Transboundary Externalities in the Environmental Transition Hypothesis

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Abstract

The Environmental Kuznets Curve (EKC) is a hypothesis which implies that it is possible to"grow out of environmental degradation". Most theoretical models of the EKC relation have not accounted for transboundary and intergenerational externalities nor have empirical studies provided evidence that validates an inverted U shaped relation between environmental degradation and economic growth for pollution problems where the effects are far–displaced or are long–delayed.

This paper integrates the theory of transboundary externalities into the most common theoretical framework applied to the EKC hypothesis. It shows that where a significant proportion of the environmental impacts of economic activity occurs outside the territories in which those activities take pace, the de–linking of growth and environmental degradation is less likely to happen.This proposition is demonstrated by assuming that decisionmakers have a Nash-type non cooperative strategic behavior.

Key words: environmental transition, growth, Kuznets, pollution, transboundary externalities.

JEL classification: D62, D91, O11, O19, Q25.

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1 Introduction

A series of empirical studies published in the 1990s show the existence of an inverted U shaped statistical relationship between some indicators of environmental impact and per capita income (Ansuategi et al (1996) and Barbier (1997) review these studies).This has been referred to as either the Environmental Kuznets Curve (after Kuznets'(1955) study of the relation between per capita income and income inequality) or the Environmental Transition Hypothesis (after the Demographic Transition Hypothesis)[1]. However, the evidence provided in these studies can hardly be regarded as conclusive. There are two main objections. First, the EKC hypothesis is intended to represent a long–term relationship between environmental impact and economic growth for an individual economy (that is why it is also called "Environmental Transition Hypothesis"), whereas data used in the empirical tests are drawn from cross–sections of countries at particular points of time. Second, the inverted U relationship exists for some impacts but not for others. More particularly, empirical studies have not provided any evidence that validates an inverted U-shape between environmental degradation and economic growth for pollution problems where the effects are geographically far–displaced or are long–delayed.

It is beyond the scope of this paper to assess whether pooled cross–sectional data are meaningful for testing the Environmental Transition Hypothesis. We assume that there is some validity in those studies. Our aim is rather to consider the theoretical issues involved. Some recent analyses of the EKC have emphasized the importance of the intergenerational and/or transboundary nature of environmental degradation in order to determine the extent to which degradation may be de–linked from economic growth (Arrow et al. 1995, Cole et al.1997). However, most models proposed in the theoretical literature do not consider the sensitivity of the curvature of the EKCs to the existence of intergenerational and/or transboundary spillovers. We expect that explicit consideration of the relation between transboundary environmental externalities and investment in environmental amenities/conservation will provide useful insights that will help understanding of the relation between economic growth and environmental quality.

The paper is organised as follows. After this introduction, section 2 motivates our hypothesis on the linkages between pollution, economic growth and the spatial incidence of pollution. Section 3 sets up the model. Section 4 solves the decisionmakers' maximization problems for the case of two symmetrical countries. The sensitivity of the curvature of the EKCs to the existence of transboundary externalities is analysed in section 5. Finally, section 6 draws some conclusions.

2 Transboundary externalities and the NIMBY phenomenon

The central difficulty with the EKC findings is that the empirical evidence is different for different classes of pollutants. Empirical studies have found that for a number of public and environmental pollution indicators, particularly public health indicators, environmental quality is a monotonically decreasing function of per capita income. For others, such as carbon dioxide emissions, it is a monotonically increasing function of income. The U-shaped curve in fact applies only to some air and water pollutants and deforestation does not show a clear pattern with income.

We consider the view that the behavior behind such varieties may be related to the spatial and temporal incidence of environmental costs. Access to safe water and provision of urban sanitation are local and urgent human needs and any threat to these tends to be addressed immediately. However, the effects on health, productivity and welfare of most air pollutants and water pollutants have less immediate effects and so are addressed only as a second order of business. Deforestation could also be considered as one of these medium–term and/or quasi–local environmental problems. Its negative impacts on soil quality, regulation of hydrological cycles and configuration of local climate will be partially "externalized" to the near future and neighbouring areas. Finally, the impacts of global warming harm people who are geographically and temporally far from the pollution site and accordingly they tend to be ignored by the polluters.

A number of studies have observed a correlation between the different spatial/temporal incidence of environmental degradation and the relationship between economic growth and environmental quality (Arrow et al., 1995; Ansuategi et al., 1996; Barbier, 1997; and Cole et al., 1997). In this paper we consider the behavioral basis for such a correlation. More particularly, we consider the behavioral basis for the empirical observation that societies address environmental problems involving external effects sequentially: addressing those with the most inmediate costs first, and those whose costs are displaced in time and space later.

There is a behavioral connection between sequential decision–making of this sort and nimbyism[2].The NIMBY phenomenon has been documented in a fairly extensive literature (O'Hare, 1977; Peelle and Ellis, 1987; Inhabler, 1992; Groothuis and Miller, 1994; and Hunter and Leyden, 1995). Much of the empirical work in the area uses survey data to test competing hypothesis about the nature of opposition to a LULU. As it may be expected, most of these studies suggest that opposition decreases as distance from a proposed facility increases (Mitchell and Carson, 1996; Lober and Green, 1994).

There are two possible ways to connect the EKC/Environmental Transition Hypothesis with nimbyism. The first is the rate at which people discount both future and geographically distant effects of current economic activity (Perrings and Hannon, 1997; Steininger and Friedl, 1998). It has already been suggested that time preference is inversely related to income (Perrings, 1989). There is reason to believe that spatial discounting is similarly related to income. There have also been studies trying to assess the effect of spatial distance in willingness to pay values (Pate and Loomis, 1995).We consider the implications of a link between per capita income and the reach in space and time of people's concern for others.Specifically, we consider the proposition that poor economies will only trade–off current consumption for abatement of short term and local effects. Few countries will be as rich as to trade–off current consumption for abatement of effects happening in the long term and far from their national boundaries. Fairly local and medium term externalities will be progressively internalized as income rises.

A second way to link nimbyism to the EKC literature takes an institutional perspective. The argument is as follows. In an ideal economy where every activity has a price, property rights are defined and protected, competition is rigorous and market information is complete, the market is the only institution needed by self-interested individuals to reach an efficient outcome – to maximize social welfare when measured as simple aggregation of the welfare of every single individual in society. But in the presence of market failures, that is, when at least one of the "ideal" conditions does not hold, some kind of intervention on a collective basis is needed for achieving the efficient outcome. This means creating an additional institution, a single decision–making body for the collective of individuals affected by this market imperfection. This new institution will also be "self–interested", which means that it will implement any necessary means to reach an efficient outcome[3]. But establishing institutions involves both transaction costs[4] and feasibility constraints. It is likely that the larger the scope of the institution the higher the transaction costs and the more binding the feasibility constraints. Poor economies will only be able to afford low scope institutions. As per capita income rises, more complex institutions will arise. In other words, internalisation of external effects (market failures) will rise as income rises. The ultimate challenge seems to be the internalisation of transboundary and intergenerational externalities. In these cases the importance of transaction costs and feasibility constraints[5] often prevent the necessary degree of cooperation for the internalisation of such externalities to take place.

Some of the papers in the Special Issue on EKCs in *Environment and Development Economics* (EDE, 1997) suggest that the scope for changing environment–income relationships depends on the effectiveness of institutional arrangements. Cole et al. (1997), for instance, conclude that "*meaningful EKCs only exist for local pollutants, whilst indicators with a more global, or indirect, environmental impact either increase monotonically with income or else have* *turning points at high per capita income levels with large standard errors – unless they have been subjected to a multilateral policy initiative".*

In this paper we consider the "institutional approach" as the basis for a proposition that says that de–linking economic growth from environmental degradation depends on whether the control costs borne locally and in the present result in private and social environmental benefits that are also realized locally and in the present. The proposition encompasses not only the inverted U relationship between income and environmental quality but also all other "exceptions". In the following section we propose a model with which to explore this general proposition.

3 A two-country model of growth and pollution

In the last decade most of the studies of the relationship between pollution and growth have been empirical in nature. However, there is also an extensive theoretical literature on pollution and growth which dates back to the early 70s and is still growing[6]. Recently an important subset of this theoretical literature has focused on developing models that can replicate the EKC–type of regularities found by the empirical analysis (López, 1994; Saint–Paul, 1994; John and Pecchenino, 1994; Jones and Manuelli, 1994; Selden and Song, 1995; John et al., 1995; Beltratti, 1996; McConnell, 1997; Stokey 1998 and Ansuategi, 1999).The models proposed in these studies differ. Inverted U-shaped relationships between pollution and economic growth have been generated by models that differ in aspects such as the residence time of pollution, the nature of pollution generating activities, the feedback effects of pollution on economic activity, the nature of growth, the nature of the decision–making body and the openness to trade. To this point the intergenerational and/or transboundary nature of pollution has not been adequately addressed in these modelling efforts[7].

This section is concerned with transboundary environmental externality. Where significant proportions of the adverse impacts of economic activity are felt in different political units from those where the emissions occur, or where significant proportions of the benefits of pollution control expenditures accrue to those living in territories outside those in which the control is effected, we hypothesize that de–linking is less likely to happen.

The model is based on one of the simplest and earliest growth models to take pollution into account: that of Forster (1973). Forster's model is a Ramsey–Cass–Koopmans (Ramsey, 1928; Cass, 1965; Koopmans, 1965) version of the neoclassical growth model where consumption and investment in physical capital are the outcome of intertemporal optimization decisions by a social planner. It incorporates pollution abatement expenditure as a control variable. Following

Selden and Song (1995), we relax Forster's assumption that pollution control is extremely efficient for low levels of abatement expenditure. Thus, we allow for the possibility of corner solutions on abatement expenditure at the earliest stages of economic development. Replicating inverted U relationships between the flow of pollution and income is also an easy task. In addition, we do not assume a physically "sealed" economy, but we consider the possibility that a part of pollution emitted by local agents is deposited beyond the jurisdiction of the local policymaker.

We start by analyzing the case of a general transboundary environmental externality with two countries. The results may easily be extended to n countries.

There are two economically closed but environmentally open countries, indexed i = a, b, producing a single homogeneous output ($Y_i(t)$), which can be used either for consumption ($C_i(t)$), for pollution abatement ($A_i(t)$) or for capital accumulation ($I_i(t)$).

The labor force is a constant proportion of a constant population. Output is generated in each country through an increasing and concave function of the capital stock ($K_i(t)$):

$$Y_i(t) = \phi(K_i(t)) \in C^{(2)} \tag{1}$$

where $\phi^{'}(K_i) > 0$, $\phi^{''}(K_i) < 0$, $\lim_{k_i \to 0} \phi^{'}(K_i) = \infty$ and $\lim_{k_i \to \infty} \phi^{'}(K_i) = 0$.

Capital stock depreciates at a constant rate (δ). The evolution of the capital stock may thus be represented by the following transition equation:

$$\dot{K}_i(t) = I_i(t) - \delta K_i(t) \tag{2}$$

Emissions ($E_i(t)$) are defined as a flow represented by a linearly separable function of the capital stock in existence at time t in country i (($K_i(t)$) and the abatement expenditure at time t in country i ($A_i(t)$):

$$E_i(t) = E_i(K_i(t), A_i(t)) \in C^{(2)} \tag{3}$$

so that $E_{i1}^{'} > 0$, $E_{i1}^{''} > 0$, $E_{i2}^{'} < 0$ and $E_{i2}^{''} > 0$. We assume that $\lim_{A_i \to \infty} E_{i2}^{'} = 0$.

Emissions are "transported" across boundaries. The transfer will be denoted by "t_{ab}" and "t_{ba}", where "t_{ab}" represents the proportion of emissions generated in a and deposited in b and "t_{ba}" represents the proportion of emissions generated in b and deposited in a.

Depositions (pollution) in each country are given by the flows

$$P_a(t) = (1 - t_{ab})E_a(K_a(t), A_a(t)) + t_{ba}E_b(K_b(t), A_b(t)) \tag{4}$$

$$P_b(t) = (1 - t_{ba})E_b(K_b(t), A_b(t)) + t_{ab}E_a(K_a(t), A_a(t)) \tag{5}$$

We assume that social welfare at any time in country i is measured by a linearly separable utility function of consumption (C$_i$(t)) and local depositions (P$_i$(t)):

$$U_i(C_i(t), P_i(t)) = U_{i1}(C_i(t)) + U_{i2}(P_i(t)) \tag{6}$$

where $U_{i1} \in C^{(2)}$, $U_{i1}(0) = 0$, $U_{i1}^{'} > 0$, $U_{i1}^{''} < 0$, $U_{i2} \in C^{(2)}$, $U_{i2}(0) = 0$, $U_{i2}^{'} < 0$, $U_{i2}^{''} < 0$, $\lim_{c\to 0} U_{i1}^{'}(C) = \infty$, and $\lim_{P_i \to 0} U_{i2}^{'}(P_i) = 0$.

The objective of the planning authority in country i is to maximize the discounted flow of utility over time:

$$W_i(t) = \int_t^{\infty} e^{-\rho_i(s-t)} U_i(C_i(s), P_i(s))ds \tag{7}$$

where $\rho_i \in [0, \infty)$ represents the rate of time preference (discount) of country i.

The interaction between the two sovereign governments will be formulated as a differential game. We suppose that country i believes that country j≠i will follow a given time path (I$_j$(t), C$_j$(t), A$_j$(t)) regardless of what (I$_i$(t), C$_i$(t), A$_i$(t)) might be. This yields an Open-Loop Nash Equilibrium. Country i's problem is then to choose (I$_i$(t), C$_i$(t), A$_i$(t)) to maximize the integral of its discounted flow of social net benefits, as specified by

$$\max \int_0^{\infty} e^{-\rho_i t} U_i(C_i(t), P_i(t))dt \tag{8}$$

$$subject\, to\, \dot{K}_i(t) = \phi(K_i(t)) - \delta K_i(t) - C_i(t) - A_i(t) \; with \; A_i(t) \geq 0 \tag{9}$$

4 The symmetrical country case

To simplify, we consider the case of symmetrical countries. Each transfers exactly the same proportion of their emissions to the other. By regarding them as symmetrical we can restrict the analysis to that of a single economy. We can also easily compare the results to those of the Forster model. Imposing the same starting conditions, utility functions and technology for both the “sealed” economy and the “non–sealed” economy, we may compare each economy's optimal choice knowing that they face identical allocation problems except that the source of pollution is different. In the “sealed” economy, depositions are defined as the by-product of internal production activities. In the “non–sealed” economy only a part of the flow of depositions comes from internal sources and part of the internal flow of emissions is deposited abroad. However, under our assumptions, in both the “sealed” and “non–sealed” cases, economies will “suffer” an amount of depositions which is equivalent to their emissions.

Because country a and country b are symmetrical, they have the same initial stock of capital (K(0)) and the same rate of transboundary transfer of pollutants (T). Dropping country subscripts for this case, the Hamiltonian function associated with the control problem given by (8) and (9) is:

$$\tilde{H}(t) = U(C(t), P(t)) + q(t)A(t) + \psi(t)\left[\phi(K(t)) - \delta K(t) - C(t) - A(t)\right] \quad (10)$$

The Maximum principle yields:

$$U_1^{'}(C(t)) - \psi(t) = 0 \quad (11)$$

$$U_2^{'}(P(t))(1-T)E_2^{'}(A(t)) - \psi(t) + q(t) = 0 \quad (12)$$

$$\dot{\psi}(t) = \left[\rho + \delta - \phi^{'}(K(t))\right]\psi(t) - U_2^{'}(P(t))(1-T)E_1^{'}(K(t)) \quad (13)$$

We can investigate the behaviour of the system in the (K,C) space, distinguishing two areas in such space:

- The corner solution set: the locus of points for which the social planner's optimal abatement expenditure is zero.
- The interior solution set: the rest of the space.

Using (11) and (12), we obtain

$$U_1^{'}(C(t)) = U_2^{'}(P(t))(1-T)E_2^{'}(A(t)) + q(t) \quad (14)$$

Thus, the locus of points on the boundary of the corner solution set are the combinations of K and C that solve the following equation:

$$U_1^{'}(C) - U_2^{'}(P(K,0))(1-T)E_2^{'}(0) = 0 \quad (15)$$

Equation (15) is the mathematical representation of all the combinations of K and C under which zero abatement expenditure is optimal.

Differentiation of (15) yields

$$\frac{dC}{dK} = \frac{U_2^{''}}{U_1^{''}} \left[E_2^{'} E_1^{'} (1-T) \right] < 0$$

which means that the corner solution set is an area to the left and below a downward–sloping curve in (K,C) space.We first consider the sufficient conditions for a corner solution set to exist. Specifically:

Lemma 1 *If* $U_1^{'}(C(t)) > (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ *at (C,K,A)=0, there will exist a nonempty set of points in (K,C)*$\in \mathbb{R}_+^2$ *space such that A(K,C)=0.*

Proof. See Appendix.

This states that a sufficient condition for optimal abatement expenditure to be zero at the first stages of development is that the marginal utility of consumption dominates the marginal disutility of domestic depositions.

The equations of motion for economies within the corner solution set, using (11) and (13), are:

$$\dot{C} = \frac{U_1^{'}}{U_1^{''}} \left(\rho + \delta - \phi^{'}(K) \right) \tag{16}$$

$$\dot{K} = \phi(K) - \delta K - C \tag{17}$$

with the planning authority free to select C(0) for a given K(0).

In the interior solution set (holding q = 0 in equation (14)) we can show the level of emissions abatement as an implicit function of the levels of consumption and capital. This condition requires that the marginal disutility of domestic depositions should equal the marginal utility of consumption:

$$U_1^{'}(C) - U_2^{'}(P(K,A))(1-T)E_2^{'}(A) = 0 \tag{18}$$

We can thus define abatement as a functions of capital and consumption, A = A(K,C), in which

$$\frac{\partial A}{\partial C} = \frac{U_1^{''}}{(1-T)U_2^{''}(E_2^{'})^2 + U_2^{'}E_2^{''}} > 0 \tag{19}$$

$$\frac{\partial A}{\partial K} = -\frac{E_1^{'}}{E_2^{'}} > 0 \tag{20}$$

The equations of motion for economies within the interior solution set, using (11) and (13), are:

$$\dot{C} = \frac{U_1^{'}(C)}{U_1^{''}(C)} \left(\rho + \delta - \phi^{'}(K) + \frac{E_1^{'}(K)}{E_2^{'}(A(C,K))} \right) \tag{21}$$

$$\dot{K} = \phi(K) - \delta K - C - A(C,K) \tag{22}$$

These enable us to identify the properties of the convergence path within the interior solution set. Lemma 2 describes the properties of the dynamic equilibrium of the system around the steady–state.

Lemma 2 *For K(0) small, these economies will exhibit saddle-path stability with C and K increasing toward their steady state values along the OLNE transition path.*

Proof. See Appendix.

Lemma 2 has two main implications. First, saddle path stability establishes some determinism in social planner's decisions, the type of determinism that underlies the environmental transition hypothesis. For each initial capital stock there is a unique initial level of consumption which will situate the economy in the single path that will lead it to the long term equilibrium. Second, as C and K are increasing towards their steady state values along the OLNE transition path, this implies that poverty traps are ruled out.In other words, underdevelopment will not persist. As we will see in the next section, both implications are crucial if we are to generate a model that deals with the environmental transition hypothesis.

5 The relation between economic growth and emissions

It is possible to interpret the environmental Kuznets curve in terms of the dynamic path followed by the economy starting with a low level of capital and approaching the steady state. Since we have not ruled out corner solutions at A = 0, we have to distinguish between the segment of the OLNE path leading to the steady state in which the dynamics of the economy are described by system (16)–(17), and the segment of the OLNE path leading to the steady–state in which the dynamics of the system are described by system (21)–(22). In what follows, we will refer to the "corner–solution segment" and "interior–solution segment" respectively. Lemmas 3 and 4 describe the growth of emissions and pollution along these two segments.

Lemma 3 *Along the corner–solution segment of the OLNE path leading to the steady state, since abatement expenditure is zero, pollution will grow at the rate given by the marginal emissions from investment. The growth of emissions and pollution will be represented by the following equation:*

$$\dot{E} = \dot{P} = E_1^{'}\dot{K}$$

Proof. See Appendix.

Lemma 4 *Along the interior–solution segment of the OLNE path leading to the steady state, since abatement expenditure is non–zero, pollution will grow at the rate given by the marginal emissions from investment and the marginal reductions from changes in abatement expenditure. The evolution of abatement expenditure depends on the pace of growth of both consumption and capital, the marginal contribution of both capital and abatement on emissions, the speed at which marginal utility of consumption declines with increases in C and the speed at which marginal concern over pollution increases with P. The growth of emissions and pollution will be represented by the following equation:*

$$\dot{E} = \dot{P} = \frac{U_1^{''}E_2^{'}\dot{C} + (1-T)U_2^{'}E_2^{''}E_1^{'}\dot{K}}{(1-T)\left[U_2^{''}(E_2^{'})^2 + U_2^{'}E_2^{''}\right]}$$

Proof. See Appendix.

We are now in a position to consider the central issue in the EKC literature: the relation between pollution and the growth of income. We now state three propositions about the shape of the relation between growth and emissions along the OLNE path:

Proposition 5 *If pollution is fully externalized across borders (T=1), the relation between economic growth and emissions along the OLNE path is monotonically increasing.*

Proof. See Appendix.

Proposition 6 *If (i)*$U_1^{'}(C(t)) > (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ *at (C,K,A)=0 and (ii) K(0) is small, there may be an inverted U shaped relation between economic growth and pollution along the OLNE path leading to the steady–state.*

Proof. See Appendix.

Proposition 7 *If (i)* $U_1^{'}(C(t)) > (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ *at (C,K,A)=0, (ii)* $U_1^{'}(C(t)) = (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ *at* $(\bar{C},\bar{K},A(\bar{K},\bar{C})) \gg 0$, *(iii) K(0) is small and (iv) there are constant returns to abatement expenditure: (a) there will exist an inverted U shaped relation between economic growth and pollution along the OLNE path leading to the steady state and (b) the inverted U will be flatter the lower the rate of transboundary transfer of emissions (T).*

Proof. See Appendix.

Note that pollution and consumption are both likely to be low during the earliest stages of development. Thus, it is of interest to consider the possibility of an initial corner solution at A=0. As Lemma 1 shows, we may expect that those cases where pollution is in the nature of purely transboundary external effects, that is, 100 per cent of emissions flow from the generator to its neighbour, there will not be any incentive at any stage of development to engage in emissions abatement expenditure. The consequence will be a monotonically increasing relation between economic growth and emissions. See Proposition 1.

Leaving aside the extreme case of purely transboundary external effects, let us focus on those cases where emissions are only partially externalized across borders. In these cases, the incentives of local governments to engage in defensive expenditures are weakened in direct proportion to the degree in which emissions are "exported". Nevertheless, as Proposition 2 shows, the environmental Kuznets curve is still a possibility in this setting.

In fact, an economy that chooses not to abate emissions at the earliest stages of development but abates emissions at the steady state and shows constant returns to abatement expenditure will always show an inverted U shaped relation between economic growth and emissions. Further, for this case it can be shown that the inverted U will be flatter the lower the rate of transboundary transfer of emissions. See Proposition 3.

The general implication of these propositions is that countries will be more likely to abate emissions as per capita incomes rise the more the damage due to those emissions affects the population of that country, and less likely to abate emissions the more the damage affects the population of other countries.

6 Concluding remarks

The EKC is a hypothesis for which its proponents claim empirical and theoretical support. However, the existing literature can hardly be regarded as providing conclusive support for the thesis of "growing out of environmental degradation". Empirical studies have not provided any evidence that validates an EKC for pollution problems where the effects are far–displaced or long–delayed. To replicate the inverted–U relations between emissions and economic growth it has been assumed either that the negative effect of emissions is fully suffered by the generators or that the economy can "export" the sources of emission via international markets. The intuition we can draw from both empirical evidence and theory is that the possibility of "passing the buck" of environmental degradation is an important determinant of the shape of the relationship between emissions and per capita income.

The main concern of this paper has been to show that where a significant proportion of the environmental impacts of economic activity occurs outside the territories in which those activities take place, the de–linking of growth and environmental degradation is less likely to happen[8]. This proposition is demonstrated by assuming that there is neither a supranational decisionmaker nor a multilateral agreement between decisionmakers that would make possible internalization of transboundary external effects.

This does not mean that de–linking of transboundary pollution problems from economic growth is impossible. International cooperation would be sufficient to change the non–cooperative (Nash equilibrium) outcome.On the other hand, nor does it imply that economic growth is an adequate way out of local or semi–local pollution problems. Wherever local institutions are unable to internalize local external effects private resource users will pollute at excessive levels. Moreover, even if we assume that each economy moves along the (locally) optimal trajectory, the EKC need not occur in all cases. As Selden and Song (1995) have noted, and as Proposition 2 also suggests, preferences and technology play an important role in determining whether the inverted U curve for pollution will take place or not.

This paper constitutes an additional step toward the decomposition of the EKC into its determinants. The model we construct is very stylized, and this makes it suitable for considering transboundary environmental externalities in a world of growing economies. The assumption that the affected countries are symmetrical is very strong, and we would like to relax this in future development of this research. However, admitting asymmetry between countries will not affect the basic propositions about the link between transboundary pollution flows and the propensity of a country to abate emissions.

APPENDIX

Proof of Lemma 1

The set of points in (K,C) space, such that A(K,C)=0, is composed of all points for which

$$q = U_1^{'}(C) - (1-T)U_2^{'}(P(K,0))E_2^{'}(0) > 0$$

Since $U_1 \in C^{(2)}$ and $U_2 \in C^{(2)}$, the function $q : (K,C) \to \mathbb{R}$ is continuous. Thus, given a point in (K,C) space, ($\tilde{K}$,$\tilde{C}$), for every scalar $\varepsilon > 0$ there exists an open ball around that point, B(($\tilde{K}$,$\tilde{C}$),δ), such that

$$q\left(B((\tilde{K},\tilde{C}),\delta)\right) \subset B\left(q(\tilde{K},\tilde{C}),\varepsilon\right) = \left(q(\tilde{K},\tilde{C})-\varepsilon, q(\tilde{K},\tilde{C})+\varepsilon\right)$$

Since $U_1^{'}(0) - (1-T)U_2^{'}(P(0,0))E_2^{'}(0) > 0$, we know that q(0,0) > 0. This means that choosing $\varepsilon < q(0,0)$, we will have an open–ball in (K,C) space around (0,0) such that q(K,C) > 0.Thus, for the sub–space in (K,C) $\in \mathbb{R}^2_+$ formed by all the (K,C) pairs that satisfy that K$\in (0,\delta)$ and C $\in (0,\delta)$, we have that q(K,C)>0, that is, A(K,C)=0. This proves that the corner solution set is not an empty–set. ■

Proof of Lemma 2

The lemma requires us to show two things: First, that the system exhibits saddle path stability. Second, that along the convergence path a growing economy involves monotonically increasing consumption.

- Stability:

Consider the case where the steady state belongs to the corner solution set. On the basis of (16)–(17) we form the Jacobian matrix and evaluate it at the steady–state point ($\bar{K}$, $\bar{C}$).

$$J_{ss} = \begin{bmatrix} \frac{\partial \dot{K}}{\partial K} & \frac{\partial \dot{K}}{\partial C} \\ \frac{\partial \dot{C}}{\partial K} & \frac{\partial \dot{C}}{\partial C} \end{bmatrix}_{(\bar{K},\bar{C})}$$

The partial derivatives, when evaluated at ($\bar{K}$, $\bar{C}$), are

$$\left.\frac{\partial \dot{K}}{\partial K}\right|_{(\bar{K},\bar{C})} = \rho > 0$$

$$\left.\frac{\partial \dot{K}}{\partial C}\right|_{(\bar{K},\bar{C})} = -1 < 0$$

$$
\begin{aligned}
\left.\frac{\partial \dot{C}}{\partial K}\right|_{(\bar{K},\bar{C})} &= -\frac{U_1^{'}(\bar{C})}{U_1^{''}(\bar{C})}\phi^{''}(\bar{K}) < 0 \\
\left.\frac{\partial \dot{C}}{\partial C}\right|_{(\bar{K},\bar{C})} &= 0
\end{aligned}
$$

implying that $\det J_{ss} < 0$. The steady state is a saddle point.

Now let us analyze those cases in which the steady state belongs to the interior solution set. On the basis of system (22)–(23) we form the Jacobian matrix and evaluate it at the steady–state (K̄, C̄).

$$
J_{ss} = \left[\begin{array}{cc} \frac{\partial \dot{K}}{\partial K} & \frac{\partial \dot{K}}{\partial C} \\ \frac{\partial \dot{C}}{\partial K} & \frac{\partial \dot{C}}{\partial C} \end{array} \right]_{(\bar{K},\bar{C})}
$$

The partial derivatives, evaluated at (K̄, C̄), are

$$
\begin{aligned}
\left.\frac{\partial \dot{K}}{\partial K}\right|_{(\bar{K},\bar{C})} &= \rho > 0 \\
\left.\frac{\partial \dot{K}}{\partial C}\right|_{(\bar{K},\bar{C})} &= -\left(1 + \frac{U_1^{''}(\bar{C})}{\begin{array}{c}(1-T)U_2^{''}(P(\bar{K},A(\bar{K},\bar{C}))(E_2^{'}(A(\bar{K},\bar{C})))^2 + \\ U_2^{'}(P(\bar{K},A(\bar{K},\bar{C}))E_2^{''}(A(\bar{K},\bar{C}))\end{array}}\right) < 0 \\
\left.\frac{\partial \dot{C}}{\partial K}\right|_{(\bar{K},\bar{C})} &= -\frac{U_1^{'}(\bar{C})}{U_1^{''}(\bar{C})}\left(\phi^{''}(\bar{K}) + \frac{E_1^{''}(\bar{K})}{E_2^{'}(A(\bar{K},\bar{C}))} - \frac{\left(E_1^{'}(\bar{K})\right)^2 E_2^{''}(A(\bar{K},\bar{C}))}{\left(E_2^{'}(A(\bar{K},\bar{C}))\right)^3}\right) < 0 \\
\left.\frac{\partial \dot{C}}{\partial C}\right|_{(\bar{K},\bar{C})} &= \frac{U_1^{'}(\bar{C})E_1^{'}(\bar{K})E_2^{''}(A(\bar{K},\bar{C}))}{\left(\begin{array}{c}(1-T)U_2^{''}(P(\bar{K},A(\bar{K},\bar{C}))(E_2^{'}(A(\bar{K},\bar{C})))^2 + \\ U_2^{'}(P(\bar{K},A(\bar{K},\bar{C}))E_2^{''}(A(\bar{K},\bar{C}))\end{array}\right)\left(E_2^{'}(A(\bar{K},\bar{C}))\right)^2} < 0
\end{aligned}
$$

Again, $\det J_{ss} < 0$, and there are two characteristic roots with opposite signs. The steady state is a saddle point. In both cases the system exhibits saddle path stability.

- Increasing consumption path:

Consider the phase diagram of the dynamic behavior of the system within the corner solution set. On the basis of (16)-(17) the $\dot{K}$=0 and $\dot{C}$=0 isoclines are defined by:

$$
\rho + \delta - \phi^{'}(K) = 0 \qquad \text{(A.1)}
$$

$$\phi(K) - \delta K - C = 0 \tag{A.2}$$

The Ċ=0 isocline, (A.1), is a vertical straight line. Since it is required that $\rho + \delta = \phi^{'}(K)$ with $\phi(K)$ monotonic, this can be satisfied only at a unique K value, K̄.

The K̇=0 isocline, (A.2), is concave. Note that

$$\left.\frac{dC}{dK}\right|_{\dot{K}=0} = \phi^{'}(K) - \delta \begin{array}{c} > \\ = \\ < \end{array} 0 \qquad\qquad K \begin{array}{c} < \\ = \\ > \end{array} \hat{K} \tag{A.3}$$

Were the economy such that the steady state would belong to the corner solution set, the intersection of (A.1) and (A.2) would determine the steady state values of K and C.

Note also that by (16) and (17)

$$\frac{\partial \dot{K}}{\partial C} = -1 < 0 \tag{A.4}$$

$$\frac{\partial \dot{C}}{\partial K} = \frac{-U_1^{'}(C)}{U_1^{''}(C)} \phi^{''}(K) < 0 \tag{A.5}$$

Thus, if K(0) < K̄, then K̇ > 0 and Ċ > 0 along the stable branch leading to the steady state.

Now consider the phase diagram of the dynamic behavior of the system within the interior solution set. On the basis of the system (21)–(22) we can draw the K̇=0 and Ċ=0 isoclines. These are defined by:

$$\rho + \delta - \phi^{'}(K) - \frac{E_1^{'}(K)}{E_2^{'}(A(C,K))} = 0 \tag{A.6}$$

$$\phi(K) - \delta K - C - A(C,K) = 0 \tag{A.7}$$

The Ċ=0 curve, equation (A.6), is downward sloping in the (K,C) space:

$$\left.\frac{dC}{dK}\right|_{\dot{C}=0} = \frac{\begin{array}{c} \left[\phi^{''}(K)E_2^{'}(A(C,K)) + E_1^{''}(K)E_2^{'}(A(C,K)) + \frac{\left(E_1^{'}(K)\right)^2 E_2^{''}(A(C,K))}{E_2^{'}(A(C,K))}\right] \\ \left[\begin{array}{c} (1-T)U_2^{''}(P(K,A(C,K)))\left(E_2^{'}(A(C,K))\right)^2 \\ +U_2^{'}(P(K,A(C,K)))E_2^{''}(A(C,K)) \end{array}\right] \end{array}}{E_1^{'}(K)E_2^{''}(A(C,K))U_1^{''}(C)} < 0 \tag{A.8}$$

Note also that, since $-\frac{E_1'(K)}{E_2'(A(C,K))} > 0$, the $\dot{C}=0$ isocline that guides the behavior within the interior solution set lies entirely to the left of the $\dot{C}=0$ isocline that guides the behavior within the corner solution set.

The $\dot{K}=0$ isocline, (A.7), is concave in (K,C) space. Note that

$$\left.\frac{dC}{dK}\right|_{\dot{K}=0} = \frac{\phi'(K) - \delta + \frac{E_1'(K)}{E_2'(A(C,K))}}{1 + \frac{U_1''(C)}{\begin{array}{c}(1-T)U_2''(P(K,A(C,K)))\left(E_2'(A(C,K))\right)^2 \\ +U_2'(P(K,A(C,K)))E_2''(A(C,K))\end{array}}} \gtreqless 0 \qquad K \lesseqgtr \breve{K} \tag{A.9}$$

Note also that by (21) and (22)

$$\frac{\partial \dot{K}}{\partial C} = -\left(1 + \frac{U_1''(C)}{\begin{array}{c}(1-T)U_2''(P(K,A(C,K)))\left(E_2'(A(C,K))\right)^2 \\ +U_2'(P(K,A(C,K)))E_2''(A(C,K))\end{array}}\right) < 0 \tag{A.10}$$

$$\frac{\partial \dot{C}}{\partial K} = \frac{-U_1'(C)}{U_1''(C)}\left(\phi''(K) + \frac{E_1''(K)}{E_2'(A(C,K))} + \frac{(E_1'(K))^2 E_2''(A(C,K))}{\left(E_2'(A(C,K))\right)^3}\right) < 0 \tag{A.11}$$

Thus, if $K_0 < \bar{K}$, then $\dot{K} > 0$ and $\dot{C} > 0$ along the stable branch leading to the steady state. ■

Proof of Lemma 3

Taking the time derivative of P(t), we have

$$\dot{P} = (1-T)\dot{E} + T\dot{E} = \dot{E} = E_1'\dot{K} + E_2'\dot{A} \tag{A.12}$$

Along the corner solution segment of the OLNE path A = 0 and $\dot{A} = 0$. Thus,

$$\dot{P} = \dot{E} = E_1'\dot{K} \tag{A.13}$$

■

Proof of Lemma 4

The time derivative of equation (14) (holding q(t) = 0) yields

$$\dot{A} = \frac{U_1^{''}\dot{C} - (1-T)U_2^{''}E_1^{'}E_2^{'}\dot{K}}{(1-T)\left[U_2^{'}E_2^{''} + U_2^{''}(E_2^{'})^2\right]} \tag{A.14}$$

Substituting (A.14) in (A.12) yields

$$\dot{P} = \dot{E} = \frac{U_1^{''}E_2^{'}\dot{C} + (1-T)U_2^{''}E_1^{'}E_2^{''}\dot{K}}{(1-T)\left[U_2^{'}E_2^{''} + U_2^{''}(E_2^{'})^2\right]} \tag{A.15}$$

■

Proof of Proposition 1

This proposition requires us to show that if T=1, the relation between economic growth and emissions along the OLNE path is monotonically increasing.

Let T = 1. It follows that the marginal benefit of emission control $\left[(1-T)U_2^{'}(P)E_2^{'}(A)\right]$ is zero. The marginal cost of pollution control in terms of foregone consumption $\left[U_1^{'}(C)\right]$ is, however, positive. To satisfy equation (14) the entire OLNE path to the steady state will be within the corner solution set. Abatement expenditure will be zero.

>From Lemma 3 we know that along the corner solution segment of the OLNE path leading to the steady state $\dot{P} = \dot{E} = E_1^{'}\dot{K}$. From Lemma 2 we have that $\dot{\mathrm{K}} > 0$ along the OLNE transition path if the initial capital stock is lower than the steady state level of capital. Since $E_1^{'} > 0$, the relation between economic growth and pollution along the OLNE path is monotonically increasing. ■

Proof of Proposition 2

This Proposition requires us to show that if $U_1^{'}(C(t)) > (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ at (C,K,A)=0 and K(0) is small, it is possible to find a set of preferences and technology that generate an inverted U relation between growth and pollution.

Let $U_1^{'}(C(t)) > (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ at (C,K,A)=0. From Lemma 1 we know that there will exist a non–empty set of points in (K,C) space such that A(K,C) = 0. If K(0) is sufficiently low we will always have a corner–solution segment along the OLNE transition path in which, from Lemma 3, $\dot{P} = \dot{E} = E_1^{'}\dot{K} > 0$.

At some point along the OLNE transition path development may create enough consumption and enough environmental damage that it will be worth committing resources to emissions abatement. From this point on, Lemma 4 shows that the OLNE path for emissions and pollution will be represented by

$$\dot{P} = \dot{E} = \frac{U_1^{''}E_2^{'}\dot{C} + (1-T)U_2^{''}E_1^{'}E_2^{''}\dot{K}}{(1-T)\left[U_2^{'}E_2^{''} + U_2^{''}(E_2^{'})^2\right]}$$

The left–hand term of the numerator is positive, the right–hand term of the numerator is negative and the denominator is negative. Thus, if preferences and technology are such that the left–hand term of the numerator dominates the right–hand term, the result will be $\dot{P} < 0$. ■

Proof of Proposition 3

The proposition requires us to show two things: First, that for those economies where consumption only dominates abatement in the earliest stages of growth and there are constant returns to scale in abatement, there is always an inverted U shaped relation between pollution and economic growth. Second, that this inverted U is flatter the lower the rate of transboundary transfer of pollution.

- Inverted U shaped relation between pollution and economic growth:

Since $U_1^{'}(C(t)) > (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ at (C,K,A)=0 and, since $U_1^{'}(C(t)) = (1-T)U_2^{'}(P(t))E_2^{'}(A(t))$ at ($\bar{\text{C}}$,$\bar{\text{K}}$,A($\bar{\text{K}}$,$\bar{\text{C}}$))$\gg$ 0, those economies starting from a sufficiently low level of K will initially choose not to engage in emissions abatement expenditure and finally will decide to abate. From Lemma 3, it follows that pollution will increase as the economy grows along the corner solution segment of the OLNE path. From Lemma 4, and considering constant returns to abatement expenditure ($E_2^{''}(A) = 0$), it follows that along the interior solution segment of the OLNE path

$$\dot{P} = \dot{E} = \frac{U_1^{''}E_2^{'}\dot{C}}{(1-T)U_2^{''}(E_2^{'})^2} < 0$$

Thus, it has been proved that the pollution curve will have both upward and downward sloping portions.

- Sensitivity of curvature of EKCs to the rate of transboundary transfer of emissions:

Consider two cases: (1) the two symmetrical countries transferring emissions across borders at a rate T and (2) the same two countries transferring emissions across borders at a rate $\text{T}^{'}$, where $\text{T}^{'} > \text{T}$.

For a sufficiently low level of K(0), these economies will choose not to engage in abatement expenditure at the earlier stages of growth and the dynamic behavior of these economies within the corner solution set will be guided by (A.1) and (A.2). Since neither (A.1) nor (A.2) depend on the rate of transboundary transfer of pollution, the OLNE path of consumption and capital accumulation will be the same under both scenarios.

However, let us define ($\check{\text{K}}$,$\check{\text{C}}$) as the point in the corner solution segment of the OLNE path for which $U_1^{'}(\check{C}) = U_2^{'}(P(\check{K},0))(1-T)E_2^{'}$. At this critical point, economies facing T will start abating pollution as income rises, but as $\text{T}^{'} > \text{T}$, economies facing T' will find that $U_1'(\check{C}) > U_2'(P(\check{K},0))(1-T')E_2'$ and yet will not consider it worth spending part of their income in abatement. Depositions will continue rising for the economies facing T' until they reach (K', C'), the (K,C) pair for which $U_1'(C') = U_2'(P(K',0))(1-T')E_2'(0)$.

In the steady state, with constant returns to abatement, the $\dot{\mathrm{C}} = 0$ isocline is a vertical straight line (as $\mathrm{E}_2'' = 0$, $\frac{dC}{dK}\big|_{\dot{C}=0} = \infty$ in (A.8)). The level of capital stock at which $\dot{\mathrm{C}} = 0$ ($\bar{\mathrm{K}}$) will be the same $\forall$ T $\in [0,1]$. In both cases the steady state net income $\big(\phi(\bar{K}) - \delta\bar{K}\big)$ for distribution between consumption and abatement is the same.

However the level of consumption at the steady state is determined by the intersection between the $\dot{\mathrm{K}} = 0$ and the $\dot{\mathrm{C}} = 0$ isoclines. Let us denote by $\bar{\mathrm{C}}$ the steady state level of consumption associated with T and $\bar{\mathrm{C}}'$ the steady state level of consumption associated with T'. We know that if the steady states belong to the interior solution set then:

$$U_1'(\bar{C}) = (1-T)U_2'(P(\bar{K},\bar{A}))E_2' \tag{A.16}$$

$$U_1'(\bar{C}') = (1-T')U_2'(P(\bar{K},\bar{A}'))E_2' \tag{A.17}$$

Since $\mathrm{T}' > \mathrm{T}$, we also know that $U_1'(\bar{C}) > (1-T')U_2'(P(\bar{K},\bar{A}))E_2'$. This means that, if (A.17) will hold and $\bar{C}+\bar{A} = \bar{C}'+\bar{A}' = \phi(\bar{K})-\delta\bar{K}$, then $\bar{C}' > \bar{C}$ and $\bar{A}' < \bar{A}$.

As shown in Figures 1 and 2, the “closer” the economy, the flatter the EKC. ■

NOTES

1. The Environmental Kuznets Curve (EKC) has been the proposition taken to support that growth in per capita income will eventually induce an improvement in environmental quality. Specifically, it is hypothesized that while economic growth may initially lead to increased pollution, market forces will induce changes in the composition of consumption and production toward less polluting activities. Also, positive income elasticities are hypothesized to lead to stricter abatement policies.

2. The NIMBY (Not–In–My–Back–Yard) phenomenon commonly arises when, in order to provide a public good, a local facility must be constructed. Locals generally enjoy the same benefits from a Locally Unwanted Land Use (LULU) as anyone else, but they bear more of the costs. This leads to strong opposition from those living in the neighbourhood where the facility is to be located.

3. Note that the decision–maker's welfare in a purely democratic society should be defined as the aggregation of the welfare of every individual in society. Thus, the objective of a "self-interested" decision-maker will be reaching an efficient outcome.

4. We suggest a working definition of transaction cost which is similar to the one suggested by Arrow (1970): "*transaction costs are costs of running the economic system*". Thus, for the purpose of this paper transaction costs are the enforcement costs, information costs and all the other costs of running an institution.

5. Note that nations are very reluctant to accept supra-national authority. Note also that negotiating with yet–unborn generations is impossible.

6. Keeler et al. (1972), D'Arge and Kogiku (1973), Forster (1973), Gruver (1976), Stevens (1976), Brock (1977), Smith (1978) and Tahvonen and Kuuluvainen (1993).

7. Note that even though several of the studies mentioned above (John and Pecchenino 1994; Jones and Manuelli 1994; and John et al. 1995) derive EKCs for an intergenerational externality, only Ansuategi (1999) does analyse the sensitivity of the results to the degree of externalisation of pollution across generations.

8. Elsewhere (Ansuategi, 1999) it is shown that where a significant proportion of the adverse impacts of current economic activity are felt by future generations, de–linking is also less likely to happen.

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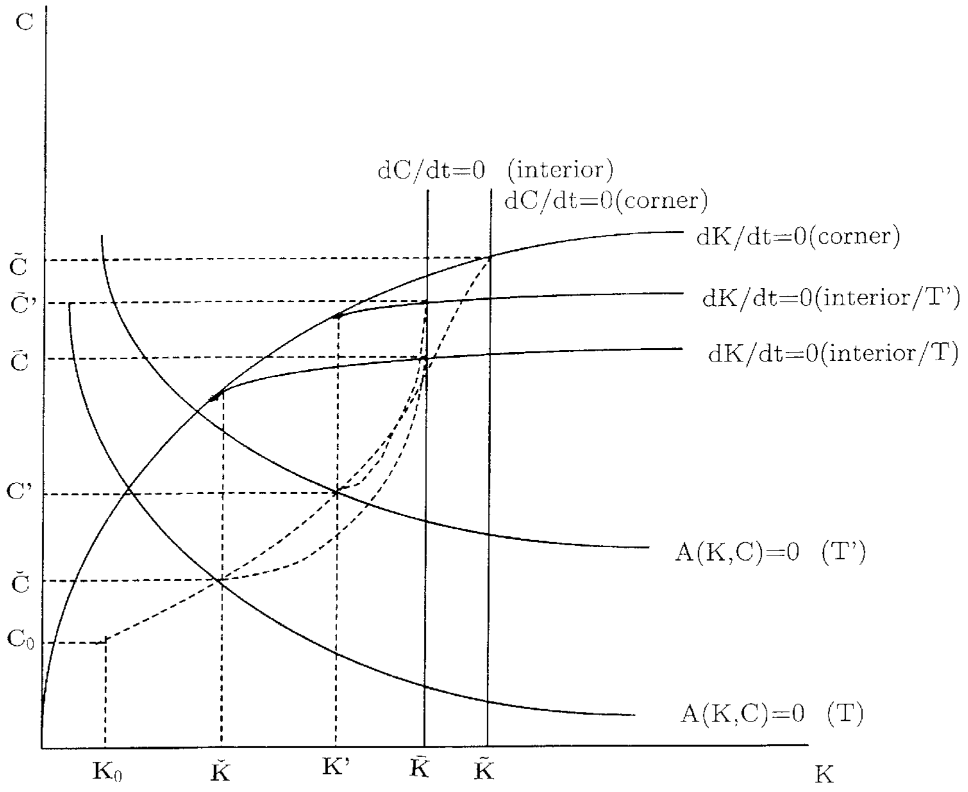

Figure 1: Phase Diagram

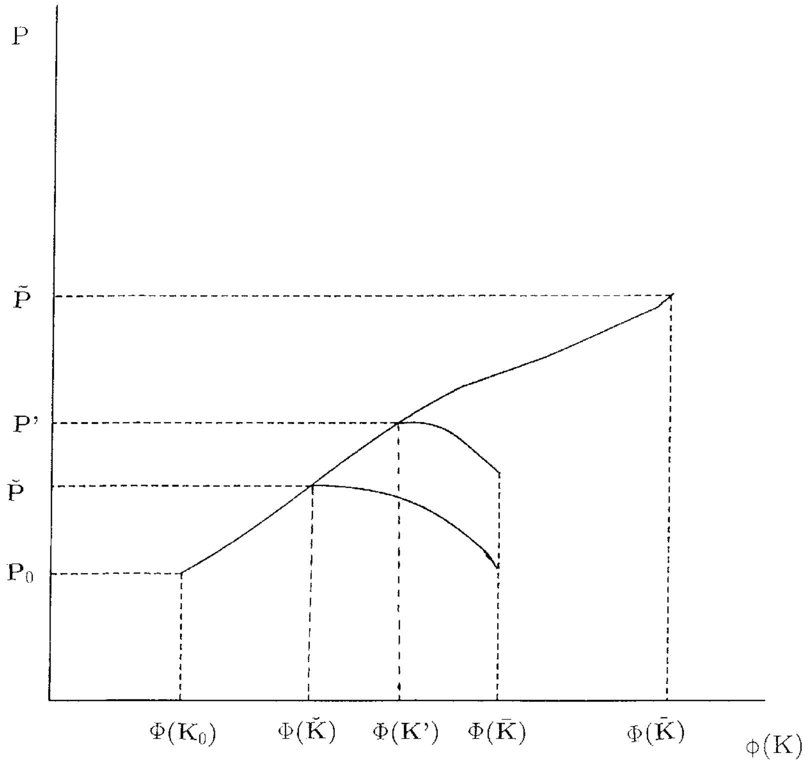

Figure 2: Income-pollution relation.