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THE RELATIONSHIP BETWEEN ENVIRONMENT AND GROWTH: A MODEL WITH EXTERNALITIES DUE TO POLLUTION

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ABSTRACT:

The goal of this paper is to analyse the relationship between economic growth and environment. We will take into account the neoclassical growth model and we will include the negative externalities on production derived from pollution. In this case, we will be able to study how the basic conclusions of the neoclassical growth model change. The results justify that opposite measures to those defended by traditional neoclassical models must be introduced to improve long term per capita income. These policies must be coordinated with the environmental policy that reduces the negative effects derived from the pollution externalities.

RESUMEN:

El objetivo fundamental que perseguimos en este trabajo es el de analizar la relación entre crecimiento económico y medio ambiente. Tomaremos como base el modelo de crecimiento neoclásico en el que incorporamos la existencia de externalidades negativas sobre la producción como consecuencia de la contaminación. Ello nos permitirá estudiar como cambian las conclusiones básicas del modelo neoclásico de crecimiento ante la presencia de dichas externlidades: un límite adicional al crecimiento económico y al nivel de renta per cápita alcanzable a largo plazo. Estos resultados justifican la aplicación de una política macroeconómica que, en general, deben tener un signo contrario al enfoque neoclásico tradicional y que debe coordinarse con una necesaria política medioambiental que atenue los efectos negativos de las externalidades por contaminación.

1.- INTRODUCTION

Economists have traditionally tried to answer the following question: Why are some countries rich and others remain poor? The answer is not easy and the different schools of thought have developed their own models pointing out the main factors explaining growth. The various approaches have been interested in analysing growth evolution and ascertaining the possibility of modifying the behaviour of some variables to improve growth and increase convergence among countries.

In Neoclassical models, mainly based on Solow (1956) and Swan (1956)[1], the long-term per capita income is exogenously determined by the technological progress. In this case the policy maker has a limited capacity to design measures addressed at modifying the long-term exogenous growth. His measures can only achieve a level effect, that is, they can only modify the long run steady state per capita income level.

In contrast, more recent approaches within the New Growth Theory (Romer, 1986, 1987 and 1990, Lucas, 1988, Rebelo, 1991, Grossman and Helpman, 1991, among others) have developed models in which the long-term growth rate is positive; the main factors driving growth in these models are specific endogenous variables (technical progress, public capital, human capital and so forth). In this framework, fiscal variables, the behaviour of human capital and R&D activities, among others, are relevant factors that can affect growth and therefore the policy-maker may influence growth by means of modifying them. In this way, he can cause a growth rate effect and not only a level effect in the long run.

In addition, during the last decades, economists have been interested in analysing the relationship between environment and the growth process. Traditionally, economists have not paid much attention to growth effects on environment. After the Great Depression it was necessary to create employment and the way to achieve this goal did not seem important. It was necessary to reach a high growth rate and capital accumulation seemed to be the best way. This accumulation often implied environmental problems. But employment was considered more important.

On the other hand, this relationship is not easy to determine. There are two opposite effects. First, there is a short-run positive impact because the use of environment as a productive factor can lead to an improvement in production and in economic growth. In the other hand, a negative effect appears when this short run growth process implies the destruction of natural resources that are difficult to renew. In this second case, the environmental exploitation leads to a lack of resources in the future and, therefore, economic agents will have an additional constrain to the growth process in the long run. That is, sustainable development is going to be negatively affected. An intermediate position can be achieved when the intertemporal negative effects of production on natural resources are considered and, in order to avoid them, the society explicity assumes the need of taking care of

[1] These initial contributions were completed and extended by Cass (1965) and Koopmans (1965) following the intertemporal optimization approach by Ramsey (1928).

the environment. This would imply that natural resources, capital and other productive factors have to be used in a different way. New production processes would have to be created, and this could favour new capital formation that could be used to maintain growth process in the long run.

The main goal of this paper is to analyse the relation between economic growth and environment. We will try to do it by taking the neoclassical approach to economic growth model as a reference but considering explicity the existence of negative externalities on production as a consequence of the use of natural environment. Previously, we are going to revise briefly how this relationship has been traditionally considered in the especialized literature.

2.- ECONOMIC GROWTH AND ENVIRONMENTAL QUALITY

The relationship between environment and economic growth has been considered by the economist since the works of Classical authors. In this way, Smith and Malthus, among others, stated that environmental resources are one of the factors that affect economic growth (O'Brian, 1975, p. 296). More recently, and since the work of Schumpeter (1939, 1950), this issue has been developed considering explicity the role of the firms. Several studies in this field have tried to show that the economic growth process implies opposed effects when environmental costs are considered. For instance, consumers may accept higher environmental costs if prices are lower. This is the reason why some economists state that the relevant variable is growth and not prices, as microeconomic studies had considered (Booth, 1998, p. 2).

In general terms, two trends in literature can be observed (Beltratti, 1997, p. 29-30):

1.- Literature that analyses the role of the environment resources (Dasgupta and Heal (1979) and Fisher (1979), among others). The conclussion is that the scarcity of resources is not a relevant problem in the next future for two reasons. First, it is possible to replace scarce resources (Dasgupta, 1993) and the prices system will indicate which resources cannot be used. Second, it is necessary to include the role of energy. If the latter is not limited, it is always possible to obtain resources from those that present a decreasing quality.

2.- Studies that consider that the exhaustion of natural capital and pollution are obstacles to growth (Keeler et al (1972), Plourde (1972), d'Arge and Kogiku (1973), Forster (1973), Asako (1980), Becker (1982), Heal (1982) y Tahvonen and Kuuluvainen (1993), among others)[2]. The behaviour of pollution has been introduced in these models in two ways: as a stock, taking into account the environmental quality, and as a flow, considering the emission level. The conclusions reached are not unanimous, but in general terms there is the agreement that the pollution effects on growth depend on the initial state of the country. So, the richest countries could afford to introduce technology aimed at reaching a steady-state with better environmental conditions. On the other hand, less developed countries would prefer more contaminating production processes that, on

[2] A survey of the literature can be found in Toman et al. (1995).

the other hand, would allow them to increase the production of consumption goods (Toman et al., 1995, p. 151).

In this sense, it is necessary to clarify the steady-state concept. The use of the steady-state term in this kind of literature is different to its use in the Neoclassical models. Following Daly (1991), such situation leads to a global economy balance taking into account the existing environmental resources. Therefore, in this case, it is necessary to take into account and determine the impact of the economic activity on the ecosystem. Knowing the losses derived from the wrong use of resources is more necessary than analysing their consumption.

Relevant literature has appeared to study the effects of several environmental indicators on per capita income (Holtz-Eakin and Selden (1992), Hettige, Lucas and Wheeler (1992), Grossman and Krueger (1993), Grossman (1994), Seden and Song (1994), Shafik (1994) and Xepapadeas and Amri (1995), among others). The conclusions reached are different. For instance, Grossman and Krueger (1993) state that there is not evidence that economic growth negatively affects environmental quality. Hettige, Lucas and Wheeler (1992), state that low income countries show a trend to increase the industrial emissions in relation to GDP and industrial production. Other works consider that economic growth initially implies an environmental damage although its quality improves in the long run. This fact is called environmental Kuznets curve (Beltratti, 1997, p. 30).

Together with the empirical analysis, theoretical economic growth models that include environmental effects have also been developed. We can consider two groups: neoclassical and endogenous growth models.

Neoclassical growth models are based on Solow model and the variables determining long run growth are exogenous. The policy-maker does not have the possibility to influence growth by modyfing such variables. Stiglitz (1974) introduced the hypothesis in the production function that resources are exhaustible, so there is not an incentive to drive the resources from one activity to another. Hartwick (1974) developes this possibility but he considers that savings are not constant and are equal to the income obtained from natural resources.

Endogenous growth models consider that the variables explaining long run growth are endogenous, so the policy-maker can design measures to influence the economic growth process. In this field Krautkraemer (1985) developed an economic growth model that extends Dasgupta and Heal's (1974) introducing the resources in the production function and in the utility function. From his point of view, environment will improve only if economic agents preferences favour the environment quality and if there is sufficient substitution between the flow of resources and the capital stock. Bovenberg and Smulders (1995) introduce environmental resources in the production function, being a exhausted but renewable resource. The conclusion is that environmental behaviour reduces long-term growth.

Michel and Rotillon (1992) supposed that production increases pollution stock, generating negative externalities. So, only in the case that marginal utility of consumption increases with a higher pollution rate, it would be a social optimum to reach a permanent growth.

Finally, we have to consider the literature that includes the innovation process as a relevant variable. In this sense, the World Bank (1992), states that the efforts to introduce technologies less pollutant have reduced air pollution and improved water quality in several countries. On the other hand, Aghion and Howitt (1998, p. 152) state that the analysis of the relation between pollution and growth is necessary to follow Schumpeter's model and technological innovation plays a relevant role in it.

In the following section an economic growth model will be developed introducing environmental externalities and their effects on growth will also be considered. The appearance of this externalities can be analysed by showing the relationship between economic activity and natural environment. This relationship can be represented, in general terms in *figure 1*. In this figure we have represented the traditional relationship between households and firms at a macroeconomic level. Households consume the goods and services that have been produced by firms using labour and capital owned by households. This can be considered as the simplest view of the economic activity. In fact, the neoclassical approach to economic growth, only takes into account this relationship between firms and households when they try to determine what are the main factors explaining economic growth. But when we consider that the economic activity of both, firms and households, is developed within the natural environment, other relationships appears that could affect the results of the economy in

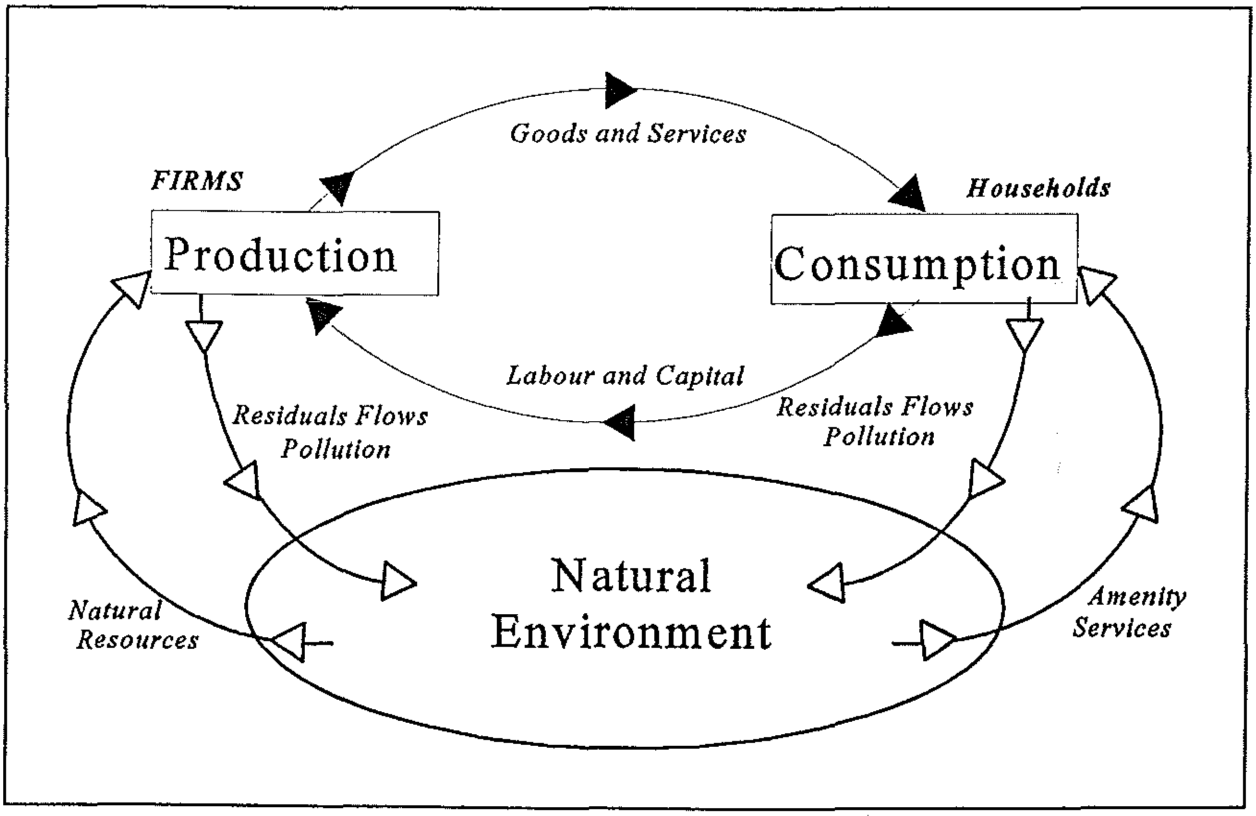

Figure 1. The relationship between the economic activity and the natural environment.

terms of production and social welfare. For example, firms use natural resources as an input in the production function but also generate residuals flows that decrease the *quality* of Natural environment. These residual flows together with those generate by households have a direct negative effect on social welfare, but also have a negative effect on production posibilities that use environment resources as an input.

These negative effects and relationships between economic activity and natural environment have been broadly studied mainly at a microeconomic level to show that the absence of a free market price system for the use of natural environment (in the two directions as an input and as a receipt of residual flows) explains that the final situation is not efficient at a social level, that is, there is an excesive use of the environment, mainly from the residual flows that can exhaust the environmental posibilities to be used in production and by households.

We are going now to show how these negative externalities can be introduced in the neoclassical approach to economic growth, and how Government can act in the economy to reduce these externalities and improve social welfare[3].

3.- AN ECONOMIC GROWTH MODEL WITH ENVIRONMENTAL EXTERNALITIES

As it has been said in the previous section, there is a relationship between the economic growth process and environmental aspects. When the dynamic process in an economy is considered, it is necessary to take into account that the long-term economic growth process is affected by several environmental restrictions, that can be determined by the following aspects (Siebert, 1998, pp. 239-240):

1.- A number of pollutants are accumulated by environmental systems and remain for several years.

2.- Pollutants could cause irreversible damage to the ecological equilibrium and the economic agents cannot change this situation.

3.- Pollutants can also influence the capability of the environmental systems to regenerate over time.

4.- The capital stock, a given sectorial structure and the technology are passed on the next generation. Therefore, the problems caused by these elements are transmitted to future generations.

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[3] We will consider only the relationship between environment and firms in order to simplify the analisys assuming that households keep a constant saving rate.

All these elements are relevant in order to analyse the long-term dynamics and they will be considered in the development of the growth model, taking into account the relations between the productivity sector and the environmental quality. The model developed is a Neoclassical one and the negative externalities derived from environmental pollution will be introduced in the production function.

In order to introduce such externalities we must consider that per capita production depends on the total factor productivity in each instant of time. This productivity factor includes all factors that affect production capacity given a level of productive factors. The latter depends, among others, on the technology and the environmental quality, that is the environmental capacity to absorb the pollution generated by the production process. In this sense, it is assumed that if the environmetal quality is introduced in the growth analysis, then a lower pollution capacity absortion by the production process, will reduce the total production capacity by the economy. The reason is that environment plays a double role. Firstly, it offers the natural resources to the production process. Secondly, worse environmental quality implies worse natural resources for the production process[4].

We assume then, that the global factor productivity of the economy, A, is a relation between the global state of the technology or knowledge state (T) and the environmental capacity to assimilate pollution (P):

$$A = T^{\phi} P^{\gamma} \qquad (1)$$

where ϕ and γ are the corresponding elasticities. We will suppose now, following the Solow growth model, that T grows at a constant rate x (*exogenous technical progress*). On the other hand, it is supposed that P depends negatively on total economic activity (production). This total economic activity will be measured indirectly by the total use of productive factors, that is by the intensity of the use of the capital per worker ratio, k, in the productivity process:

$$P_t = p(k_t) \qquad (2)$$

We assume, that such relationship shows a simple negative lineal form:

$$P_t = a - b \cdot k_t \qquad (3)$$

This relation is shown in *figure 2*. When capital is not used, P (*environmental quality*) reaches its highest level a, and the system becomes congested when the capital is used with an intensity m.The increase of the negative effect of the intensity of the use of capital on P, is mesured by b. Taking into account such congestion rate, equation (3) can be written as:

$$P_t = b(m - k_t) \qquad (4)$$

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[4] The different roles played by the environment in the productivity process are analysed by Common (1996). The positive role played by the environment on the economic agents utility is not considered in this model. This question has been developed by Siebert (1998, pp. 241-254).

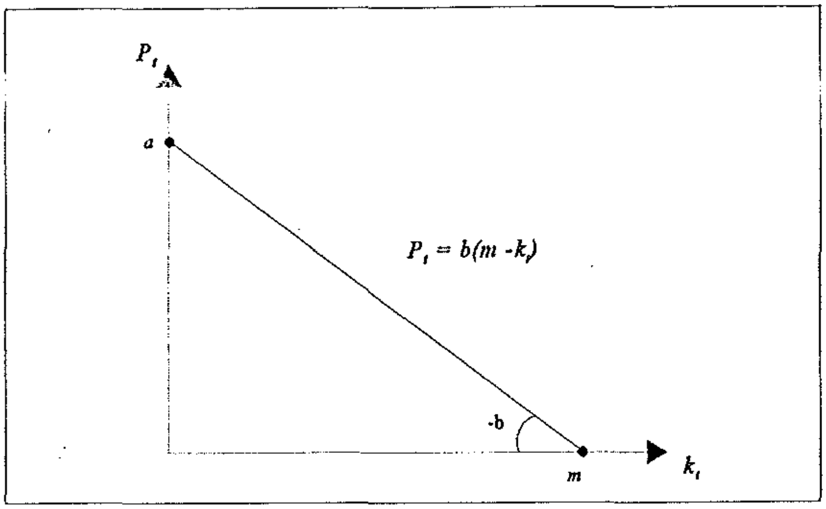

Figure 2.

or

$$P_t = a(1 - \kappa_t) \tag{5}$$

being $\kappa = k/m$, the indicator of the intensity in the use of capital measured in relation to the maximum level of congestion m.

The global productivity indicator (A) obtained from (1) and (5) can be introduced in the Solow Neoclassical growth model in order to analyse how the main conclusion of the original model changes when environmental quality is taken into account[5].

We can start then from the Cobb-Douglas production function used in the original Solow model where the technical progress (T) is neutral *á la* Harrod, $\phi = 1$ and where we consider explicily the relation between environment and total factor productivity. In this way, per capita income can be written as:

$$y = TP^{\gamma}k^{\beta} \tag{6}$$

where $y = Y/L$ income (Y) per worker (L)[6], and $k = K/TL$ is the capital stock (K) per efficient worker (TL). Introducing (5) into production function (6), we obtain:

$$y = Ta^{\gamma}(1-\kappa)^{\gamma}k^{\beta} \tag{7}$$

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[5] We use the Solow growth model with constant saving rate because we think that this restrictive assumption permit us to simplify the analysis when we are interested mainly in the long term solution of the neoclassical growth model.

[6] We can identify per capita income and income per worker under the neoclassical assumption about real wage flexibility that ensures full employment and considering that all the population is part of the labour force.

that is, a production function in which the negative externalities by pollution $(1-\kappa)^{\gamma}$ are included. Considering that $\kappa = k/m$ the production function per worker, can be finally written as:

$$y = Tm^{\beta}a^{\gamma}(1-\kappa)^{\gamma}\kappa^{\beta} \tag{8}$$

Per capita income depends on three types of factors: technological (T, β), productive factors used (k), and environmental ones (m, a, γ). In this sense, a higher environmental self-capacity to regenerate, a, a higher congestion level, m, and a lower dependence on productive system of natural environment, γ, implies a higher production per worker[7]. So, environmental policies, i.e. investment in technologies less pollution-intensive, ensures a positive effect on per capita production level.

Technological improvement (T), that is technological progress x, will have a positive effect on per capita production, while a higher capital utilisation (k) implies an ambiguous total effect on per capita production. There will be a direct positive effect determined by its elasticity β and an indirect negative effect on production because a higher capital utilisation will imply higher pollution and less environmental capacity to regenerate, worsening the environment quality and the economy productive capacity. This negative effect is included in the negative externalities $(1-\kappa)^{\gamma}$, that depend on γ.

On the other hand, the production function also shows that per capita income dynamics depends on technical progress (x) and on the capital stock dynamics κ. Similar to the Neoclassical model, capital accumulation can be obtained by considering the equilibrium condition ($S=I$) in the economy[8]

$$\dot{K} = sY - \delta K \tag{9}$$

and considering that:

$$\dot{k} = \frac{\dot{K}}{TL} - k\left(\frac{\dot{T}}{T} + \frac{\dot{L}}{L}\right) \tag{10}$$

and:

$$\dot{\kappa} = \frac{\dot{k}}{m} \tag{11}$$

the dynamics of the economy can be expressed as:

$$\dot{\kappa} = sB(1-\kappa)^{\gamma}\kappa^{\beta} - \kappa(n+x+\delta); \quad B = m^{\beta-1}a^{\gamma} \tag{12}$$

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[7] $\partial y/\partial a = \gamma(y/a) > 0$; $\partial y/\partial \gamma = y \cdot \ln[a(1-\kappa_t)] < 0$; $\partial y/\partial m = \beta(y/m) + (\kappa/m)[\gamma y/(1-\kappa) + \beta y/\kappa] > 0$

[8] We follow here the Solow model considering that savings are a constant proportion of income $S=sY$, and that depreciation is a constant rate of capital stock (Depreciation = δK). Then, the equilibrium condition in a closed economy without Public Sector is S=I

The normalized capital stock per worker growth rate is from (13):

$$\frac{\dot{\kappa}}{\kappa}=sB(1-\kappa)^{\gamma}\kappa^{\beta-1}-(n+x+\delta) \qquad (13)$$

This equation represents the fundamental dynamics of the growth model. Although (13) has not an analytical solution, we can analise its long-term behaviour by using *figure 3*. In that figure, it can be observed that κ (capital per efficient worker measured in relation with the saturation point), is defined between *0* and *1* and that the economic dynamics converges in the long-term to a steady-state κ^* that, in general terms, will be below that corresponding to the maximum growth rate κ_1 and maximum per capita income rate κ_2. The reason for such long term results is that the externalities on environment are considered.

From our anlysis it is possible to consider some differences between our model and the traditional neoclassical and endogenous growth models. If we consider first the neoclassical model, the main discrepance is the explicit consideration in our model of the externalities derived from pollution, $\gamma>0$. In traditional neoclassical models these effects are not considered, $\gamma=0$, that is, they assume that the relationship between productive system and environment is only based in the use of natural resources in production. In addition, they assume that there are perfect competitive markets, and that ensures

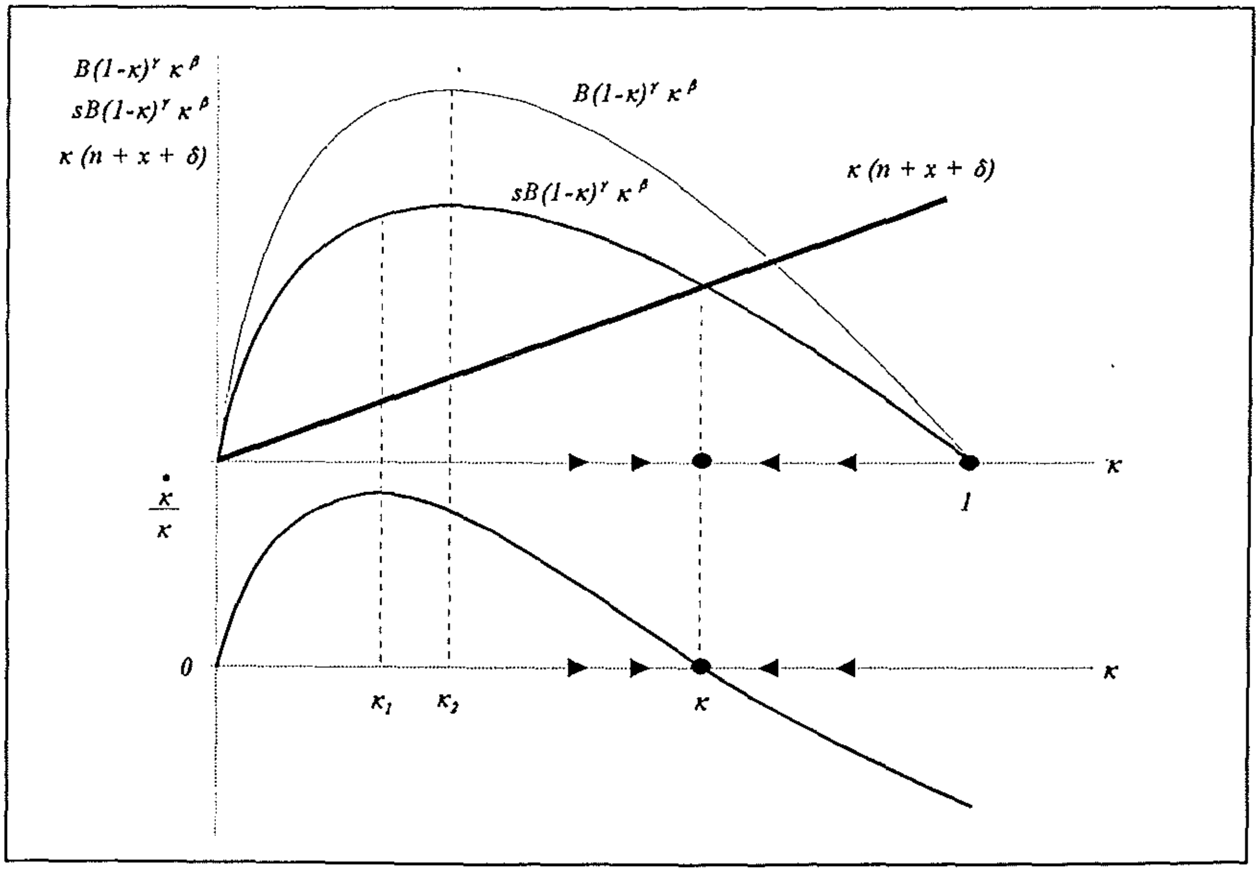

Figure 3.

the achievement of an optimum use of the environment. In fact, in the neoclassical model the use of natural resources is similar to the labour factor utilisation.

The model previously developed constitutes, then, a simple generalization of the neoclassical growth models that permits the consideration of negative externalities due to pollution. This can be shown when we normalize the per capita production function of the neoclasical growth model - without negative externalities due to pollution- by m:

$$y=Am^{\beta}\left(\frac{k}{m}\right)^{\beta} \tag{14}$$

or

$$y=Am^{\beta}\kappa^{\beta} \tag{15}$$

that is equal to the equation used in the model with negative externalities (equation (8)) when the global factor productivity does not depend on environmental factors $A=T$[9]. Now, we can compare both models taking into account that when $\gamma=0$ in equation (12) both models are identical. *Figure 4* represents the dynamics of both models jointly. Long-term capital stock achieved in the model with externalities, κ_2*, is lower than the long term capital stock achieved in the neoclassical model, κ_1*, depending such difference on the value of the externalities γ and on β[10]:

$$\kappa_2^*=\kappa_1^*\cdot\left(\frac{1}{a\left(1-\kappa_2^*\right)}\right)^{\frac{\gamma}{\beta-1}} < \kappa_1^* \tag{16}$$

Considering this result, we can reach some conclusions in the discrepances between both models. First, the capital stock in neoclassical model does not achieve any rate of saturation. For that reason, the environment does not represent a restriction to the long-term economic growth[11]. The opposite

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[9]When we introduce the externalities in our model we suppose that the global factor productivity depends on the technology state and environmetal factors: $A=T^{\phi}P^{\gamma}$. As it is known, in the neoclassical model does not consider these environmental factar, that it γ=0, and if we suppose that ϕ=1, we will obtain the global factor productivity in the neoclassical approach $A=T$.

[10]The capital stock κ_2 has been normsalised to get the values between 0 and 1, and then:

$$\left(\frac{1}{a\left(1-\kappa_2^*\right)}\right)^{\frac{\gamma}{\beta-1}}<1$$

[11] In the neoclassical approach, the limits to long term economic growth are due to diminishing returns to capital factors.

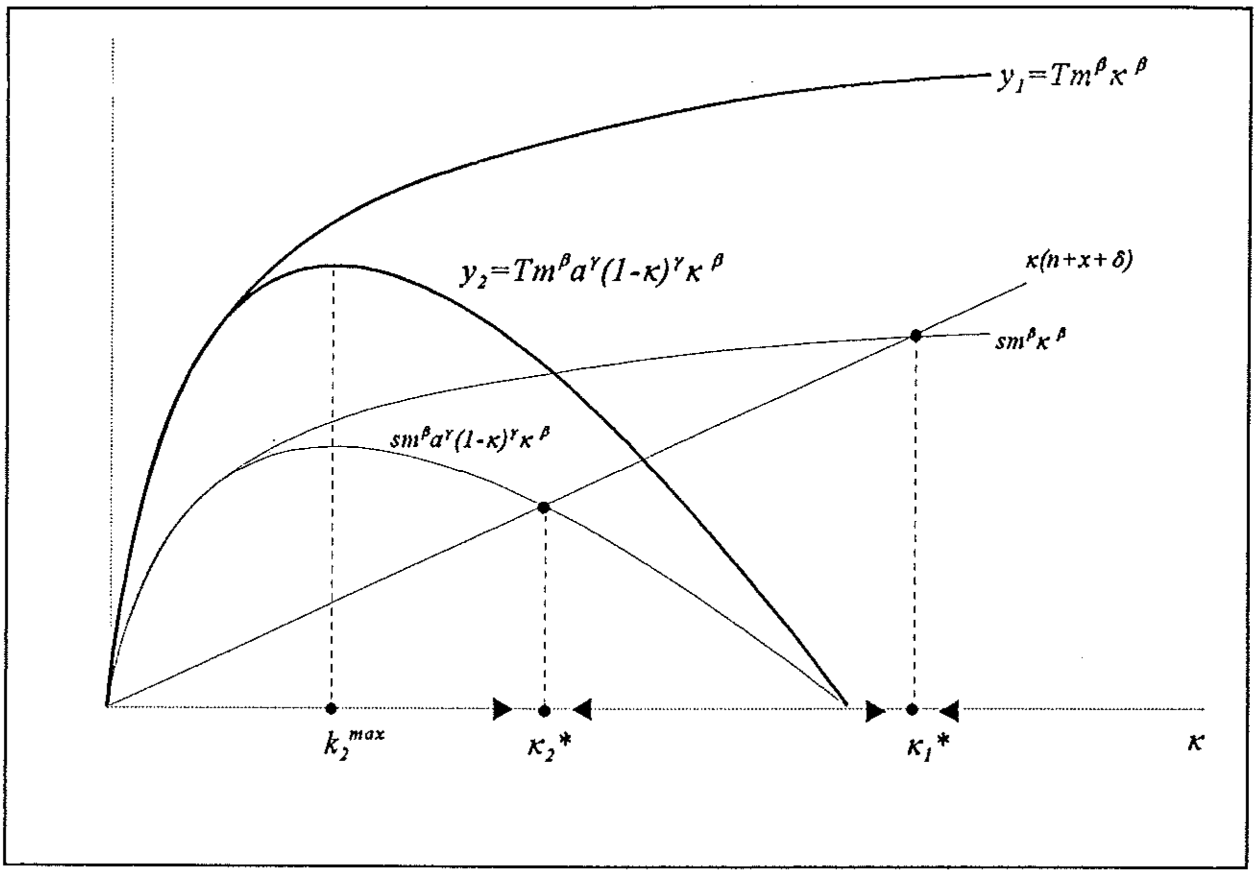

Figure 4.

occurs when we introduce the environmental externalities, being then necessary to introduce an environmental policy to reduce these negative effects on growth. Second, the long-term per capita income rate it is reduced by pollution externalities, and such reduction depends, again, on γ and β values[12]:

$$y_2^*=y_1^*\cdot\left(\frac{1}{a\left(1-\kappa_2^*\right)}\right)^{\frac{\gamma(1+\beta)}{\beta-1}}<y_1^* \tag{17}$$

Finally, we also have to consider the results on the convergence process among countries. In general terms, when the pollution externalities are introduced in the neoclassical model, the

[12]Again this result is achieved because the capital stock κ_2 has been normalised to take values between 0 and 1, so:

$$\left(\frac{1}{a\left(1-\kappa_2^*\right)}\right)^{\frac{\gamma(1+\beta)}{\beta-1}}<1$$

convergence among countries is accelerated as a consequence of the negative externalities on production[13].

We can consider now the differences between the endogenous growth models and the model with negative externalities by pollution. As it is well known in the endogenous growth models there are constant capital returns and if this assumption is introduced in the model with negative externalities, β=1, a similar equation to (8) and (15) is obtained:

$$y = Tm\kappa \tag{18}$$

This equation shows that the endogenous growth model type *AK* can be considered as a special case of the negative externalities model on environment, when in the latter case is assumed that $\beta=1$ and $\gamma=0$. When it is considered that $\gamma\neq 0$, the basic conclusions of the endogenous growth model are strongly changed. In that situation, long term endogenous growth desapears because the capital stock κ tends to a steady state at long-term. This result is achieved automaticaly when the assumption $\beta=1$ is introduced in the basic equation of the environmental growth model (12):

$$\frac{\dot{\kappa}}{\kappa} = sa^{\gamma}(1-\kappa)^{\gamma} - (n+x+\delta) \tag{19}$$

The dynamics of this *AK* endogenous growth model including the pollution externalities is considered in *figure 5*, assuming that $\gamma>1$. In that case, the model converges to a steady state κ^* that corresponds to the null growth rate:

$$\kappa^* = 1 - \frac{1}{a}\left(\frac{n+x+\delta}{s}\right)^{\frac{1}{\gamma}} \tag{20}$$

In this situation the conclusions about conditional convergence of the original AK model are changed. As it is known, different to Solow model, *AK* model states that there is not conditional convergence because of the constant returns to capital factor. In the model developed now , in spite that it que is assumed that β=1, the existence of negative externalities implies that the total capital returns are diminishing, so the conditional convergence conditions appear again.

We can conclude that although it is assumed that β=1, the pollution externalities impose a limit to the long-term economic growth. Endogenous growth will only appear when the total returns on capital are constant, that is when in spite of pollution effects, direct returns are sufficiently high to compensate such negative externalities. Even in the case that there is not exogenous technical progress, it is necessary to achieve positive externalities enough high to compensate the pollution negative externalities (such as learning by doing, human capital, public capital ...) on productive

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[13]The convergence in the neoclassical models is due to diminishing returns on capital. In the model developed here such returns are diminishing and, indeed, negative when the capital stock is over a certain value (κ_2 in *figure 3*), and for that reason the initial capital stock differences in homogenous countries are quickly eliminated.

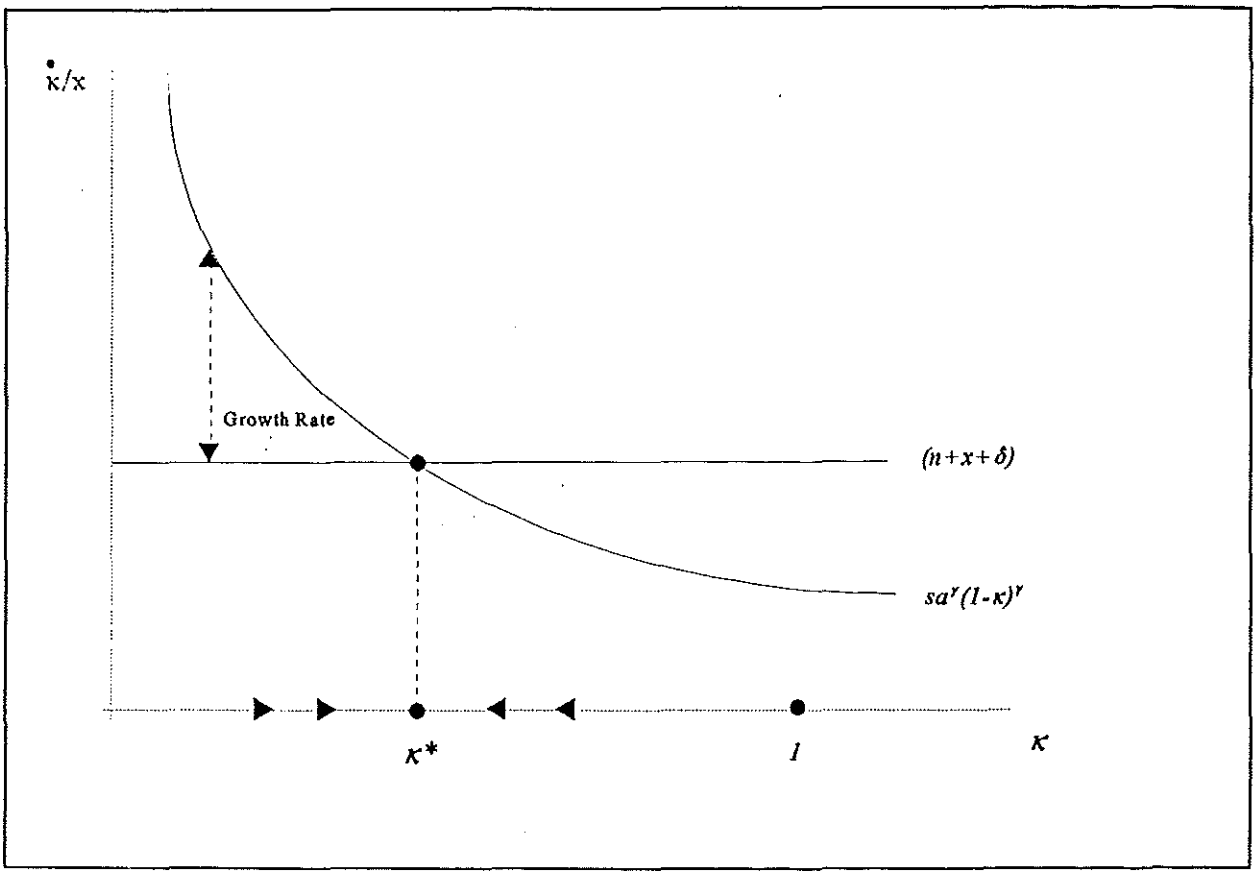

Figure 5.

capacity of the economy. So, the condition for the existence of an endogenous growth type *AK* is[14]:

$$\beta=1+\gamma \tag{21}$$

5.- ECONOMIC POLICY IMPLICATIONS

In this section we are going to consider some economic policy implications derived from the model developed in previous sections. In this model there are two ways to try to maximize long-term

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[14] This condition is obtained from the long term solution of the dynamics equation (13), that implies that in the steady state the capital stock growth rate is constant and therefore:

$$\frac{d\,(\dot{\kappa}/\kappa)^*}{dt}=0$$

The verification of this condition requires either $(\dot{\kappa}/\kappa)^*=0$, or $\beta=1+\gamma$. In the later case, $(\dot{\kappa}/\kappa)^*$ can achieve any value and it is possible to obtain endogeneus growth. In other case, the growth rate is cero in the long-term and, therefore, there is exogenous growth.

per capita income[15].

First, the policy-maker could modify the relationship between capital stock and environmental quality $(\Delta a, \Delta m, \nabla\gamma)$. In this sense, enviromental policies as subsidy to R&D projects with less pollutant technologies, reductions of pollutant emissions, introduction of penalties to pollutant agents....would approach the steady-state to maximum income rates. The necessary increase of taxes to finance such subsidies will reduce the positive efects of the measures. To analyse the global effect on growth, it is necessary to introduce the public expenditure on production function being of interest in future developments of the model.

Second, the traditional measures on savings, population growth rate and technical progress, have also an important role to improve long term per capita income. These policies would be addressed to reduce the long-term capital stock, as is represented in *figure 6*. In this sense, these policies differ

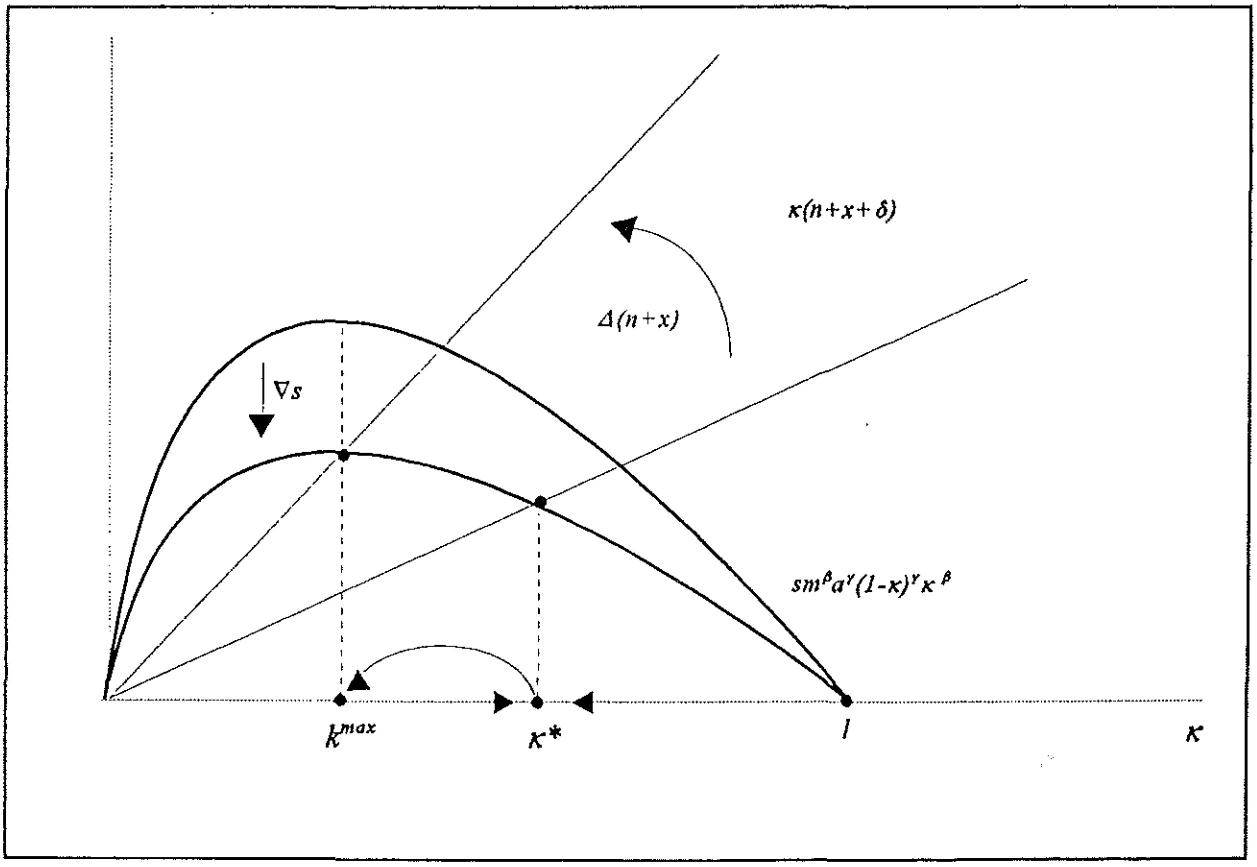

Figure 6.

[15] Our constant saving rate assumption avoids an economic policy analysis based on the maximisation of the households welfare that depends on consumption and environmental use. For that reason, we are going to simplify the economic policy analysis assuming that the average saving rate is equal to the saving rate that maximises the consumers long-term welfare. For that reason, we can assume that economic welfare depends only on long-term per capita income rate and its growth rate.

from those proposed by the traditional neoclassical model. Therefore, an increase in savings reduces economic growth in the model. The reason for that situation is that higher savings imply higher investment, so new physical capital is introduced in the production process, and such capital can be pollutant, and therefore cause negative effects on growth. In that case, policies that encourage saving and are not suitable to improve growth. But the problem in this case is that policies that encourage consumption probably can also have negative effects on growth, because a higher demand stimulates firms to increase their production and use more natural resources, worsening environmental quality.

On the other hand, it is also necessary to introduce the double role of technology in this process because, although the technological progress is the only factor that allows an improvement of long term per capita growth rate, not all kinds of technical progress will have the same results on the productive capability of the economy. In our model, as in others, technology has a positive direct effect on growth. But additionally, if the new technology introduced in the production process is less pollutant, then a indirect positive effect on growth will also be present. So it is necessary to design a technological policy that encourages the introduction of such technologies. Therefore, the technology could improve or reduce growth, depending if it is more or less pollutant.

Concluding with the economic policy analysis of our model, we have that, in general terms, and in addition of the necessity of an environmental policy, traditional policies must be designed in the opposite way to recommended policies derived from the neoclassical model. Such traditional policies must be considered as a necessary complement of the environmental policies, because the latter cannot achieve always the maximum long term per capita income rates. In fact, although the three environmental policies considered ($\Delta a, \Delta m, \nabla\gamma$) improve the long-term income rate, only when $\nabla\gamma$ -reduction in production dependence on natural environment-, it is possible to approximate long-term per capita income to its maximum level. In the endogenous growth models case, it is possible to achieve positive growth rates only when such dependence is cero or when the negative externalities are compensate with positive ones.

6.- CONCLUSIONS

In the previous section we have considered the relationship between environmental factors and growth. We have considered some characteristics and the literature on such relation. A growth model is developed introducing the negative externalities derived from a productive capacity when the environmental problem is considered. The main conclusion of the model is that opposite measures to those defended by the traditional Neoclassical models must be introduced to improve long term per capita income, mainly those directed to reduce savings. Such traditional policies will have to be accompanied with environmental policies in order to reach the maximum long-term per capita income level. In the same way, it is necessary to consider the role of the technological policies because the introduction of less pollutant technologies can reinforce long-term economic growth, and in spite that all environmental policies mentioned in the paper improve long-term per capita income, the optimal environmental policies are those addressed to reducing the dependence of the productive activity on natural environment and those aimed at incentivating the use of technologies less pollutant.

References.

Aghion, P. and Howitt, P. (1998): *Endogenous Growth Theory*, The MIT Press, Massachusetts.

Asako, K. (1980): "Economic Growth and Environmental Pollution under the Max-min Principle", *Journal of Environmental Economics and Management*, 7, pp. 157-183.

Becker, R. A. (1982): "Intergenerational Equity: the Capital-Environment Trade-off", *Journal of Environmental Economics and Management*, 9, pp. 165-185.

Beltratti, A. (1997): "Growth with natural and environmental resources" in Carraro, C. and Sinisclaco, D. (Eds.), *New Directions in the Economic Theory of the Environment*, Cambridge University Press, Cambridge.

Booth, D. E. (1998): *The Environmental Consequences of Growth*, Routledge, London.

Bovenberg, A. L. and Smulders, S. (1995): "Environmental Quality and Pollution-Augmenting Technological Change in a Two-Section Endogenous Growth Model", *Journal of Public Economics*, 57, pp. 369-391.

Cass, D.(1965): «Optimum Growth in an Aggregative Model of Capital Accumulation». *Review of Economic Studies*, 32, pp 233-240.

Common, M. S. (1996): *Environmental and Resource Economics. An Introduction*, London.

Daly, H. E. (1991): *Steady State Economics*, Island Press, Washington

Dasgupta, P. (1993): "Natural resources in an Age of Substitutability", en Kneese, A. V. and Sweeney, J. L. (Eds.), *Handbook of Natural Resources and Energy Economics*, vol. III, North-Holland, Elsevier.

Dasgupta, P. and Heal, G. (1974): "The Optimal Depletion of Exhaustable Resources", *Review of Economic Studies*, pp. 3-28.

Dasgupta, P. and Heal, G. (1979): *Economic Theory and Exhaustable Resources*, Cambridge University Press, Cambridge.

d'Arge, R. C. and Kogiku, K. C. (1973): "Economic Growth and the Environment", *Review of Economic Studies*, 40, pp. 61-77.

Fisher, A. (1979): "Measures of Natural Resource Scarcity" in Smith, V. K (Ed.), *Scarcity and Growth Reconsidered*, Resources for the Future, Johns Hopkins University Press, Baltimore.

Forster, B. (1973): "Optimal Consumption Planing in a Polluted Environment", *Economic Record*, 49, 128, pp. 534-545.

Grossman, G.M. and Helpman, E. (1991): *Innovation and growth in the global economy*, MIT Press, Cambridge.

Grossman, G. M. (1994): "Pollution and Growth: What Do We Know?", in Goldin, I. and Winters, A. (Eds.), *The Economics of Sustainable Development*, Cambridge University Press, Cambridge.

Grossman, G. M. and Krueger, A. B. (1993): Environmental impacts of a North American Free Trade Agreement", in Garber, P. M. (Ed.), *The Mexico-US Free Trade Agreement*, MIT Press, Cambridge.

Hartwick, J. M. (1974): "Intergenerational Equity and the Investing of Rents from Exhaustable Resources", *American Economic Review*, 67, pp. 972-974.

Heal, G. H. (1982): "The Use of Common Property Resources", in Smith, V. K. and Krutilla, J. V. (Eds.), *Explorations in Natural Resource Economics*, Resources for the Future, Johns Hopkins University Press, Baltimore.

Hettige, H., Lucas, R. E. B. and Wheeler, D. (1992): "The Toxic Intensity of Industrial Production: Global Patterns, Trends and Trade Policy", *American Economic Review*, 82, pp. 478-481.

Holtz-Eakin, D. and Selden, T. M. (1992): "Stoking the Fires? CO2 Emissions and Economic Growth", *National Bureau of Economic Research*, Working Paper, nº 4248.

Keeler, E., Spence, M. and Zeckhauser (1974): "The Optimal Control of Pollution", *Journal of Economic Theory*, 4, pp. 19-34.

Koopmans, T.C.(1965): «On the Concept of Optimal Economic Growth» en *The Econometric Approach to Development Planning*. North Holland, Amsterdam

Krautkraemer, J. A. (1985): "Optimal Growth, Resource Amenities and the Preservation of Natural Environments", *Review of Economic Studies*, 52, pp. 153-170.

Lucas, R.E. Jr. (1988): "On the mechanics of economic development", *Journal of Monetary Economics*, 22, pp. 3-42.

Michel, P. and Rotillon, G. (1992): "Pollution's Disutility and Endogenous Growth", Université París I.

O'Brian, (1975): *The Classical Economists*, Oxford University Press, Oxford.

Plourde, C. G. (1972): "A model of waste accumulation and disposal", *Canadian Journal of Economics*, 5, 1, pp. 199-225.

Ramsey, F.P. (1928): «A mathematical Theory of Saving». *Economic Journal*, 38 (152), December, pp. 543-59.

Rebelo, S. (1991): "Long-run policy analysis and long-run growth", *Journal of Political Economy*, 99, pp. 500-521.

Romer, P.M. (1986): "Increasing returns and long-run growth", *Journal of Political Economy*, 94, pp. 1002-1037.

Romer, P. M. (1987): "Growth based on increasing returns due to specialization", *American Economic Review*, 77, 2, May, pp. 56-62.

Romer, P.M. (1990): "Endogenous technological change", *Journal of Political Economy*, 98, pp. 71-102.

Schumpeter, J. A. (1934): *The Theory of Economic Development*, Harvard University Press, Cambridge

Schumpeter, J. A. (1950): *Capitalism, Socialist, and Democracy*, Harper & Row, New York.

Selden, T. and Song, D. (1994): "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?", *Journal of Environmental Economics and Management*, 27, pp. 147-162.

Shafik, N. (1994): "Economic Development and Environmental Quality: An Econometric Analysis", *Oxford Economic Papers*, 40, pp. 757-775.

Siebert, H. (1998): *Economics of Environment*, Springer, Berlin.

Solow, R.M. (1956): "A contribution to the theory of economic growth", *Quarterly Journal of Economics*, pp. 65-94.

Stiglitz, J. (1974): "Growth with exhaustable natural resources: Efficient and optimal growth paths", *Review of Economic Studies*, pp. 123-137.

Swan, T. R. (1956): «Economic Growth and Capital Accumulation», *Economic Record*, 32, pp. 334-361.

Tahvonen, O. and Kuuluvainen, J. (1993): "Economic Growth, Pollution and Renewable Resources", *Journal of Environmental Economics and Management*, 24, pp. 101-118.

Toman, M. A., Pezzey, J. and Krautkraemer, J. (1995): "Neoclassical Economic Growth Theory and "Sustainability"" in Bromley, D. W. (Ed.), *Handbook of Environmental Economics*, Basil Blackwell, Oxford.

World Bank (1992): *World Report*, Washington.

Xepapadeas, A. and Amri, E. (1995): "Environmental Quality and Economic Development: Empirical Evidence based on Qualitative Characteristics", *Nota di Lavoro*, Milan.