Transitional Dynamics Towards Sustainability: Reconsidering the EKC Hypothesis

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Summary

The Environmental Kuznets Curve (EKC) hypothesis is one of the most debated economic issues. Despite its fascinating appeal for any policy maker, neither theoretical nor certain empirical evidence has been found to clean up all doubt. The aim of this paper is to present an economy where environmental quality and polluting emissions do enter the maximisation problem, and provide a transitional dynamics analysis to pursue a new different version of the EKC, depending on the level of development finally achieved.

Keywords: Environmental Quality, Endogenous Economic Growth, Sustainable Development.

JEL Classification: O41, Q01, Q32

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1 Introduction

A key problem environmental economists are always concerned with is to determine whether pollution loads do necessarily decrease as nations develop, and societies demand that more attention be paid to environmental issues.

The bulk of literature on this field has attempted to find an empirical justification to this thesis by means of the so-called "Environmental Kuznets Curve" (EKC, henceforth).[1] Although this intriguing hypothesis has immediately had great success amongst researchers and policy-makers, many authors still seriously doubt on the evidence in favour of it.

The EKC is a hypothetical relationship between some measures of environmental degradation and per capita income. In the first stages of economic growth, degradation and pollution are supposed to increase, but beyond some turning-point level of income, to be determined for each environmental indicator, this trend reverses, such that economic growth might lead to environmental improvement, and depict the so-common inverted U-shaped function.

Basically, the EKC concept first emerged in the early 1990s with Grossman and Krueger's (1991) seminal study, which encouraged folks of economists and policy-makers not to take so serious consideration of the recurrent alarmist environmental cries, as future development would necessarily "clear" the problem afterwards. In this light, the EKC has been always seen as an essentially empirical phenomenon to deal with, despite the need of a robust

[1] The EKC is so named after the Nobel Prize economist Simon Kuznets (1955) who first argumented that income inequality first rises and then falls as economies develop.

theoretical support cannot be ignored.

Moreover, empirical evidence has never shown that the EKC hypothesis can be applied to all pollutants, thus forcing recent contributions to consider the theory itself somewhat doubtful. For example, river-basins' quality unambiguously worsen with increasing income, or rather both concentration of municipal waste and carbon dioxide emissions tend to increase when income rises (see, for example, Perman and Stern, 2003; Day and Grafton, 2003).[2] The problem is that, as countries develop, they never become completely clean, despite more stringent environmental regulations might be adopted. In fact, as the older pollutants are cleaned up, new ones emerge, such that the environmental impact as a whole is not reduced. And even when an inverted U-shaped curve is empirically observed, the quarrel turns on the turning-point income level at which the concentration of pollutants starts decreasing.

As a matter of fact, the new EKC scenario does not reject the inverted U-shaped curve at all, but does find evidence of an N-shaped curve instead for some indicators, such that as income grows environmental degradation increases in a first stage, then decreases, and finally rises again (see, for example, Grossman and Krueger, 1991; Shafik, 1994; Grossman, 1995). In this light, the inverted-U function does simply represent the first stage of a more complex behaviour.

[2] Lopez (1994) points out that in the EKC studies local pollutants are more likely to display an inverted U-shape relation with income, while global impacts such as carbon dioxide emissions do not.

It is then commonly assumed nowadays that the classic EKC hypothesis is neither theoretically nor empirically adequate to model the existence of a relationship between pollution and per capita income (see, for example, Copeland-Taylor, 2004). In other words, the new economic literature is moving beyond the usual EKC.

The aim of this paper is to provide a theoretical support to a new version of the EKC hypothesis to better explain why may economic systems still perform differently when environmental concerns are taken into account. To do so, we consider an economy populated by infinitely-lived agents of two types: families of consumers and producing firms. The former are supposed to care about the environment they live in, though the latter do not. We assume also that households own both physical and human capital they provide to the producing sector, and are always willing to pay something to overcome a potential loss in environmental quality. On the contrary, firms aim only at producing final output, despite the damages and consequences could possibly arise therefrom.

What does really matter for converging to optimality is the different perception of pollution amongst agents. In other words, public intervention equalises the firms' welfare loss to the families welfare gains due to polluting emissions. Or better, the former are paying a tax directly to the latter to compensate for any harmful emitted pollutant. We are saying that the government fixes a tax h on current emissions, and families do receive the entire revenue. The same as if we assign to families the property rights on some pollution permits that firms have to buy to pollute "legally". Of course, according to the Coase theorem this immediately leads to the optimal efficient allocation of resources, since no one has an incentive to "free ride" anymore.

To this end, we formalise the problem and organise the rest of the paper as follows. In section 2, we analyse a centralised economy, and derive the growth rate of a system where the social planner (representative household) intervenes to maximise the welfare in a let us say "sustainable" way. In section 3, we concentrate instead on the transitional dynamics of this economy around the steady state, and give a possible interpretation of our findings in the light of the literature concerning the EKC hypothesis. The final section concludes, and a subsequent Appendix provides all the necessary proofs.

2 The maximisation problem

Let us consider a centralised economy where the representative household maximises the following CIES utility function[3]

$$\int_0^\infty \frac{(CE)^{1-\sigma}-1}{1-\sigma} e^{-\rho t} dt$$

[3]The utility function we are going to deal with possesses the useful property of unitarian *green preferences*. To this end, if we define $\phi(C,E)$ as the relative preference for the environment, or rather the ratio of the values of environmental quality and consumption, both evaluated at their marginal utilities, it follows that

$$\phi(C,E) = \frac{E \cdot U_E}{C \cdot U_C} = 1$$

(see, Ayong Le Kama-Schubert, 2004).

where both consumption, C, and environmental quality, E, do enter the utility function as two substitute goods;[4] subject to the following constraints on physical capital (K),

$$\dot{K} = rK + hP - C \tag{1}$$

and environmental quality (E),

$$\dot{E} = \theta E - P \tag{2}$$

The budget constraint in Eq. (1) assumes that households own the entire amount of capital K in the economy, being r the gain from renting it to producing firms, and consume a number of goods named C.[5] Moreover, they receive the tax (h) being paid by all producing firms on each unit of emitted pollution (P), as a compensation for any damage being caused to the quality of the environment they live in.[6] On the other hand, following Musu (1995),

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[4]Necessary condition for C and E to be substitutes requires that

$$\frac{\partial^2 U}{\partial C \partial E} = \frac{1-\sigma}{(CE)^\sigma} < 0$$

and consequently, $\sigma > 1$.

[5]To simplify the analysis, we assume hereafter capital K to be the only producing input, as commonly found in the so-called AK-model literature.

[6]Obviously, since pollution and environmental quality are seen as external by firms and households, market failures arise thus driving a wedge between the optimal and the decentralised growth paths of the economy. As no incentives to invest in pollution abatement or prevention arise, governmental intervention is called for to induce firms and households to make less extractive use of the environment, and maximise the social welfare by internalising the externality due to polluting emissions. That is to say, if firms act in an unregulated production market, and there is no fixed limit to polluting emissions, they feel

we constrain environmental quality to improve over time, $\frac{\partial \dot{E}}{\partial E} = \theta > 0$, being θ the speed at which nature regenerates, and to decay as pollution loads (P) increase, $\frac{\partial \dot{E}}{\partial P} = -1 < 0$, as in Eq. (2).

Therefore, Pontryagin's maximisation rule yields the following current Hamiltonian function

$$H_C = \frac{(CE)^{1-\sigma} - 1}{1-\sigma} + \lambda\left[rK + hP - C\right] + \mu\left[\theta E - P\right]$$

which is linear in P. This implies that the problem could not be well defined without imposing an upper bound of P, $\bar{P}$, which possibly depends on K, $\bar{P} = \bar{P}(K)$. Therefore, given $g_x = \dot{x}/x$ for a function of time $x(t)$, the Maximum Principle suggests the following

Proposition 1 *A sustainable steady state solution requires*

$$C(t) = \varepsilon E(t), \qquad \varepsilon = h(r - \theta) > 0$$

to hold on every interior optimal path.

Proof. See the Appendix ■

Basically, along a sustainable balanced growth path the economy evolves

free to produce (and, conversely, to pollute) as far as economic growth is possible. On the contrary, a public intervention fixing a tax on each polluting emission being realised, may slow down any *dirty* production activities, and drive the system back along the socially optimal balanced growth path.

according to

$$g_C = g_E = \frac{r-\rho}{2\sigma-1} \tag{3}$$

that is, any increase in consumption is allowed only if environmental quality does grow accordingly. But this constrain pollution P to the same growth rate, as if we allow polluting emissions to raise only when compensated by a proportional environmental improvement due, for example, to a recycling programme,

$$g_E = g_P \tag{4}$$

or rather

$$\frac{P}{E} = \gamma, \qquad \gamma > 0 \;\; \text{(constant)} \tag{5}$$

where, for simplicity, we assume hereafter $\gamma = \theta - \frac{r-\rho}{2\sigma-1}$.

Remark 2 *A weak sustainability rule of thumb allows environmental quality to grow constantly over time.*

The assumption of weak sustainability permits to overcome the environmental constraints, by considering Nature as part of the total amount of capital, which is finally held constant.[7] Both natural and physical capital are therefore seen as substitutable, thanks to technological progress that allows agents to extract more and more value from a declining amount of natural resources.

[7] "Weak sustainability requires that the amount of natural capital necessary for the life-supporting system of the Earth is non-decreasing, and the sum of man-made and non-critical natural capital is constant," (Pearce and Turner, 1990).

On the other hand, neither we underestimate the limits nor we neglect the biophysical laws that characterise the use of a natural resource.[8] Notwithstanding, we justify the assumption given so far about sustainability, as environmental quality is supposed to constantly improve over time ($g_E > 0$). In fact, although a technological sector is left out from our analysis, it is not difficult to think of it as an economy where new technologically clean products to preserve the environment are continuously introduced whether new pollutants may on the contrary emerge (see also Musu, 1995).

The problem we have been dealing with so far has shown the way a social planner has to follow to determine the optimal allocation of pollution and make a sustainable growth consequently feasible, given a constraint on environmental quality and physical capital. However, a deepen investigation on the evolution of this economy in the neighbourhood of the steady state needs to be conducted. We dedicate the next section to this end.

3 Equilibrium dynamics along the BGP

Perturbing a system to check for the behaviour of its solution when approaching the steady state can be noteworthy, and might help the policy maker to better understand the appropriate decisions that drive the system towards the long run equilibrium. The analysis conducted so far in section 2 allows

[8]Above all, the second law of thermodynamics states that every system always tends to move from order to disorder, and its energy tends to be progressively transformed into lower levels of availability, until no more availability for further processes is reached

us to rewrite the problem in a more suitable fashion, and consequently derive the following

Proposition 3 *The motion generated by a sustainable decentralised solution implies the following two-dimensional system of first-order differential equations:*

$$\begin{aligned} \dot{K} &= rK + \left(h - \frac{\varepsilon}{\gamma}\right) P \\ \dot{P} &= (\theta - \gamma)P \end{aligned}$$

given constancy of environmental quality's growth rate, g_E. The system possesses an unstable interior steady-state.

Proof. See the Appendix. ■

Our scope is to finally interpret our findings in the light of the EKC literature, and eventually determine the way polluting emissions react at changes in physical capital. To this end, we shall adopt the following convenient variable substitution, $x = \frac{P}{K}$, and finally come to the subsequent equation of motion

$$\dot{x} = \left[\frac{2r(1-\sigma) - \rho}{2\sigma - 1}\right] x - \left(h - \frac{\varepsilon}{\gamma}\right) x^2 \qquad (6)$$

Graphic representation of Eq. (6) is more direct and straightforward, and yields the following Figure 1[9]

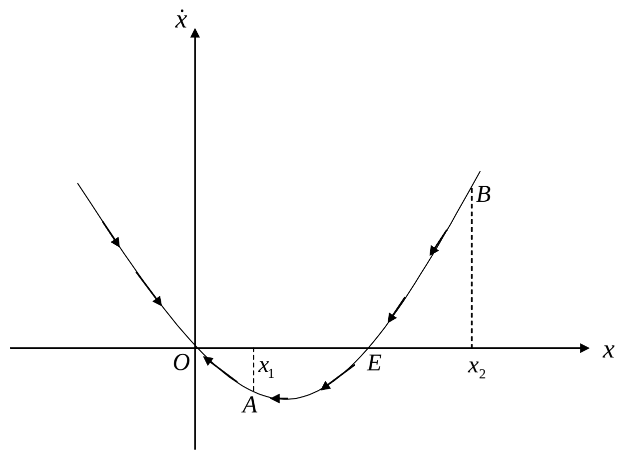

Figure 1: Dynamics of the system

To summarise, a dynamic behavioural analysis permits to understand the appropriate policy intervention that should be made to attain the steady-state, given the initial level of our state-like and control-like variables. Moreover, thorough analysis of equilibrium coordinates provides some interesting findings. To begin with, we may consider an economy which starts up at point A with endowment x_1. This resembles the case of a *clean* society starting with a high natural regeneration rate (i.e., low level of pollution), gradually changing its production processes to abate the associated polluting emissions.

[9]Note that $\dot{x}$ can be interpreted as the speed at which the pollution to capital share evolves over time.

The system does finally converge to O, with pollution being finally weeded out. Conversely, if we consider a *dirty* economy with a very high pollution to capital share, starting, for example, at point B with endowment x_2, the system approaches equilibrium from the right-hand side, passing through E, and constantly reducing the amount of polluting emissions, until the system collapses again to O. Finally, it seems that an economy will "naturally" converge to the *virgin state* of nature. Nevertheless, the speed at which a society decides to change its production processes, and reduce pollution loads, might be slightly different. Whereas the rich economy in B starts decreasing its pollution at a very high speed, once a minimum threshold is reached, it becomes more difficult to get rid of a *dirty* production process, and convergence to the stable virgin state O starts lessening.

It is also easy to interpret these findings according to the classic EKC (Environmental Kuznets Curve) hypothesis, that associates increasing pollution with increasing levels of income at a starting phase of development, though pollution is assumed to slow down instead when a turning point is reached at some high levels of national income.

In our case, nonetheless, a starting point at B resembles the assumption of high income societies that are more devoted to environmental concerns, and start reducing their emission levels. It can basically depict a situation where polluting emissions are very high. Then, the engine of development and growth either increases the amount of physical capital available to the economy or progressively abates polluting emissions, thus reducing the pollution/capital share, and thus finally drive the system towards the equilibrium point, E.

Unfortunately, equilibrium E is not stable, that is either the system lies on it from the beginning, or it is unavoidably pushed back to the stable solution in O. It seems then theoretically plausible that the EKC hypothesis fails at representing a sustainable economic development as depicted in this paper. Indeed, we can expect that whenever a society has reached a sustained level of development, and its citizens beg for more environmental care policies, it might very well happen that they continue to ask for a reduction of polluting emissions, until the system collapses to the stable solution, where pollution definitely disappears.

4 Concluding remarks

Nowadays pollution is still considered a *dirty* word. The main question is whether continued environmental degradation might be considered a necessary part of the process of industrialisation. In other words, we ought to investigate whether or not polluting emissions do continue to increase without bound as more and more countries develop. The problem is that a clear relationship between growth and environmental quality is particularly complex: some indicators appear to improve with growth; others worsen; still others exhibit a somewhat doubtful trend.

Basically, the concern that environmental issues may limit current growth opportunities is not new. The problem of sustainable development was firstly debated during the 1970s, but strongly fostered during the last decade. This is probably due to the recent political quarrels on climate change and the Kyoto Protocol effectiveness, but also to the emergence of a vast literature on the so-called "Environmental Kuznets Curve hypothesis" (EKC), where the relationship between pollution and income is assumed to have the shape of an inverted U, that is pollution might increase only in the first stage of economic development, while it necessarily decreases when developed societies seek a less polluted environment to live in, and become more willing to invest in new technologies that clean-up the production processes of their economic activities. Unfortunately, lots of criticisms have been raised against this theory, since polluting problems seem to be nowadays an unavoidable burden that developed societies have to deal with.

It seems from our analysis that behaving sustainably is not a concept that economists might easily agree upon, as we noticed instead that a sustainable steady state outcome mainly represents a knife-edge solution to be achieved when the economy collapses, and Nature goes back to its Virgin state. Basically, we are assuming that whenever a sustainable policy be implemented to allow polluting emissions grow at the same rate of consumption, this might cause an awkward effect that might drive the system back to a situation where solutions annihilate. On the contrary, a positive solution may be achieved, but only if the economy starts from the beginning, and stays forever, with endowment x_2.

To summarise, this paper has presented an economy where environmental concerns affecting the welfare of future generations enter the decision making problem of a *green* social planner. To this end, some interesting results arise when studying the transitional dynamics of this economy. In fact, the type of equilibrium that characterises our economy allows us to give a new contribution to the still controversial EKC hypothesis. It seems to be confirmed that, as nations or regions experience greater prosperity, their citizens demand that more attention be paid to the noneconomic aspects of their living conditions. The richer countries which tend to have relatively cleaner urban air and river basins, also have relatively more tightening environmental standards and stricter enforcement of their environmental laws than the middle-income and poorer countries, many of which still have pressing environmental problems to address. However, instead of a possible downward sloping and inverted U-shaped pattern, we noticed that as countries develop, they always cease to produce certain pollution-intensive goods, no matter their starting level of development. Nevertheless, it might very well happen that the speed at which rich societies start changing the composition of pollutants in their production processes be higher than the pace less developed economies do experiment when moving towards a sustainable solution.

A Appendix

Given the current Hamiltonian function

$$H_C = \frac{(CE)^{1-\sigma} - 1}{1-\sigma} + \lambda\left[rK + hP - C\right] + \mu\left[\theta E - P\right]$$

and assuming that $g_x = \dot{x}/x$ for a function of time $x(t)$, and $U_C = \partial U/\partial C$, the Maximum Principle suggests

$$\frac{\partial H_C}{\partial C} = U_C - \lambda = 0 \Longrightarrow (1-\sigma)g_E - \sigma g_C = g_\lambda \tag{A.1}$$

$$\frac{\partial H_C}{\partial P} = \lambda h - \mu = 0 \Longrightarrow g_\lambda = g_\mu \tag{A.2}$$

$$\dot{\lambda} = -\frac{\partial H_C}{\partial K} + \lambda\rho = -\lambda r + \lambda\rho \Longrightarrow g_\lambda = \rho - r < 0 \tag{A.3}$$

$$\dot{\mu} = -\frac{\partial H_C}{\partial E} + \mu\rho = -U_E - \mu\theta + \mu\rho \Longrightarrow g_\mu = (\rho - \theta) - \frac{U_E}{\mu} \tag{A.4}$$

Since $g_\lambda = g_\mu$ is constant from (A.2) and (A.3), (A.4) implies

$$g_\mu = \frac{d\ln U_E}{dt} = (1-\sigma)g_C - \sigma g_E \tag{A.5}$$

From (A.1), (A.2) and (A.5),

$$(1-\sigma)g_E - \sigma g_C = (1-\sigma)g_C - \sigma g_E \Longrightarrow g_C = g_E \tag{A.6}$$

and thus,

$$g_C = g_E = \frac{r-\rho}{2\sigma - 1} \tag{A.7}$$

from (A.1) and (A.3). Also, we have

$$C^*(t) = \varepsilon E^*(t), \quad \varepsilon > 0 \ \text{ (constant)}, \tag{A.8}$$

on an interior optimal path. Since $U_E/U_C = C/E = \varepsilon$, (A.4) yields

$$g_\mu = (\rho - \theta) - \frac{U_E}{\mu} = g_\mu = (\rho - \theta) - \varepsilon\frac{\lambda}{\mu} = g_\mu = (\rho - \theta) - \frac{\varepsilon}{h}. \tag{A.9}$$

From (A.9), (A.2) and (A.3), it follows that

$$\varepsilon = h(r - \theta) \tag{A.10}$$

Note that constant g_E implies

$$g_E = g_P, \text{ and } \frac{P}{E} = \theta - \frac{r-\rho}{2\sigma-1} = \gamma \tag{A.11}$$

for $g_E = \theta - P/E$. The initial values C_0 and P_0 are finally obtained as

$$C_0 = h(r-\theta)E_0, \text{ and } P_0 = \left(\theta - \frac{r-\rho}{2\sigma-1}\right)E_0. \tag{A.12}$$

Finally, (A.8) is obtained without any assumption of BGP, and thus holds on *every* interior optimal path. In fact, since ε is constant not only on an optimal BGP, but also on any interior optimal path, one cannot perturb the system by varying ε for a local analysis around the steady state.

In any case, nonnegativity conditions impose some restrictions on the parameters:

$$r > \theta \text{ for } C > 0 \tag{A.13}$$

and

$$\theta(2\sigma - 1) + \rho > r \text{ for } P > 0 \tag{A.14}$$

As another restriction, the objective functional is well defined iff $2g_E(1-\sigma)-\rho < 0$. Or, equivalently,

$$\rho > 2(1-\sigma)r. \tag{A.15}$$

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