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Economic Growth and the Environment with Clean and Dirty Consumption

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Keywords: Environmental Kuznets Curve, Economic Growth, Pollution, Consumption, Consumption behaviour

JEL Classification: C61, Q56, O44

This paper has been presented at the 18th Annual Conference of the European Association of Environmental and Resource Economists (EAERE 2011), held on the campus of the University of Rome Tor Vergata, June 29th to July 2nd.

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Economic growth and the environment with clean and dirty consumption

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Abstract

This paper aims to verify the existence of the Environmental Kuznets Curve (EKC) or inverted U-shaped relationship between economic growth and environmental degradation in the context of endogenous growth. An important feature of this study is that the EKC is examined in the presence of pollution as a by-product of consumption activities; also, pollution is a stock variable rather than a flow and tends to accumulate over time. In order to highlight the role of consumption on the environment, consumers do not consider directly pollution in the maximization problem and are assumed to choose between two different consumption types, characterized by a different impact on the environment (i.e. dirty and clean consumption).

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1 Introduction

The Environmental Kuznets Curve (EKC) hypothesis states that there is an inverted U-shaped relationship between environmental degradation and economic growth. Since the seminal contribution of Grossman and Krueger (1993), this pattern has been intensively debated in empirical terms (recent reviews are provided by Dinda 2004 or Dasgupta et al. 2002). The EKC has also captured large attention from policymakers and theorists. To some extent, this is due to the fact that the EKC hypothesis implies that pollution diminishes once a critical threshold level of income is reached. As a consequence, economic growth is a pre-condition for environmental improvement. Thus, one of the main questions we have to address using growth theory is whether the EKC occurs automatically in the course of economic growth or whether environmental policy plays a crucial role in causing the downturn of the EKC.

Theoretical models have been employed to explain the EKC; each of these explanations yields a different policy implication. First, demand for better environment increases with income. One of the reasons is the fact that people fear of incurring in irreversible damage. Provided that relatively advanced political institutions exist, higher demand for environmental quality causes increasingly stricter environmental regulations. This is actually the conclusion from several theoretical models that assume perfect internalization of external effects.

Internalization can cause technological progress to move in an environmentally friendly direction. For example, the policy-induced introduction of end-of-pipe technologies has been important for the reductions in several air pollutants. This is corroborated by decomposition analyzes, which show that changing technologies have been crucial for the downturn of the EKC. However, when appropriate policies are absent, technological progress may well be pollution-enhancing. Smulders and Bretschger (2000) propose that pollution increases after introduction of a new technology, that after pollution has raised public concern a tax is imposed, and that this tax induces the invention of a clean technology that allows the downturn of the EKC. However, it may later transpire that a substance emitted by the 'clean' technology is also polluting. This opens up the possibility of cycles. These cycles imply that one pollutant is substituted for by another. A regulated flow or local pollutant could be replaced by a stock or global pollutant which is not subject to regulation. In fact, end-of-pipe technologies have precisely this effect. Nuclear power has also replaced energy gained from fossil fuels. Another explanation is related to the change in the structure of the economy. Structural change can explain the rising branch of the EKC in poor countries, but to cause the downturn the absolute production level of an industry must shrink. This is only plausible when dirty industries migrate from developed into developing countries. The evidence suggests that structural change alone cannot explain the EKC. Therefore the migration of dirty industries is usually not so rapid that the absolute level of production of these industries will decline considerably in developed countries. Nevertheless, dirty industries can grow fast in developing countries. Hence, while the migration of dirty industries may explain the cross country EKC, it cannot explain the EKC of a single growing developed country over time. Migration causes serious problems as soon as the developing countries attempt to lower pollution because they cannot relocate pollution but must actually reduce it. It has also been shown that the cross country EKC shifts upward with economic growth when the EKC is based on migration. Therefore a country on the falling branch of the cross country EKC may well see its pollution rise in the course of economic growth due to this upward shift of the EKC. Finally, increasing returns to scale in abatement can allow rich countries to abate at lower average costs than poor countries. This may bring about the EKC.

By contrast to many of these prior explanations, following the tradition of one-sector endogenous growth models, we developed a simple dynamic model of economic growth and pollution. This analysis advances beyond previous work in three respects. First, as the purpose of this paper is to highlight the role of consumption on the environment, pollution is modeled as a by-product of consumption instead of production activities. Consumption has a direct impact on the environment: higher levels of consumption require larger inputs of energy and material and generate larger quantities of waste byproducts. Consumption has also an indirect impact on the environment: consumers' behaviors and consumption decisions form an important part of production-consumption chain as it is the consumer who makes the final choice about which goods and services he consumes. When we think of daily activities that cause pollution we tend to think of driving, heating or washing. But a larger impact of individuals is through the products that they buy. Ultimately, it is consumers (including companies and government) buying products that trigger the chain of events that leads to most pollution. If you buy a television set, you "share" responsibility for the energy used by the shop and for the transport of the TV set from its country of assembly.

In most theoretical macroeconomic models, consumption is treated as a homogeneous good. Usually this hypothesis can be accepted as a plausible simplification without relevant consequences on the generality of the model's findings. However, sometimes commodity heterogeneity turns out to be important in representing particular economic phenomena. An example is given by the case of goods which give place to different effects on the environment; in this case, building up models allowing for different kinds of commodities is relevant; in particular, the distribution between "clean" and "dirty" goods affects pollution and thereby welfare, economic activity etc. Commodities can be defined as "clean" or "dirty" according to the environmental impact connected to their production and/or consumption. Consider for instance the consumer choice of urban transportation (i.e. car, bus, train etc.); besides the polluting effects due to the production of each of these goods, there is an additional and different impact on the environment for each kilometer run by car, by bus or by train[1]

Second, the model is distinctive also in representing pollution as a stock and not only as a flow variable. Pollution degrades environmental quality which can be restored only after the passage of some period of time - shorter for some pollutants than others. For example, sulfur dioxide emissions are less important for their effects on air concentrations than for their enduring effects on soil chemistry, forest stocks, lake chemistry, and aquatic biodiversity. Persistent effects on environmental quality also result from chlorofluorocarbons (CFCs) and many other industrial pollutants. Therefore, this paper analyzed the state of the environment characterized as a stock that can change as a result of emissions on one hand and corrective consumption decisions on the other.

In this respect, it is also important to stress the fact that consumers do not always observe pollution *per se* but rather its impact on the environment; sometimes, even the effect of pollution

[1]Several examples of clean consumpion can be provided: (i) green electricity, produced from renewable energy; (ii) food or beverages packaged in ecologically favorable material like PET or multi-way bottles or cardboard containers, instead of cans or one-way bottles; (iii) eco-detergents containing lemon or acetic acid, instead of aggressive detergents. The same holds for washing powder. The reason is that water purification becomes less expensive, the less pollutants reach the groundwater or the water recycling plant; (iv) food from eco-farmers who do not use mineral and chemical fertilizers and pesticides which pollute the groundwater; or (v) paper recovered from waste paper instead of paper produced from trees. Clean consumption also means that a consumer will pay attention to: (i) the origin of juice, bottled-drinking water and wine, because the environment will not be burdened by long-distance transport if those products come from a neighboring area; (ii) the justifieded keeping of animals. He prefers meat and eggs produced under such conditions, although products from mass production in agriculture, combined with negative environmental externalities, are frequently less expensive than regional farm products; (iii) not buying less expensive electronic entertainment equipment, that are inefficient in terms of energy consumed.

on the environment is not "observable" immediately. This is true if we think, for instance, to the depletion of the ozone layer; and it is also true if we think about climate change (which is a long-term change whose effects on the environment are, fortunately, not fully evident yet).

On the one hand, the flow pollutant has an immediate on the environment. On the other hand, the stock pollutant harms the environment only in the future since stock pollutants frequently need time to accumulate before the damage occurs.

For all these reasons, we analyze a growth model distinguishing between two types of consumption, an environmentally friendly "clean" consumption that abates pollution and a "dirty" consumption that generates pollution.

We are interested in analyzing the welfare and environmental effects when the population of green consumers increases. In our model, environmental consciousness is measured by the "size" of green consumption compared to that of dirty consumption. Intuitively, we should expect a greener environment (less emissions) as environmental consciousness grows. We show that intuition can be misleading. We find the counterintuitive result that pollution can be higher as the proportion of green consumers increases. The result depends on the degree of product differentiation (consumers valuation of the physical and environmental attributes) and how costly it is to produce the good with the environmental attribute. When the proportion of green consumers is low, both firms compete for very few consumers as dirty consumers do not care for the environmental attributes and always buy from the firm that uses the dirty technology. Product differentiation becomes less important and the advantage in costs makes the dirty firm charge a low price and capture almost the whole market. A marginal increase in the population of green consumers makes competition tougher and both firms reduce their prices. Although the clean firm sells more, the difference in costs makes the dirty firm charge a very low price and its output increases. This effect is reversed when the proportion of green consumers is sufficiently high. Once a critical value is reached, further increases in the population of green consumers reduce the dirty firms output as product differentiation becomes more important.

In this model, the utility function of the representative agent does not depend directly on pollution but only indirectly through the consumption decisions. In other words, in this model, pollution *per se* does not create disutility. We can think in this case of a social planner that takes into account the environmental problem only through the pollution constraint because consumers do not consider the stock pollution directly in their utility function but only indirectly through consumption decisions.

Third, focusing on the social planner's problem, we derived closed-form solutions for the resulting dynamic system. This enabled us to determine how pollution evolves over time and identify the economic determinants behind its path.

2 Dynamic growth model with stock pollution

Using the paper of Andreoni and Levinson (2001) as a starting point, we extend their model in a dynamic context in which pollution is treated as a stock variable rather than as a pure flow and pollution is a result of consumption activity. As pointed out in the introduction, it is more reasonable to assume as a stock some environmental degradation (such as heavy metals, deforestation and the depletion of the ozone layer) because these pollutants are cumulative and self decaying very slowly.

In particular, we assume a competitive economy which is closed to international markets and is populated by identical and infinitely lived agents. The production technology is given by

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

where Y denotes aggregate output and K the aggregate capital stock at time t. The positive constant A is assumed to be sufficiently large to enable positive growth of output, as analyzed later.The absence of diminishing returns to capital may seem unrealistic but the idea becomes more plausible if we think of K in a broad sense to include human and natural capital, knowledge, infrastructures and so on.

In this economy, there are two different ways of consuming this aggregate good: a 'dirty' consumption that generates waste and, as a consequence, damages the environment and a 'clean' consumption, that mitigate the environmental impact of products purchased and reduce pollution.

Utility of the representative agent positively depends on the two types of consumption. Moreover, utility does not depends directly on the pollution stock. The reason is that consumers do not observe pollution *per se* but rather its impact on the environment. Since many pollutants tend to accumulate over time (e.g. CO_2 emissions) and to have a visible impact on the environment only when they reach a certain level, this may not be unrealistic. Up to that level, pollution does not affect human activity. Usually, the effect of pollution on the environment may last long after the pollution itself is gone. This does not mean that agents do not care about the environment or do not have environmental and ecological concerns. On the contrary, they do take into account the environment through the consumption behavior. In every instant of time t, they decide which type of consumption prevails (wheter it is the dirty or the clean consumption). In this sense, a way to reduce environmental impacts of consumer expenditure is through the encouragement of more sustainable consumption patterns. Society's environmental awareness and education play a significant role in a household's decision making process.

Thus, a representative agent maximizes the following utility function over an infinite horizon,

$$U = U[D, C] \qquad (U_D > 0, U_C > 0, U_{DD} < 0, U_{CC} < 0) \tag{2}$$

where D is the level of dirty consumption and C is the clean consumption. D and C generate utility in the same way, both having positive and diminishing marginal utility, as conventionally assumed.

3 Social optimum

In this section we consider the social planner's problem and characterize the economy. We derive the time path of pollution and verify the existence of the Environmental Kuznets Curve.

The dynamic maximization problem may be expressed as follows:

$$\max_{D,C} \int_0^\infty U[D(t), C(t)]e^{-\rho t} dt$$

s.t.

$$\begin{cases} \dot{K}(t) = F[K(t)] - \delta K(t) - zD(t) - hC(t) & K(0) = K_0 \geq 0 \\ \dot{P}(t) = \alpha D(t) - \beta C(t) - \gamma P(t) & P(0) = P_0 \geq 0 \end{cases}$$

where, $D(t) > 0$ and $C(t) > 0$.

In this model, D is dirty consumption, C is clean consumption, K is the capital stock for production, P is the pollution stock, $F[K]$ is the production function of output, ρ is the discount rate of time preference and δ is the depreciation rate of the capital stock; z and h are positive parameters that measure the different cost for society of two types of consumption. Consumption D and C, are control variables.

To characterize the transitional growth path and the optimal solutions of the above problem, we assume that the utility function, production function and pollution function have the following functional forms

$$U[D,C] = ln(D^{\sigma}C^{\theta}) \tag{3}$$

$$F[K] = AK \tag{4}$$

$$\dot{K}(t) = AK(t) - \delta K(t) - zD(t) - hC(t) \tag{5}$$

$$\dot{P}(t) = \alpha D(t) - \beta C(t) - \gamma P(t) \tag{6}$$

Pollution is a function of both types of consumption, D and C and tends to accumulate over time. Pollution is proportional to the amount of dirty consumption D (i.e. an increase in this consumption determines an increase in pollution, with α being a measure of pollution intensity); on the contrary, pollution is inversely proportional to eco-friendly consumption C (i.e. an increase in this consumption abates pollution in a proportion equal to β). Finally, the pollution stock is subject to exponential decay at the rate $\gamma > 0$.

Parameters σ and θ stand for the elasticities of the utility function of two types of consumption D and C. They measure the responsiveness of the agent's utility to a change in the level of two types of consumption. So σ and θ can be considered as a measure of a consumer's environmental 'awareness' and concern.

The Hamiltonian function H reads as follows:

$$H = ln(D^{\sigma}C^{\theta}) + \lambda[AK - \delta K - zD - hC] + \phi[\alpha D - \beta C - \gamma P] \tag{7}$$

and the necessary FOC are:

$$\frac{\partial H}{\partial D} = \frac{\sigma}{D} - z\lambda + \alpha\phi = 0 \tag{8}$$

$$\frac{\partial H}{\partial C} = \frac{\theta}{C} - h\lambda - \beta\phi = 0 \tag{9}$$

$$\dot{\lambda}(t) = -(A - \delta - \rho)\lambda(t) \tag{10}$$

$$\dot{\phi}(t) = (\gamma + \rho)\phi(t) \tag{11}$$

$$\lim_{t\to\infty}\{K(t)\lambda(t)e^{-\rho t}\} = 0 \tag{12}$$

$$\lim_{t\to\infty}\{P(t)\phi(t)e^{-\rho t}\} = 0 \tag{13}$$

where λ is the co-state variable with respect to capital stock K and ϕ the co-state variable with respect to pollution stock P.

Since λ denotes the shadow price of a valuable resource, from an economic point of view, it should have a positive sign while the shadow price of pollution ϕ should be non-negative as it will be shown later.

Interpreted economically, equations (8) and (9) state that the effect on utility of both dirty and clean consumption should be equated to the shadow value of capital K, measured by λ, adjusted for the shadow price of pollution via the $\alpha\phi$ term.

Conditions (8) and (9) show how the central planner determines the optimal distribution of consumption between clean and dirty goods by simply equalizing their marginal utilities. If the planner does not care for the environment, i.e. $\phi = 0$ and the cost for society of dirty and clean consumption is the same, i.e. $z = h$, we have $U'_D = U'_C$. However, if ϕ is different from zero, marginal utility of dirty goods must include the additional (negative) term $\alpha\phi$ and marginal utility of clean consumption must include the additional (positive) term $\beta\phi$. This means that in order to restore the equivalence between the marginal rate of substitution and price ratio, U'_C needs to decrease (and U'_D needs to increase), i.e. clean (dirty) consumption must rise (fall).

From (10) and (11) we have:

$$\lambda(t) = \lambda_0 e^{-(A-\delta-\rho)t} \tag{14}$$

$$\phi(t) = \phi_0 e^{(\gamma+\rho)t}. \tag{15}$$

From (8) and (9), using (14) and (15), we have:

$$D(t) = \frac{\sigma}{z\lambda(t) - \alpha\phi(t)} = \frac{\sigma}{z\lambda_0 e^{-(A-\delta-\rho)t} - \alpha\phi_0 e^{(\gamma+\rho)t}} \tag{16}$$

and

$$C(t) = \frac{\theta}{h\lambda(t) + \beta\phi(t)} = \frac{\theta}{h\lambda_0 e^{-(A-\delta-\rho)t} + \beta\phi_0 e^{(\gamma+\rho)t}}. \tag{17}$$

From (16) and (17) we see that if ϕ_0 is positive (or negative) $D(t)$ (or $C(t)$), as t grows, sooner or later will become negative. Since we are assuming a consumption greater than zero, we must conclude that ϕ_0 is zero; this implies that $\phi(t)$ also is always zero and that $\lambda(t) > 0$ must hold. Equation (8) and (9) show that along the optimal growth path, marginal utility of dirty and clean consumption must equal the shadow price of capital λ adjusted for the shadow value of pollution ϕ.

Therefore we have that

$$D(t) = D_0 e^{(A-\delta-\rho)t} \tag{18}$$

and

$$C(t) = C_0 e^{(A-\delta-\rho)t}. \tag{19}$$

Since the shadow value of pollution is zero, the steady state level of capital (or the long-run growth rate) is independent of the social planner's concern about pollution. The steady state requires $\dot{D} = \dot{C} = 0$ implying that $A = \delta + \rho$. Hence, the level of capital which satisfies this condition is the same as the one resulting from the underlying growth model without pollution.

Next, considering an endogenous growth framework leading to sustained growth (i.e. $A - \delta - \rho > 0$) implies that $\frac{\dot{D}}{D}, \frac{\dot{C}}{C} > 0$.

From equation (5), after dividing by K, we get

$$\frac{zD(t)}{K(t)} + \frac{hC(t)}{K(t)} = (A - \delta) - \frac{\dot{K}(t)}{K(t)} \tag{20}$$

In the steady state (where, by definition all variables grow at constant rates) the growth rate of capital is constant. Therefore, the right hand side of the above expression is constant. Consequently, $\frac{zD+hC}{K}$ is constant, and the growth rate of capital (and hence, the the growth rate of output, Y) equals the growth rate of consumption D and C given by equations (18) and (19).

To compute the growth rate of capital outside the steady state, we substitute D into (5) and, solving the linear differential equation and recalling (12), we get:

$$K(t) = K_0 e^{(A-\delta-\rho)t} \tag{21}$$

where $D(0) = D_0$ and $C(0) = C_0$ are such that

$$\frac{zD_0 + hC_0}{\rho} = K_0 \tag{22}$$

Using equations (8) and (9) we have:

$$zD(t) + hC(t) = \frac{\sigma + \theta}{\lambda(t)}$$

Hence,

$$\lambda_0 = \frac{\sigma + \theta}{zD_0 + hC_0} = \frac{\sigma + \theta}{K_0 \rho}$$

Therefore, substituting λ_0 into (14), we can write:

$$\lambda(t) = \frac{\sigma + \theta}{K_0 \rho} e^{-(A-\delta-\rho)t} \tag{23}$$

Since $\phi(t) = 0$, recalling (8) and (9), we obtain

$$D(t) = \frac{\sigma K_0 \rho}{z(\sigma + \theta)} e^{(A-\delta-\rho)t} \tag{24}$$

$$C(t) = \frac{\theta K_0 \rho}{h(\sigma + \theta)} e^{(A-\delta-\rho)t} \tag{25}$$

It is worth noting the relationship between the two types of consumption:

$$\frac{C}{D} = \frac{\theta z}{\sigma h} \tag{26}$$

Consumers substitute clean consumption with dirty consumption depending on the ratio $\frac{\theta z}{\sigma h}$. Clean consumption increases if its marginal utility θ increases and if its cost (h) is lower than that of dirty consuption (z).

To compute the growth rate of pollution, we substitute D and C into (6) and, solving the linear differential equation in P, we get:

$$P(t) = \left[P_0 - I\left(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h}\right)\right] e^{-\gamma t} + I\left(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h}\right) e^{(A-\delta-\rho)t} \tag{27}$$

where $I = \frac{K_0 \rho}{(\sigma+\theta)(A-\delta-\rho+\gamma)}$

4 Analytical results

Equation (27) describes how pollution evolves over time. The first term of the equation measures the natural decay or assimilative capacity of the environment. The second part, is pollution due to human consumption activity.

From (21) we know that $A > \rho + \delta$ is a necessary condition for sustained growth in the absence of environmental considerations. This also implies $A + \gamma > \rho + \delta$ since γ is a positive number. Thus, we can conclude that $A - \delta - \rho + \gamma > 0$.

From (24) and (25), we see that $(\sigma + \theta) \geq 0$ must hold in order to have a positive consumption.

Since K_0, ρ, h and z are also positive parameters, I in equation (27) is always positive and the sign of (27) only depends on the difference $(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h})$.

Thus, the evolution of P depends on the interaction of three types of variables: the elasticity of substitution between clean and dirty consumption (measured by σ and θ); the pollution/abatement intensity of two types of consumption (measured by α and β); the cost for the economy of two consumption categories (measured by z and h).

In what follows, we will evaluate the pollution pattern over time and we will verify the existence of an EKC.

4.1 The time path of pollution P when $\frac{\alpha\sigma}{z} > \frac{\beta\theta}{h}$

In this case, pollution stock initially decelerates due to the regeneration capacity of nature. As human dirty consumption activity grows, pollution rises exponentially. As we can see in figure 1, we have a U-shaped relationship where pollution initially decreases and, after a period of time, inverts this relationship and it starts to increase.

The case when α and σ are both greater than β and θ and $z < h$ is straightforward since we can expect that pollution increases if proportion of dirty consumption exceeds that of clean consumption ($\sigma > \theta$), pollution intensity of dirty consumption is greater than abatement intensity of clean consumption ($\alpha > \beta$) and costs for society of clean consumption (h) are greater than those of dirty consumption (z); thus it is more interesting to look at three 'extreme' cases: a) $\sigma > \theta$, $\alpha < \beta$ and $z = h$; b) $\sigma < \theta$, $\alpha > \beta$ and $z = h$; c) $\sigma < \theta$, $\alpha < \beta$ and $z < h$.

In what follows, the underlying baseline set of parameters used to illustrate the evolution of P, is in line with usual growth model calibrations (e.g. Ortigueira and Santos, 1997). To analyze the different cases, only relevant parameters (i.e. σ and θ, α and β, z and h) change.

4.1.1 case a) $\sigma > \theta$, $\alpha < \beta$ and $z = h$

In this case, even if abatement intensity of clean consumption β is greater than pollution intensity of dirty consumption α, σ is large enough to guarantee that the product $\alpha\sigma$ is greater than $\beta\theta$. Since σ and θ are a measure of the elasticity of substitution between clean and dirty consumption, a greater value of σ with respect to θ means that a given amount of dirty consumption causes more utility and individuals will accordingly spend more on it. As a result, pollution will increase over time.

An illustration of the time path of pollution is given in figure 1, where a simulation has been carried out using parameters in table 1.

P_0	K_0	α	β	σ	θ	γ	ρ	A	δ	z	h
10	1	0.4	0.6	0.7	0.3	0.1	0.04	0.12	0.06	0.5	0.5

Table 1: Baseline parameters for case a).

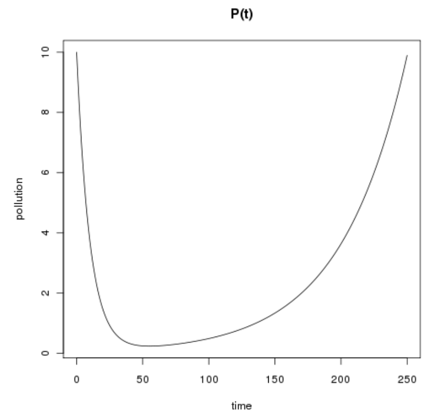


Figure 1: Case a)

4.1.2 case b) $\sigma < \theta$, $\alpha > \beta$ and $z = h$

In this case, society "prefers" clean to dirty consumption (since $\sigma < \theta$); a small amount of clean consumption gives society a slight gain in utility. However, this positive effect is offset by the fact dirty consumption has a very damaging impact on the environment through the parameter α. The net effect is a sort of U-shaped relationship where pollution initially decreases and then starts to increase (see figure 2).

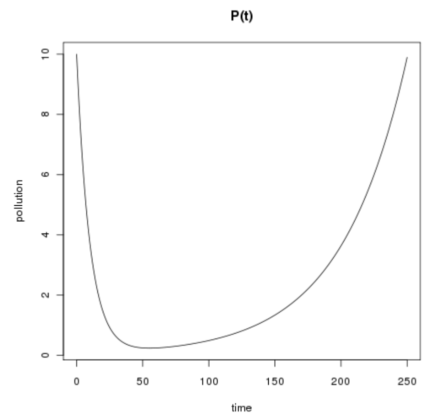


Figure 2: Case b)

P_0	K_0	α	β	σ	θ	γ	ρ	A	δ	z	h
10	1	0.7	0.3	0.4	0.6	0.1	0.04	0.12	0.06	0.5	0.5

Table 2: Baseline parameters for case b).

4.1.3 case c) $\sigma < \theta$, $\alpha < \beta$ and $z < h$

In this case, it is the different cost for the economy of the two types of consumption that matters. In figure 3, we can see that, pollution initially decreases, tends to zero and then starts to increase as it does in the other cases but after a longer period of time. After less than 50 years, pollution tends to zero and remains zero for 150 years and then starts to increase. The "whole story" takes around 200 years.

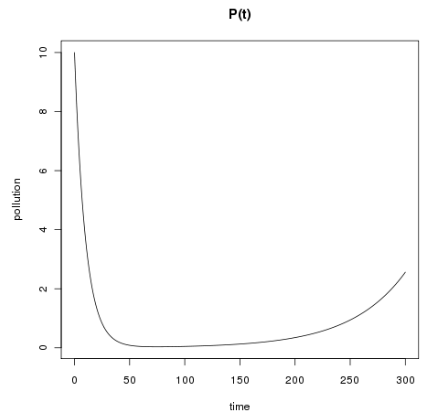


Figure 3: Case c)

P_0	K_0	α	β	σ	θ	γ	ρ	A	δ	z	h
10	1	0.4	0.6	0.4	0.6	0.1	0.04	0.12	0.06	0.3	0.7

Table 3: Baseline parameters for case c).

In particular, $z < h$ implies that clean consumption costs more than dirty consumption. When we think of clean consumption we usually imagine something that is more expensive for individuals or a society in general. In fact, in many cases, environment-friendly products are costlier to produce. As an example, consider a municipality which has to decide whether to design and construct a waste management program that integrates a recycling process or not. But this is not always the case. For instance, if we have to decide how to go to work, we have to choose between three different possibilities: walking, taking a public bus or driving a car. In this case, a clean consumption is also the less expensive choice (i.e. walking). On the other hand, however, dirty consumption generates pollution and as a consequence damages the environment; this implies a series of requalification activities that require efforts and resources.

An interesting result to note is that, in this case, we can have a rising pollution even if consumers prefer clean to dirty consumption. The fact that consumers gain more utility from clean consumption is not sufficient to guarantee a decreasing pollution over time.

4.2 The time path of pollution P when $\frac{\alpha\sigma}{z} < \frac{\beta\theta}{h}$

Now we consider the case in which $\frac{\alpha\sigma}{z} < \frac{\beta\theta}{h}$. Equation (27) has two parts: the first part tends to zero as t increases, while the second is a negative exponential function: thus, in this case, pollution has a negative slope and tends to zero in the long-run, becoming negative at some point (see figure 4).

Since in this case $\frac{\alpha\sigma}{z} < \frac{\beta\theta}{h}$, either consumers "prefer" clean to dirty consumption (i.e. $\sigma < \theta$) or clean consumption abates more than dirty consumption pollutes ($\alpha < \beta$) or cost of dirty

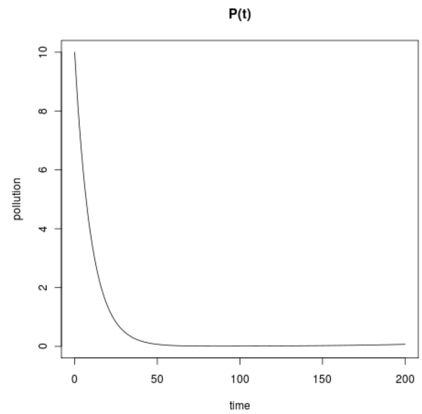


Figure 4: Case 2 - $\frac{\alpha\sigma}{z} < \frac{\beta\theta}{h}$

P_0	K_0	α	β	σ	θ	γ	ρ	A	δ	z	h
10	1	0.4	0.6	0.4	0.6	0.1	0.04	0.12	0.06	0.4	0.6

Table 4: Baseline parameters when $\frac{\alpha\sigma}{z} < \frac{\beta\theta}{h}$.

consumption is greater than that of clean consumption (i.e. $z > h$) or a "mix" of these three options apply.

Thus, although we will not get into details since the same considerations given in the previous paragraph apply in this case, it is important to remark that the evolution of pollution over time is the result of the interaction of three different parameters.

All these three parameters are a consequence of consumption differentiation: consumption differentiation affects consumers' preferences because consumers gain different utility from clean and dirty consumption; product differentiation also affects the pollution stock because clean consumption abates pollution while dirty consumption increases pollution with an "intensity" given by the two parameters α and β; this latter aspect is measured through the parameters α and β: α measure the marginal damage of dirty consumption and β measure the social marginal benefit of abatement activity of clean consumption. Finally, consumption differentiation also affects the accumulation of capital K because clean and dirty consumption have different costs; we can suppose that $z < h$ because clean consumption requires more effort and more resources to be performed. However, due to the environmental damage caused by dirty consumption, one can suppose that $z > h$ because the cost of environmental restore and requalification activities can be very high.

4.3 The non-existence of the EKC

Results of the dynamic model do not indicate the existence of the EKC. This can be showed if we use equation (27) and derive an analytical expression for the Pollution Income Relationship (PIR). In particular, substituing equation (21) into (27) and remembering that $Y = AK$, we can derive the following expression:

$$P(Y) = \left[P_0 - I\left(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h}\right)\right] e^{-\gamma t} + I\frac{1}{K_0 A}\left(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h}\right) Y \tag{28}$$

where $I = \frac{K_0 \rho}{(\sigma+\theta)(A-\delta-\rho+\gamma)}$.

Hence, since I, K_0 and A are positive parameters, the PIR is linear and its sign depends on the difference $(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h})$.

Consequently, as income grows, pollution either increases or deacreases depending on the specific values parameters (α and β, σ and θ, z and h) take. We have already analyzed in detail the role and the meaning of these parameters in the previous section. The absence of the EKC has important implications for environmental policy. Results of our model show that it is possible to have sustained growth and, at the same time, reduce the accumulation of pollution. However, to achieve this goal, economic growth alone is not sufficient: attention should be devoted to the pollution/abatement intensity of dirty/clean consumption, to the costs for the economy of producing the types of consumption and the environmental awareness (measured by the elasticities of substitution between the two consumption types).

It is worth noting that these three variables are deeply related to the traditional arguments often cited to explain the EKC. Substitution of clean consumption with dirty consumption "measures" the composition effect, the change in the structure of the economy that gradually increases activities (consumption in this model) that produce less pollution. Pollution/abatement intensity of dirty/clean consumption "measures" the technique effect: the dirty and obsolete technologies are replaced by upgraded new and cleaner technology, which improves environmental quality. At the same time, since more resources are devoted to the development of cleaner technologies, the economy can afford the cost of a clean consumption. What's relevant in the results of this model, is that economic growth *per se* does not produce these effects. Hence, there is no inverted U-shaped relationship between economic growth and environmental degradation.

It is obvious that an increasing demand for a better environment induces structural changes in the economy that tend to reduce environmental degradation: on one hand, increased environmental awareness and 'greener' consumer demand contribute to shift production and technologies toward more environmental-friendly activities; on the other hand, they can induce the implementation of enhanced environmental policies by the government (such as stricter ecological regulations, better enforcement of existing policies and increased environmental expenditure). However, the linkage from income growth to alleviation of environmental deterioration is not automatic.

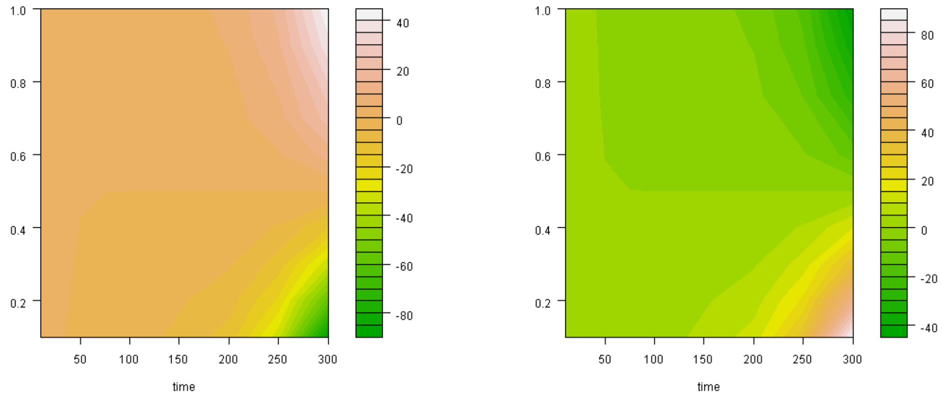
5 Environmental awareness, costs and pollution-abatement intensities

What does it happen to pollution when $\frac{\alpha\sigma}{z}$ and $\frac{\beta\theta}{h}$ are not fixed but vary between zero and one? The answer to this question is illustrated in figure 5: it contains two level plots with the areas between the levels filled in solid color, identifying the values of P. Figure 5a shows what happens to P as $\frac{\alpha\sigma}{z}$ increases, ceteris paribus; figure 5b shows what happens to P as $\frac{\beta\theta}{h}$ increases, ceteris paribus. A key showing how the colors map to pollution values is shown to the right of the plot.

Figure 5 shows that the pollution path depends on the interaction of all these parameters.

P_0	K_0	$\frac{\alpha\sigma}{z}$	$\frac{\beta\theta}{h}$	γ	ρ	A	δ
10	1	0-1	0-1	0.1	0.04	0.12	0.06

Table 5: Baseline parameters for figure 5.



(a) (b)

Figure 5: Pollution over time with varying $\frac{\alpha\sigma}{z}$ (a) and $\frac{\beta\theta}{h}$ (b)

As mentioned before, σ and θ measure how consumers' utility change when dirty or clean consumption change; they gives a measure of consumers desire for a better environment, since if we care for the environment and we are aware of the damages a dirty consumption causes on the environment we should gain more utility if a greater proportion of clean consumption is performed; increasing environmental awareness implies a θ greater than σ; in other words, a θ greater than σ reflect the demand for a better environmental quality (i.e. environmental awareness); demand for a better environment induces changes in the distribution of consumption between dirty and clean goods in favor of the clean goods and this tends to reduce environmental degradation. A very high σ and a corresponding low θ mean that people do not care for the environment and consume dirty polluting commodities. On the contrary, a low σ and a corresponding high θ mean that consumers care for the environment and prefer clean commodities.

Environmental awareness tends to increase with income: when a country achieves a sufficiently high standard of living, people attach increasing value to environmental amenities. After a particular level of income, the willingness to pay for a clean environment rises by a greater proportion than income (Roca, 2003). This will be reflected through defensive expenditures, donations to environmental organizations or choice of less environmentally damaging products. Thus, rich people value the clean environment and preserve it. Generally, it is recognized that income elasticity of environmental quality demand and resource goods is in excess of unity, i.e., clean environment and preservation are luxury goods.

Many EKC models have emphasized the role of income elasticity of environmental quality demand and this elasticity is often invoked in the literature as the main reason to explain the reduction of emission level. An adequate explanation of observed EKC relationships for some pollutants, are consistent with the high-income elasticity of environmental quality demand. Poor people have little demand for environmental quality, however, as a society becomes richer, its members may intensify their demands for a more healthy and cleaner environment. The consumers with higher incomes are not only willing to spend more for green products but also create pressure for environmental protection and regulations. In most cases where emissions have declined with rising income, the reductions have been due to local and national institutional reforms, such as environmental legislation and market-based incentives to reduce environmental degradation.

The demand for a better environment depends on several factors and not only on income:

market mechanisms (i.e. prices of the clean goods), education and information accessibility, regulation and others' behavior (friends, parents, partners, media).

In the model developed in this study, environmental awareness alone is not sufficient to guarantee a decreasing pollution path. We must take into consideration also the costs for society and the pollution/abatement intensities of two types of consumption. Thus, we have a counterintuitive result that pollution increases even when the proportion of clean consumers is relatively high compared to the proportion of dirty consumers.

This is very easy to see if we inspect equation (27),

$$P(t) = \left[P_0 - I\left(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h}\right)\right] e^{-\gamma t} + I\left(\frac{\alpha\sigma}{z} - \frac{\beta\theta}{h}\right) e^{(A-\delta-\rho)t}$$

It is possible to have a U-shaped pollution path (i.e. $\frac{\alpha\sigma}{z} > \frac{\beta\theta}{h}$), even if $\sigma < \theta$: this happens when the marginal damage of dirty consumption is high (i.e. $\alpha > \beta$) and the social cost of clean consumption is greater than that of dirty consumption (i.e. $h > z$).

6 Conclusions

Environmental pollution is generated either through the production process or through the consumption of goods and services. There is a need to concentrate on the impacts of consumption activities on environmental pollution rather than those of production activities since production is induced mainly by consumption and few studies have examined this so far.

This paper investigated the relationship between economic growth and pollution focusing on the impact of consumption behavior on the environment. Different assumptions on the way consumers value the environmental quality lead to very different results. This paper employed a simple AK endogenous growth model and analyzed the consequences in terms of economic growth and pollution of having two types of consumption behavior: a clean one (pro environment) that abates pollution and a dirty one that increases pollution, where pollution does not enter directly the utility function. In fact, consumers do not always observe pollution *per se* but rather its impact on the environment; sometimes, even the effect of pollution on the environment is not "observable" immediately. This is true if we think, for instance, to the depletion of the ozone layer; and it is also true if we think about climate change (which is a long-term change whose effects on the environment are, fortunately, not fully evident yet).

The results showed that there is no environmental Kuznets curve relationship between economic growth and pollution. The path of pollution over time crucially depends on the pollution intensity of dirty consumption and abatement intensity of the clean consumption, on the costs for the economy of producing the types of consumption and the environmental awareness (measured by the elasticities of substitution between the two consumption types).

Regarding this latter aspect, we have found that only under some specific conditions an increase in the proportion of clean consumption reduces pollution. This result requires the costs of producing environmental differentiation to be sufficiently low. However, depending on the values that the relevant parameters (i.e. cost of product differentiation, pollution intensity of dirty consumption and efficacy of abatement activity of clean consumption) take, the level of polluting emissions can grow with environmental awareness.

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