Democratic Transition, Environmental Concern and the Kuznets Curve

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Discussion Paper 2005-1

Département des Sciences Économiques
de l'Université catholique de Louvain

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Running Title: Demography and Environment.

July, 2004.

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*We have benefitted from the comments of R. Boucekkine, O. Licandro and M. Sánchez-Moreno. We acknowledge the financial support from the Spanish CICYT, Project SEC2000-0260, and the Belgian research program ARC 03/08-302.

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Abstract:

In an endogenous growth model with pollution and abatement we characterize the socially optimal solution. We find that the rate of growth depends negatively on the weight of environmental care in utility and positively on the population growth rate. We also find a trade-off between growth and environmental quality beyond which an environmental Kuznets curve is derived in the long term. This one emerges from the implications of the demographic transition for the rate of population growth, and the accompanying variation in the willingness to pay for environmental quality as the economy develops.

Keywords: Optimal Growth, Environment, Population Growth, Preferences.

JEL classification: C61, C62, O41, Q5.

1 Introduction

One important issue in ecological economics programmes has been the study of the environmental Kuznets' curve (EKC) hypothesis, which says that there is an inverted U-shaped relationship between pollution emissions and per capita income levels. Or, put in other way, that economic growth usually leads to environmental degradation in the early stages of the process, but in the end the best and probably the only way to attain a decent environment is to become rich [Beckerman (1992)]. The EKC hypothesis has lead some analysts to conclude that pollution will not be a problem in the long-run because of the beneficial effects of economic growth on the environmental quality. This proposition implicitly assumes that growth is essentially good for the environment because as levels of income go up the emissions flow will decline. Consequently, no governmental interventions are needed.

However, it is well-known that only a naive interpretation of the EKC hypothesis may lead people to believe that the best role for policy-makers is to keep away from active environmental protection policies. As Arrow et al. (1995) observed, growth is not a panacea for the environment, and in no one case can be expected that the pollution problem will automatically be solved as a result of economic growth without any government intervention. In fact, growth creates the conditions for environmental improvement by raising the demand for environmental quality once it has been reached high levels of income per capita, but it is not a substitute for environmental public policies which are necessary to control pollution emissions. There is no reason to believe that the eventual positive relationship linking growth and environmental quality is inevitable, because even though economic growth directly fosters higher abatement expenditures it also increases pollution. In this context, policy has a very important role to play by promoting both sustained growth and the environment.

Theoretical foundations for the EKC hypothesis have been proposed on the ground of the short-run transitional dynamics generated into neoclassical growth models [Tahvonen and Kuuluvainen (1993), Selden and Song (1995), Kelly (2003)], as well as in models of endogenous growth where pollution is decoupled from the engine of growth under the premise that not every increase in output due to technological advances will lead to increased pollution [Byrne (1997)].[1] Beyond these short-run dynamic interpretations of the EKC for an isolated country, we supply a long-run alternative view connected with the development process historically experienced by economies. This view, moreover, gives theoretical support to the bulk of empirical studies, because it allows for a well-defined EKC based on the variability of population growth rates and the willingness to pay for cleaner environment, while it leaves any other technical and preference parameters unchanged.

All these questions will be analyzed more accurately here in a simple model of endogenous growth. Our model builds upon the traditional Rebelo's (1991) one-sector AK model to which we incorporate pollution. Welfare depends on consumption but also on the quality of the environment where agents consume, i.e. households show environmental concern. In this model pollution arises from production, as a by-product, and enters the consumer's

[1] Alternative foundations for the EKC hypothesis may be found in Jones and Manuelli (2001) built upon a dynamic overlapping generations model, but also in the context of a static model as in McConnell (1997), Stokey (1998), Munasinghe (1999) or Andreoni and Levinson (2001).

utility function playing the role of an externality. We ignore any other pollution externality which could play a role by affecting the productivity of factors. Pollution may be mitigated by means of emissions abatement activities, which allow to control for the degree of dirtiness associated with production technologies as well as for the net flow of pollutants to the environment. However, these activities are costly because they absorb resources, reducing investment and consumption possibilities.

Since environmental preferences and population growth rates are decisive in this framework, government may implement indirect policies such as information and awareness campaigns that make people more environmentally conscious, enhance education levels, improve health, and perform population control actions that accelerate the demographic transition process. These long term policies may complement the more direct ones which focus on incentives to adopt cleaner technologies using environmental corrective taxes and subsidies.

The article is organized as follows. Section 2 describes the economy and introduces the assumptions featuring a general equilibrium one-sector endogenous growth model. In sections 3 and 4 we study the Pareto optimal solution assuming sufficient conditions for interiority. Using the unconstrained trajectories, we characterize growth and analyze under which conditions sustained balanced growth is feasible. Section 5 deals with the environmental Kuznets' curve hypothesis and the implications for environmental policies. One major critique is that this relationship only describes statistically the link between income and pollution, but does not explain why it occurs. In this section we supply an alternative long term explanation for the EKC.

Finally, section 6 summarizes and concludes.

2 The economy

The model economy is a one sector closed economy. Gross output Y is obtained according to an aggregate production function of the AK type where capital is the only factor needed to produce,

$$Y(t) = AK(t). \tag{1}$$

Input K is an aggregate composite of different sorts of capital which, in a broad sense, includes physical as well as human capital. For the sake of simplicity, we assume that this production function arises from the direct summation of the individual production functions for many identical firms.

In this economy there is an aggregate pollution flow $P\left(Y(t), \mathcal{B}\left(t\right)\right)$, which arises as a by-product of economic activity. The emissions flow is increasing with respect to gross output and decreasing with respect to abatement $\mathcal{B}$, i.e. $P_1 > 0$ and $P_2 < 0$. Function $P\left(.\right)$ is assumed homogeneous of degree zero, i.e. an equally proportional increase in both output and abatement leaves the emissions flow unchanged independently of the population size. Consequently, it may be rewritten as

$$P\left(Y(t), \mathcal{B}\left(t\right)\right) = E\left(\frac{\mathcal{B}(t)}{Y(t)}\right), \tag{2}$$

where we assume strict concavity: $E' < 0$, $\lim\limits_{x \to 0^+} E' < 0$, $-\infty < \lim\limits_{x \to 1^-} E' < 0$, $E'' < 0$, $E\left(0\right) = E^M > 0$ and $E\left(1\right) = 0$. Actually, E^M represents an effective upper bound for the emissions function.

The above-mentioned abatement effort $\mathcal{B}$, which is costly and endogenously decided by agents, will be measured in terms of output in such a way that these two variables relate to each other according to

$$\mathcal{B}(t) = (1 - z(t))\, Y(t). \tag{3}$$

Here z represents, as in Stokey (1998), a measure of the effective dirtiness of the technique used to produce. Obviously, $z(t) = 1 - \frac{\mathcal{B}(t)}{Y(t)} \in [0, 1]$ because resources devoted to clean pollution could never pass the upper bound established by current production. Therefore, any choice for z close to zero or one automatically makes the existing technique less or more polluting respectively. Taking as reference $z = 1$ which implies that no abatement effort is done and that emissions flow reaches the maximum level E^M, the larger the reduction in z the more effective the reduction in emissions. Or, put in other words, as long as we produce with a cleaner technology, the effectiveness measured in terms of emissions reduction of any additional pollution abatement that reduces z, will be larger.

Moreover, according to the aggregate resources constraint, net output may be devoted to consumption or capital accumulation. For the sake of simplicity we do not consider capital depreciation. Hence, net investment equals gross investment and the capital stock is governed by the following differential equation

$$C(t) + \dot{K}(t) = Y(t) - \mathcal{B}(t). \tag{4}$$

This equation also reflects the cost of the abatement activity in a very simple way. One unit of additional abatement effort is transformed automatically into a lower unit of output available for consumption or capital accumulation. This particular 'one-to-one' transformation, although not strictly necessary, contributes to simplify our analysis.

The economy is populated by many identical and infinitely lived agents. Population, denoted by N, is assumed to be growing at a constant rate $0 < n < A$. The initial population $N(t_0)$ is normalized to one. Individual preferences are assumed to be represented by a twice continuously differentiable instantaneous utility function $V\left(c(t), P(t)\right)$, which depends positively on the current per capita consumption c and negatively on the emissions flow P [Gradus and Smulders (1993), Ligthart and Ploeg (1994), Selden and Song (1995), Reis (2001)]. Under this assumption, households do not take care for the stock of pollutants in the environment, but only for the current flow of polluting emissions. This may be justified on the basis that the local stock effect of pollution is assumed short-lived and the abatement activity, which reduces emissions and facilitates regeneration, makes the local stock effect negligible.[2]

Using (2) and (3) we find that P is an increasing monotonous transformation of z. Therefore, the instantaneous utility function may be written as

[2] This also implies that we ignore global stock effects in the representation of households' preferences. An important stream of literature considers that welfare depends on the stock of pollution rather than on the current flow [Huang and Cai (1994), Mohtadi (1996), Tahvonen and Salo (1996), Byrne (1997), Kelly (2003)]. However, if the flow of pollution is increasing with production, then capital accumulation that increases future output also increases future flows of pollution. Hence, we find a general consensus in the literature [Gradus and Smulders (1993), Smulders and Gradus (1996), Aghion and Howitt (1998), Reis (2001)] according to which, in the context of this model, if we consider the stock of pollution as an argument in the utility function, we will obtain the same fundamental results but at the cost of a more complex analysis.

$U(c(t), z(t))$ with $U_c > 0$ and $U_z < 0$, where the two ordinal utility functions represent the same preference ordering. Moreover, we assume decreasing marginal utilities: $U_{cc} < 0$ and $U_{zz} < 0$, as well as strict concavity with respect to both arguments taken together, $U_{cc}U_{zz} - (U_{cz})^2 > 0$.

Given that the structure of the model allows for the existence of a long-run balanced growth path, defined as an allocation in which consumption per capita grows at a constant rate and the dirtiness index is constant, following Bovenberg and Smulders (1995; 1996) and Smulders and Gradus (1996) we assume that the particular instantaneous utility function is multiplicatively separable and of the CIES form

$$U(c(t), z(t)) = \frac{c(t)^{1-\Phi}}{1-\Phi} (1 - z(t))^{\alpha(1-\Phi)} . \tag{5}$$

In this function, the parameter that represents the relative weight of environmental care in utility is assumed to be positive and lower than one, $0 < \alpha < 1$, and the inverse of the constant intertemporal elasticity of substitution is allowed to be lower or greater than one, $0 < \Phi \lesseqgtr 1$. The strict concavity assumption requires as sufficient condition that the determinant of the Hessian matrix be positive, which implies the parameter constraint $\Phi > \frac{\alpha}{1+\alpha}$.

3 Optimality conditions

Given the presence of a welfare pollution externality, the equilibrium path corresponding to the non-regulated competitive economy will not be Pareto optimal. Agents have no individual incentives to internalize this negative externality, which will lead to insufficient abatement and too much pollution.

This situation call for some kind of intervention because without any corrective environmental policy, the environment will be damaged up to a level of irreversible catastrophe and sustained growth, if there exists, will not be sustainable [Aznar-Márquez and Ruiz-Tamarit (2004)]. Consequently, from now on we will focus on the socially optimal solution for the model economy described in the previous section, where the central planner internalizes all the costs and benefits associated with pollution abatement activities.

We will only study interior solutions. Accordingly, we solve the problem and obtain the unconstrained optimal trajectories, for which we derive below sufficient conditions on parameters that ensure the control constraints hold. We use lowercase letters to represent variables in per capita terms. Under these premises the planner's problem consists in choosing the sequence $\{c(t), z(t), t \geq t_0\}$ which, for a given positive social rate of discount $\rho > n$, solve the optimization problem

$$\max_{\{K,c,z\}} \int_{t_0}^{\infty} \left[\frac{c^{1-\Phi}}{1-\Phi} (1-z)^{\alpha(1-\Phi)} \right] e^{-(\rho-n)(t-t_0)} dt$$

$$s.t. \qquad (1), (3), (4)$$

$$\text{and } k(t_0) = k_0 > 0.$$

Using q to represent the shadow price of k, the first order necessary conditions are

$$q = c^{-\Phi} (1-z)^{\alpha(1-\Phi)}, \tag{6}$$

$$q = \frac{\alpha c^{1-\Phi} (1-z)^{\alpha(1-\Phi)}}{Ak(1-z)}. \tag{7}$$

As we have seen, gross product may be allocated to consumption, investment or abatement. On the margin, according to (6), goods must be equally valuable if they are consumed or accumulated as new physical capital, i.e. the marginal utility of consumption today must be equal to the marginal shadow value of physical capital (consumption tomorrow). According to (7), at equilibrium the implicit price of a more dirty technique, qAk, must be equal to the marginal utility of a cleaner one. Namely, the valuation of a marginal reduction in resources devoted to abatement, which contributes to increase consumption (present or future) as well as the stock of pollutants, must be equal to the marginal utility of those resources when they are devoted to abatement, which contribute to increase environmental quality. Moreover, the dynamic conditions are

$$\overset{\bullet}{k} = Akz - c - nk, \tag{8}$$

$$\overset{\bullet}{q} = \rho q - Azq, \tag{9}$$

together with the initial condition k_0 and the transversality condition

$$\lim_{t \to \infty} e^{-(\rho - n)(t - t_0)} qk = 0. \tag{10}$$

From (6) and (7) we get the control functions

$$c = c(k, q) = \left(\frac{\alpha}{A}\right)^{\frac{\alpha(1-\Phi)}{\Phi - \alpha(1-\Phi)}} q^{\frac{-1}{\Phi - \alpha(1-\Phi)}} k^{\frac{-\alpha(1-\Phi)}{\Phi - \alpha(1-\Phi)}}, \tag{11}$$

$$z = z(k, q) = 1 - \left(\frac{\alpha}{A}\right)^{\frac{\Phi}{\Phi - \alpha(1-\Phi)}} q^{\frac{-1}{\Phi - \alpha(1-\Phi)}} k^{\frac{-\Phi}{\Phi - \alpha(1-\Phi)}}. \tag{12}$$

Now, substituting (11) and (12) into (8) and (9), we get the dynamic system

$$\overset{\bullet}{k} = (A - n) k - A^{\frac{-\alpha(1-\Phi)}{\Phi - \alpha(1-\Phi)}} \left[\alpha^{\frac{\Phi}{\Phi - \alpha(1-\Phi)}} + \alpha^{\frac{\alpha(1-\Phi)}{\Phi - \alpha(1-\Phi)}}\right] q^{\frac{-1}{\Phi - \alpha(1-\Phi)}} k^{\frac{-\alpha(1-\Phi)}{\Phi - \alpha(1-\Phi)}}, \tag{13}$$

$$\overset{\bullet}{q} = (\rho - A) q + A^{\frac{-\alpha(1-\Phi)}{\Phi - \alpha(1-\Phi)}} \left[\alpha^{\frac{\Phi}{\Phi - \alpha(1-\Phi)}}\right] q^{\frac{-(1-\Phi+\alpha(1-\Phi))}{\Phi - \alpha(1-\Phi)}} k^{\frac{-\Phi}{\Phi - \alpha(1-\Phi)}}, \tag{14}$$

with the initial condition $k(t_0) = k_0$ and the transversality condition (10). These two differential equations conform a non-linear dynamic system, which may be solved in closed form [Ruiz-Tamarit and Ventura-Marco (2004)]. We find that it does exist a unique optimal solution trajectory for $k(t)$ and $q(t)$, represented by

$$k(t) = k_0 \exp\left\{\frac{A-\rho-\alpha(\rho-n)}{\Phi-\alpha(1-\Phi)}(t-t_0)\right\}, \tag{15}$$

$$q(t) = q(t_0) \exp\left\{-\Phi\frac{A-\rho-\alpha(\rho-n)}{\Phi-\alpha(1-\Phi)}(t-t_0)\right\}, \tag{16}$$

$$q(t_0)^{\frac{1}{\Phi-\alpha(1-\Phi)}} k_0^{\frac{\Phi}{\Phi-\alpha(1-\Phi)}} = \frac{\Phi-\alpha(1-\Phi)}{\rho-A+\Phi(A-n)}\left(\frac{\alpha}{A}\right)^{\frac{\alpha(1-\Phi)}{\Phi-\alpha(1-\Phi)}}. \tag{17}$$

Given k_0 equation (17), which arises from the transversality condition, gives the initial value for $q(t_0)$. Once the two initial values are known, equations (15) and (16) determine the complete trajectories for these two variables. For any $q(t_0)$ other than the one supplied by (17) the economy places on an explosive trajectory, which does not satisfy optimality conditions. Moreover, given $b_x \equiv \alpha^{\frac{\alpha(1-\Phi)}{\Phi-\alpha(1-\Phi)}} > 0$, the transversality condition holds if, and only if, $a_x \equiv \frac{\rho-A+\Phi(A-n)}{\Phi-\alpha(1-\Phi)} > 0$. This parameter constraint must be satisfied for any positive intertemporal elasticity of substitution, i.e. $0 < \Phi \gtrless 1$, what is not obvious. However, the strict concavity assumption on the utility function imposes the additional parameter constraint $\Phi > \alpha(1-\Phi)$. Hence, the transversality condition (10) holds if, and only if,

$$\rho > A(1-\Phi) + \Phi n. \tag{18}$$

Given (15) and the production function in per capita terms, which arises from (1), we obtain

$$y(t) = Ak_0 \exp\left\{\frac{A-\rho-\alpha(\rho-n)}{\Phi-\alpha(1-\Phi)}(t-t_0)\right\}. \tag{19}$$

And using the control functions as given in (11) and (12) we get

$$\frac{c(t)}{k(t)} = \left(\frac{c}{k}\right)^{*} = \frac{\rho - A + \Phi(A-n)}{\Phi - \alpha(1-\Phi)}, \tag{20}$$

$$z\left(t\right) = z^{*} = \frac{A\Phi - \alpha\rho + \alpha\Phi n}{A(\Phi - \alpha(1-\Phi))}. \tag{21}$$

Moreover, the dirtiness index is expected to be bounded, i.e. $0 \leqslant z^{*} \leqslant 1$. For this to be ensured we need additional parameter constraints. In particular

$$\Phi\left(A-n\right) + n\left(\Phi - \alpha(1-\Phi)\right) \geqslant \alpha\left(\rho - n\right), \tag{22}$$

$$\Phi\left(A-n\right) \geqslant A - \rho, \tag{23}$$

where it may be easily checked that (23) encompasses (18).

4 Sustained growth and pollution

The previous results completely characterize the dynamic system corresponding to the Pareto optimal solution. Along their respective optimal trajectories, the growth rates of per capita capital stock, consumption and output are equal to each other and constant over time, while the rate of growth of the dirtiness index is zero

$$\gamma_{y}(t) = \gamma_{c}(t) = -\frac{\gamma_{q}(t)}{\Phi} = \gamma_{k}(t) = \gamma^{*} = \frac{A - \rho - \alpha(\rho - n)}{\Phi - \alpha(1-\Phi)}, \tag{24}$$

$$\gamma_{z}^{*} = 0. \tag{25}$$

The ratio consumption to capital stock is constant and positive and the dirtiness index remains fixed forever at a constant value between zero and one. Therefore, the model does not predict transitional dynamics and all the endogenous variables conform a balanced growth path from the beginning.

From (24), given $\Phi > \alpha(1-\Phi)$, a positive rate of growth $\gamma^* > 0$ arises when $A - \rho > \alpha(\rho - n)$. This condition is compatible and may be combined with the parameter constraint corresponding to the transversality condition, as well as those representing the lower and upper bounds for z^*, giving

$$\Phi\left(A-n\right)+n\left(\Phi-\alpha(1-\Phi)\right)>\Phi\left(A-n\right)\geqslant A-\rho>\alpha\left(\rho-n\right)>0. \quad (26)$$

The absence of transitional dynamics that makes the short-run identical to the long-run simplifies the comparative analysis for the socially optimal rate of growth and dirtiness index. We find the following parameter dependences for these two endogenous variables

$$\gamma^* = \gamma\left(\overset{+}{A}, \overset{-}{\rho}, \overset{-}{\Phi}, \overset{-}{\alpha}, \overset{+}{n}\right), \quad (27)$$

$$z^* = z\left(\overset{+,-}{A}, \overset{-}{\rho}, \overset{-}{\Phi}, \overset{-}{\alpha}, \overset{+}{n}\right). \quad (28)$$

The signs associated with A, ρ and Φ are the usual in the canonical AK model, i.e. the larger the capital productivity and the higher the patience of agents, the greater the rate of growth. However, two new results are found here. First, the more intuitive one, according to which the higher the weight of environmental care in utility (higher values of α that imply a higher marginal utility of abatement and a lower rate of return on capital) the smaller the rate of growth (the central planner optimally decides to devote more resources to abatement and less to capital accumulation and growth). Second, the more striking result of a positive relationship between the rate of growth and the population growth rate. This result depends on the presence of environmental care in the model, because only in such cases a higher population growth rate leads the central planner to divert resources from abatement and consumption towards capital accumulation. This effect is stronger as higher is the weight of environmental care in the utility function.[3]

The dirtiness index, in turn, depends positively on the productivity parameter when the intertemporal elasticity of substitution is greater than one, but the sign of this relationship cannot be analytically determined for values of such elasticity lower than one. Moreover, for a positive balanced growth path, the higher the patience of agents the higher the value of z. When consumers show a high level of patience, the central planner optimally decides to reallocate resources towards capital accumulation, which enhance growth. This is done so intensively that even diverts some of the resources previously devoted to pollution abatement, which leads to produce with a more dirty technique. Because of the crowding out effect, we find that the higher the weight of environmental care in the utility function the smaller the dirtiness index. Finally, we also find that the greater the population growth rate the higher the dirtiness associated with the effective production technique. This occurs because for higher population growth rates the central planner decides to divert more resources from abatement effort.[4]

These two variables are closely related to each other. Actually, we can make this relationship evident using (6), (7) and (8). If we take the third

[3] A similar result may be found in Bartolini and Bonatti (2003).

[4] The results concerning the population growth rate are consistent with propositions dicussed and tested in Cropper and Griffiths (1994). In that paper, the environment is not a factor that limits productivity as population expands, but a good which quality is degraded by a growing population.

one and divide by k, and then substitute for the ratio $\frac{c}{k}$ from the first two we get, for any $\alpha > 0$,

$$\gamma^* = -\left(\frac{A + \alpha n}{\alpha}\right) + \left(\frac{A + \alpha A}{\alpha}\right) z^*. \tag{29}$$

This positive relationship between γ^* and z^* suggests that, even though conditions for a positive long-run rate of growth are satisfied, there is a trade-off between growth and environmental quality. This trade-off, which results from agent decisions, means that tighter pollution controls and increased abatement that reduce the dirtiness index, will have negative effects on the optimal rate of growth. This fact reflects the previous crowding out result according to which, greener preferences associated with a shift in preferences towards more environmental concern, affects negatively both the dirtiness index and the rate of growth.

5 Long term environmental Kuznets' curve and environmental protection policies

Beyond the problem of the existence of an optimal long-run balanced growth path we have to deal with the environmental Kuznets' curve (EKC) hypothesis, which suggests that there exists an inverted U-shaped relationship between pollution emissions and the level of income per capita. Recent empirical work on this subject have documented cases, countries and types of pollutants, for which the previous pattern holds [World Bank (1992), Hettige et al. (1992), Shafik and Bandyopadhyay (1992), Selden and Song (1994), Holtz-Eakin and Selden (1995), Grossman and Krueger (1995), Cole et al.

(1997), Bruyn et al. (1998), List and Gallet (1999), Harbaugh et al. (2000)]. Namely, economic growth leads to higher emissions until income reaches a critical turning point, and thereafter as per capita income increases emissions decrease. Some analysts recognize in this hypothesis the justification for the classical proposition which asserts that pollution will not be a problem in the long term because of the beneficial effects of economic growth for the environmental quality.[5] Now, we will show that an inverted U-shaped function connecting emissions and output per capita may also be deduced from our own framework. Overall, we conclude that economic growth alone is not a definitive solution for the environmental pollution problem and that there is still wide scope for active environmental policies.

From a theoretical point of view, the EKC hypothesis has had a traditional intertemporal dynamic interpretation for an isolated country [Borghesi (2001)], built upon growth models that show short-run transitional dynamics. Our model, instead, because of its particular nature cannot produce transitional dynamics. Consequently, we introduce here an alternative long-run lecture of this hypothesis, which connects with the concept of development and relates to some parameter changes experienced by economies along such

[5] According to this, if the EKC hypothesis is satisfied, instead of being a threat to the environment, economic growth that moves the economy from lower to higher levels of income per capita improves it. This conclusion is not generally accepted in the literature, among other reasons because the EKC seems to be only a valid description for a subset of all possible pollutants and countries [Grossman and Krueger (1996), Stern et al. (1996), Bimonte (2001), Borghesi (2001)]. However, many authors have recommended a policy of *wait-and-see*, based on an absolute trust in such a naive and misleading interpretation of the EKC hypothesis.

a process [Arrow et al. (1995), Bruyn (1997), Vincent (1997)].

Our construction relies on two cornerstones. On the one hand, beyond the three most conventionally assumed channels whereby income growth affects environmental quality (scale, composition and technique effects), Grossman and Krueger (1995), McConnell (1997) and Panayotou (1997) consider that the state of the environment may deteriorate or improve along time if consumer tastes shift toward less or more environmental concern, causing an autonomous shift in demands for environmental safeguards. In general, different levels of institutional and organizational development are accompanied by the corresponding different levels in education and awareness of the effects of pollution. Therefore, we can identify three fundamental states. First, the agricultural one where people live in a stationary equilibrium with nature. Given that survival depends on environmental sustainability people show a high environmental concern, which is incorporated in traditional habits of consumption and inherited technics of production. This equilibrium is low in pollution intensity. Second, the industrial one where people are more concerned with earning one's own living and other material needs and they show a low concern for environmental quality. Individuals cannot afford either much expenditure on abatement and, consequently, this state is high in pollution intensity. Finally, the post-industrial one where people demand higher levels of environmental quality. This state is low in pollution intensity because individuals show a high environmental concern, but also because they have the needed resources to abate pollution. According to this, an eventual improvement of the environment may arise from the increased demand for environmental protection, based on the increased willingness to pay for environmental care at higher levels of income per capita.

On the other hand, there is an empirically well-documented demographic relationship between per capita income levels and population growth rates, the *demographic transition* phenomenon, which happens along the development process. This transition has very clear implications for the rates of population growth in agricultural, or subsistence, industrializing and services-oriented economies respectively [Kremer (1993), Mincer (1995), Dahan and Tsiddom (1998), Tabata (2003)]. In general, the demographic transition occurs along three stages of development. At stage I both birth and death rates are high, and the population grows slowly. At stage II, because of the improved sanitation and health care, the death rate falls. However, the birth rate remains high, and the population grows rapidly. At stage III, because of the changes in marginal costs and benefits of having children, the birth rate falls approaching the death rate, which has remained low. The population grows again slowly.

Combining the two previous ingredients we conclude that development and income growth provoke fundamental changes in the economy, in such a way that we can first postulate for low rates of population growth and high environmental concern at the initial stages of the development process, when economies are essentially agricultural and they suffer a limited impact from economic activities on the environment. Then, at the intermediate stages, when economies become fundamentally industrial, the rates of population growth are higher and the environmental concern lower. Thus, increased emission of pollutants and more dirty technologies lead to increase the environmental damage. Finally, for high developed and basically services-oriented economies the rates of population growth are again low and the environmental concern high. Now, cleaner technologies and a growing ability and willingness to pay for a better environment lead to reduce the environmental degradation. Therefore, we can modelize a long term EKC on the basis of the evolution and changes experienced by two structural parameters of the model alone. In the long term, the economy moves from the less-developed state with a low level of income per capita towards the more developed one with higher levels of income per capita. According to what has been said above, this economy may be characterized with the corresponding low or high values of the rate of population growth, n, and the environmental concern, α, for any given set of invariant parameters A, ρ and Φ.

Consequently, taking into account the comparative statics results for the long-run rate of growth as summarized in (27), $\gamma = \gamma\left(\overset{-}{\alpha}, \overset{+}{n}\right)$, we can hypothesize the following relationship between the level and the rate of growth of the per capita income

$$\gamma = \phi y \left(2\omega - y\right), \tag{30}$$

where the constant and positive parameter ϕ represents the transformation coefficient from the level to the rate of growth, and ω stands for the level of income per capita for which the maximum rate of growth is attained. Moreover, the result shown in (29) allows us to transform from the rate of growth to the value of the dirtiness index z, which in combination with (30) gives us

$$z = \left(\frac{A + \alpha n}{A + \alpha A}\right) + \left(\frac{\alpha\phi}{A\left(1 + \alpha\right)}\right) y \left(2\omega - y\right). \tag{31}$$

Finally, we may connect with the emissions flow, E, using the function $E\left(1 - z\right)$, which has been characterized before as a function satisfying $E' <$

0, $\lim_{x \to 0^+} E' < 0$, $-\infty < \lim_{x \to 1^-} E' < 0$, $E'' < 0$, $E(0) = E^M > 0$ and $E(1) = 0$. Then, substituting for z from (31) into (2) we get the Environmental Kuznets Curve

$$E = E\left(\left(\frac{\alpha (A - n)}{A(1+\alpha)}\right) - \left(\frac{2\alpha\phi\omega}{A(1+\alpha)}\right) y + \left(\frac{\alpha\phi}{A(1+\alpha)}\right) y^2\right). \qquad (32)$$

This function shows the properties: (i) $\frac{\partial E}{\partial y} = -E' \frac{2\alpha\phi}{A(1+\alpha)} (\omega - y) \gtreqless 0$, being positive for $y < \omega$ and negative for $y > \omega$, and (ii) $\frac{\partial^2 E}{\partial y^2} = E' \frac{2\alpha\phi}{A(1+\alpha)} < 0$, $\forall y$. Consequently, the relationship between emissions flow and income per capita is strictly concave, increasing for low levels of income per capita and decreasing for higher levels of this variable beyond the critical value ω. This pattern just replicates the observed hump-shaped relationship between pollution and income[6], and emerges as a direct consequence of the inverted U-shaped relationship between z, the index of dirtiness associated with the technique, and the level of activity y, as obtained in (31). Moreover, it can be easily checked that, for any given level of per capita income, emissions are higher as lower is the capital productivity A and the relative weight of environmental care in utility α, but also as higher is the population rate of growth n, the transformation coefficient ϕ, and the exogenous level of income per capita ω.

One variable which has played an important role in the discussion of the EKC hypothesis is the income elasticity of demand for environmental quality. The value of this elasticity is placed among the main factors causing the downturn of polluting emissions, but there is not a general consensus about

[6] Recent empirical studies have shown that, for some countries and pollutants, the best functional form is cubic, implying that for very high levels of income per capita environmental degradation starts to increase again [Torras and Boyce (1998)].

the exact definition of this 'good' with respect to income [Magnani (2000)]. In spite of the fact that many authors have claimed that environment is a luxury good and the income elasticity is above unity, others manifest serious doubts about this assumption and even prove that it is neither a necessary nor sufficient condition for the EKC hypothesis to be satisfied [McConnell (1997)]. In our framework, the abatement effort is an indirect indicator of the environmental quality. If we rewrite (3) in per capita terms as $\mathfrak{b} = (1-z)\, y$, then the income elasticity may be easily computed,

$$\epsilon_{\mathfrak{b},y} = 1 - \frac{2\alpha\phi y\,(\omega - y)}{A\,(1+\alpha)\left(\left(\frac{\alpha(A-n)}{A(1+\alpha)}\right) - \left(\frac{2\alpha\phi\omega}{A(1+\alpha)}\right) y + \left(\frac{\alpha\phi}{A(1+\alpha)}\right) y^2\right)}. \tag{33}$$

The last term on the r.h.s. is positive for $y < \omega$ and negative for $y > \omega$. Consequently, the income elasticity of demand for environmental quality $\epsilon_{\mathfrak{b},y}$ is less than one for $y < \omega$ but bigger than one for $y > \omega$. That is, along the initial stages of development the elasticity of abatement effort to income remains below unity, but for higher development levels this elasticity becomes greater than one. Accordingly, the environmental quality appears as a luxury good only for high levels of income per capita: as countries get richer abatement expenditures will increase, but only when a certain level of income per capita has been surpassed will they increase more than proportionally reducing z and, hence, pollution emissions too. This feature is also shown by many other goods, as for example education, with which environmental quality shares an important property: they all generate positive externalities over the economy.

Our view of the EKC may be supported by a vast empirical literature which, analyzing cross-sectional or panel data, finds that economic growth and development bring an initial phase of environmental deterioration followed by a subsequent phase of improvement. The picture has been perfectly summarized by Panayotou (1993) in the following sentences: "*At low levels of development both the quantity and intensity of environmental degradation is limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. As economic development accelerates with the intensification of agriculture and other resource extraction and the take off of industrialization, the rates of resource depletion begin to exceed the rates of resource regeneration, and waste generation increases in quantity and toxicity. At higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in leveling off and gradual decline of environmental degradation*". Therefore, the EKC hypothesis accounts for an evolutionary progression associated with different stages of the development process, as historically followed by many nations, from clean agricultural economies to clean services economies, going through polluting industrial economies with high detrimental effects on the environmental quality.

Despite the previous considerations about the classical hypothesis of an inverted U-shaped relationship between pollution emissions and per capita income levels, only a very superficial interpretation of its meaning could lead the analysts to believe that the best thing the policy-makers can do is to keep away of active environmental protection policies. Actually, growth is not a panacea for the environment [Arrow et al. (1995)]. As we have seen, the externality associated with pollution emissions and abatement makes the environmental problem very difficult, if not impossible, to resolve in a competitive decentralized economy. Consequently, in no one case can be expected that the pollution problem will automatically be solved as a result of economic growth without government interventions and active environmental policies.

In this paper, while studying the socially optimal solution to the environmental problem as opposed to the decentralized one, we have identified different opportunities for government interventions. First of all, an institutional one, which involves the government correcting the externality associated with pollution, by enforcing property rights and contracts as well as setting the usual pollution standards and taxation that make the competitive economy to work efficiently. Alternatively, the government may develop an allocative function, which implies a direct participation providing the economy with public abatement. Moreover, from a long term perspective, the government has an important role to play implementing indirect environmental policies such as information or awareness campaigns [Chevé (2000)]. These policies look to influence fecundity behavior of households and social preferences for environmental protection. Hence, increasing participation makes people more environmentally conscious, increases the demand for environmental quality and prevents the environment to be felt as an obstacle to growth [Bimonte (2001)]. Moreover, population control policies and other development encouraging actions that accelerate the demographic transition, can help to reduce environmental degradation at low income levels and speed up improvements at higher income levels. Taken together, the above-mentioned policies may affect in the long term both the population growth rate and the environmental willingness to pay. Namely, the two main parameters in our explanation of the environmental Kuznets curve.

6 Conclusions

In this paper, we have built a general equilibrium one-sector endogenous growth model in which pollution is a by-product of economic activity but it may be reduced by spending a fraction of the aggregate output on abatement. We consider the existence of a welfare pollution externality associated with the emissions flow, and then we study the socially optimal equilibrium. We have proved that the optimal path does exists, it is unique, and does not show transitional dynamics. We found that the rate of growth depends negatively on the weight of environmental care in utility and positively on the population growth rate. Moreover, the latter effect is stronger as higher is the weight of environment in the utility function. We also found a trade-off between growth and environmental quality because increased abatement effort crowds out resources from capital accumulation and growth.

Using this framework, we have got an alternative explanation for the environmental Kuznets curve, which relates the emissions flow to the stage of development of a country. Our construction relies on two structural parameters: the rate of population growth and the households environmental concern. At the initial stage of the development process economic activity has a limited impact on the environment. At the intermediate stage, however, economic activity increases pollution intensity which results in an increasing environmental damage. Finally, as the economy becomes highly developed, pollution intensity decreases and economic activity appears associated with environmental improvements. In the case of low income developing countries there is evidence that, for local pollutants, an eventual reduction in emissions emerges with higher levels of income per capita as the willingness and capability to pay for pollution abatement increase and the population growth rate decreases.

Growth creates the conditions for environmental improvement by raising the demand for environmental quality once it has been reached high levels of income per capita, but policy makers should not assume that economic growth will automatically solve pollution problems. Economic growth is not a substitute for environmental public policies, which are necessary to control pollution emissions. There is no reason to believe that the eventual positive relationship linking growth and environmental quality is inevitable, because even though economic growth directly fosters higher abatement expenditures, it also increases pollution. Moreover, environmental damage need not be inextricably linked to economic growth since, for this to be validated, we need conscious public interventions to protect environment. Therefore, policy has a very important role to play because, on one hand, economic development alone is not sufficient to avoid irreversible damages and, on the other hand, a permanent conflict between economic policies encouraging growth and environmental quality seems to be omnipresent.

In this context, some policies can help to promote both sustained growth and the environment. Since environmental preferences and population growth rates are decisive in this framework, government may implement indirect policies such as information and awareness campaigns that make people more environmentally conscious, enhance education levels, improve health, and perform population control actions that precipitate the demographic transition process. These long term policies should be complemented with the more direct ones which focus on incentives to adopt cleaner technologies using environmental corrective taxes and subsidies. Summing up, it is important to implement policies that involve people in the growth and decision making processes.

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ISSN 1379-244X D/2005/3082/001