and D is higher than at point E. This is so, as with a smaller D and the same C as in the initial equilibrium, the consumers and the society are willing to increase material consumption by sacrificing somewhat through a rise in D.

The final outcome is that there is definitely a rise in consumption C, as some of the gains achieved in pollution control are also spent on material needs. This further implies that the domestic environmental abatement stock Z_i is going to decline.

So we reach the conclusion that if the neighbour country offers at the margin better environmental investment opportunities than in the home country, domestic environmental investment are definitely going to decline. This also means that the pollution tax is lowered in the donor country as otherwise the capital stock K does not expand.

Country j benefits from this aid by its neighbour country i in several ways. First, also its environment is cleaned. Secondly, it can maintain or increase its material production, i.e. capital stock. Thirdly, it can increase its consumption more rapidly. Let us consider exactly what country j will do as a consequence of environmental aid extended by country i.

The evolution of the marginal value h_j of the environmental aid stock for j is the following,

$$(28) \qquad \dot{h}_j = -\mu_j a_{jj} G_{zj}(Z_j + Z_{ij}) + \delta h_j \ .$$

Combining this with condition (11e) for country j shows that α_j and h_j are both equal. This means that country j allocates its environmental aid in such a way as to achieve the same marginal value from aid as from consumption. Note that in (28) the optimum refers to total pollution abatement stock Z_j+Z_{ij} in country j, not only to its own investment Z_j.

In the context of a standard neoclassical growth model, if country j were integrated into the world capital markets, a permanent flow of aid would be consumed right away, see on this Blanchard and Fischer (1989), p. 66-67. A temporary aid also leads to a permanent but a smaller rise in consumption than a permanent aid. In this case international aid does not cause a change in investment behaviour by country j. But if the recipient country j is not integrated into the international capital market, a permanent aid will change the saddlepoint path leading to the new equilibrium in such a way that a part of the aid will be invested and a part consumed. Such an outcome would be produced by the standard neoclassical one sector growth model with the exception of a certain type of the utility function.[9] The rise in consumption C leads to a reduction in its marginal utility U_c. This means that the shadow price α of the total capital stock H declines and there is a reduction in the interest rate $r-(\dot{\alpha}_j/\alpha_j)$.[10]

In our growth and pollution case, however, it is intuitively easy to understand that the inflow of capital is allocated by country j in an optimal manner, not only to current and future consumption, but also to protect the environment. A rise solely in material consumption would not be enough to reach a new optimal path. As α goes down, (12c and d) show that the marginal productivity of the physical capital K_j declines and that of the abatement capital Z_j increases. This change calls for a corresponding shift in these two capital stocks, a rise in Z and a decline in K in country j. On the other hand, it can be inferred that the abatement capital Z_j+Z_{ij} is not going to rise by the full amount of the environmental aid, as then country j would not raise its consumption at all. So we can infer that, as a first round effect, the environmental aid is going to lead to a partial offset of the own environmental investment by the recipient country, to a reduction in its material investment and to a rise in material consumption.

However, these reactions are based on partial analysis only. The environmental aid raises the supply of capital in country j as the resources of the households rise, see discussion in connection with (17) above. The demand for capital also rises as in (12f) $H_{p/\alpha}>0$. So, there is a larger total capital stock K_j+Z_j than initially. We cannot definitely tell, whether the capital stock K_j is finally larger or smaller than initially. It is also likely that the pollution tax is reduced as the own environmental investment by country j are offset by the foreign aid. This results in an increase in transboundary pollution spillovers to the donor country, which eliminates to some extent the gains to the donor from its environmental aid.[11)]

The equilibrium reactions, i.e. when country j is also in the steady state, can be solved from the equation system (13). However, the dependence U_D through consumption on the aid complicates the situation, so let us disregard it and concentrate on the case of separability between C and D in consumption. We can solve for the changes in the price of environment in both countries as follows,

$$[(-d_i(\delta+d_i)/U_{DD})-a_{ii}(G_i)_p]dp_i - a_{ji}(G_j)_p dp_j = a_{ji}G_{Zj}d(Z_j+Z_{ij})$$

(29)

$$a_{ij}(G_i)_p dp_i + [(-d_j(\delta+d_j)/U_{DD})-a_{jj}(G_j)_p]dp_j = a_{jj}G_{Zj}d(Z_j+Z_{ij}).$$

Now we can definitely infer that if the determinant (29) is positive and as $d(Z_j+Z_{ij})$ is positive, the price of environment in both countries declines as a result of an increase in environmental abatement investment in country j through aid extended by i. This holds if the positive diagonal elements dominate on the left-hand side, as is plausible.

The environmental tax in country j (and i) is not, however, determined by the total stock of pollution abatement capital Z_j+Z_{ij}, but by the optimal own capital Z_j. Above we have argued that it is going to decline as a result of the aid. Solving the steady state value of $t_{Ej}=-\mu_j a_{jj}/\alpha_j$ from (11e), we can easily derive the outcome that the pollution tax is lowered also in country j. This is also intuitively clear, as the aid is a substitute for own environmental measures by j.

In an extreme case, country i invests all the environmental investment in country j and the latter need not carry out any of its own, i.e. $Z_j=0$. As we normally assume a_{ij} to be smaller than a_{jj}, country i would not be willing on pure efficiency grounds to go this far. However, country j may have a lower valuation of the nature so that, due to the differences in the p/α-relation, country i considers also this extreme case. Country i may thus invest more in the environment than j would wish, and now h_j becomes less than α_j. Country j cannot reach its first best optimum and will equate the marginal value of consumption and investment in material capital K. In this case clearly the aid leads to a rise in the total environmental capital stock Z_j+Z_{ij}.

Above we referred to the extreme case where country j is polluting so much that the spillover from it to country i exceeds the sustainable value for country i. In this case the desire of country i to turn to environmental aid of the kind discussed above is even higher than considered above.

The present situation in the Baltic countries may resemble the following situation. Currently they have no environmental capital, and the Baltic countries should first carry out a shift in resources from material growth to abatement when they adjust their economies to the optimal accumulation path, i.e. to the stable arm northeast of the equilibrium in figure 1, as was discussed above. This can only be achieved by reducing material production for consumption needs. Of course, they also have to abandon a lot of their old and outdated inefficient capital, which further leads to a cut in their living standards. Western environmental aid is able to alleviate this difficult structural change and matching of the conflicting priorities.

6. Conclusions

In this paper we have discussed growth and the environment in the context of the international economy, especially from a dynamic point of view. The model should have some relevance in the present situation in Europe and the Baltic region, where matching of the environmental problems and material growth needs is acute. Without

Western aid the Eastern European countries should invest in their environment substantial resources which they prefer to use for material needs.

We showed that Western environmental aid leads to a rise in consumption in the recipient country, but also discourages environmental measures by the recipient countries themselves. However, total environmental capital is increased in the recipient country. International environmental aid also leads to a reduction in the domestic pollution tax in the donor country if environmental projects with higher return can be financed there than at home. The pollution tax is also lowered in the recipient country. Material consumption is going to rise in both countries.

If the donor invests more into the recipient's environment than the latter would do on its own, then the environment improves more substantially. In practice, the donor country would mostly be willing to finance those projects which the recipient does not want to carry out on its own; see Alho (1992) for a treatment of this case. The potential for gains from environmental aid is bigger than in the aggregate model considered here.

Footnotes

1) A warning on the relationship between the environment and material growth is in place. This relationship fundamentally differs from two-sector growth optimization where both goods are produced and consumed by human resources for human needs only. The environment is governed by ecological laws and therefore human welfare considerations may violate the long-run sustainability of nature. Instead of predetermined preferences we should specify endogenous ones which adjust so as to become consistent with the preservation of nature when necessary. This wider problem setting lies outside the limits of the present paper, but is essential when considering optimization of material economic activities.

2) A country has to keep track of being able to avoid the following caveat in its growth. Assume that the marginal productivity of labour in terms of material production is positive at all levels of labour input available to the society. There is, however, a possibility that at some level of production the marginal utility of consumption is just equal to the marginal value of the environmental damage caused by production, i.e. in (11c) $\alpha+\mu a_{ii}G_Q=0$. Now the marginal social value of labour would be zero. (12c) shows that at the same time the net social value of additional material investment would be negative as the marginal social product is zero and the investment cannot pay any of the related interest expenses.

In this possible backlog in growth the economy cannot use all of its resources in a useful way because of this environmental preference constraint. There is a chronic unemployment, i.e. overpopulation in relation to technology and the bearing ability of the environment. However, the possibility of environment constrained growth is not very likely only because of preferences. These should favour the environment very much indeed in order to lead to this kind of state.

3) From (12c) and (12d) we can derive by differentiating the following two equations to determine optimal K and H,

$$\begin{bmatrix} F_{KK}-pa_{ii}(G_{KK}-G_{KZ}) & -pa_{ii}G_{KZ} \\ pa_{ii}(G_{ZZ}-G_{ZK}) & -pa_{ii}G_{ZZ} \end{bmatrix} \begin{bmatrix} dK \\ dH \end{bmatrix} = \begin{bmatrix} a_{ii}G_K \\ a_{ii}G_Z \end{bmatrix} dp + \begin{bmatrix} 1 \\ 1 \end{bmatrix} dr ,$$

where G is now defined as G(Q(K),Z). With the assumptions on F and G made above, the determinant on the left-hand side is positive as it should be as the allocation of total capital H, given the price ratio p/α, maximizes the green national product. Now we can infer that $dH/dp > 0$, $dH/dr < 0$, and $dK/dr < 0$. The sign of dK/dp is ambiguous, as discussed above. The smaller the price p, the more likely it is that $dK/dp < 0$.

4) This is proven in the following way. Take the first row of the determinant of the dynamic system, i.e. (13a). The stable arm is given by the characteristic vector related to the negative

characteristic root, say y, i.e. $(d-y)(D-D_e)+a_{ii}G_{ip}(p-p_e) = 0$, where the subscript e denotes the equilibrium value of the variable concerned. It is now easily seen that the stable arm has a positive slope as y is negative.

5) This condition states that $e^{-rt}B(t)$ approaches zero as the time goes to infinity; see on this Blanchard and Fischer (1989), chapter 2.

6) See their model in sections 6 and 7 and its stability conditions.

7) Note that the firm behaviour can be derived from a static optimization as there are no adjustment costs of capital accumulation included in the model.

8) Use (14)' above to derive the result that in equilibrium $C_i = Q_i - rZ_{ij}$.

9) As regards the standard growth model see Blanchard and Fischer (1989), chapter 2. However, this result does not hold uniformly. If the utility function has the property of constant relative risk aversion, international aid or producticity shock is partially consumed and the rest is invested, but if the utility function is of the constant absolute risk aversion type, all of the gain is consumed.

10) This can be intuitively understood as the aid leads country j towards the situation where the marginal utility of consumption would be constant and there is less room for future reduction in the marginal utility of consumption.

11) In public finance the question of provision of public goods and redistribution of income has produced a neutrality theorem, which says that aggregate voluntary contributions to a public good are independent of redistribution of income among the contributors, see Bergström et al. (1986) on this. In our case, however, the conditions for neutrality are not fulfilled as there are two public goods E_i and E_j, and after the transfer from country i to j the aggregate income of the contributors of E_i does not remain unchanged, as is required. Another point is that, as the country j is not integrated into the world capital markets, marginal utility of income is not equalized between i and j. I owe Parkash Chander for raising this public finance aspect to my attention.

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