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A GROWTH RATE FOR A SUSTAINABLE ECONOMY

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Abstract

A sustainable growth rate – i.e. a growth rate which allows economy to expand without compromising the equilibrium of the natural system – is one of the most important and stimulating topics in growth literature. In this paper two findings will be presented. First of all, a brief discussion of both concepts – growth and development – is presented. A new sight for their relationship is suggested. The usual distinction between quantitative and qualitative variables is shown to be unsatisfactory. Growth and development must fit in a sustainability framework and therefore, progress should be based on steps of sustainable economic growth in order to have higher development levels. Secondly, a two-sector-closed-economy model is presented to demonstrate the existence of a positive sustainable growth rate for the GDP.

Keywords: economic growth, sustainable growth, development, sustainability

JEL Classification: O100, O400, O490, Q010, Q500, Q560

1. Introduction

The distinction between growth and development has usually been conducted at level of the difference between quantitative and qualitative variables, in related literature. Coherently with this view, according to Shearer (1961), economic growth refers to an increase in the output of goods and services (being therefore a quantitative concept), while economic development implies a more general and qualitative concept, including personal and social values. Nonetheless, this apparently simple distinction has not always been sufficiently clear according to Sen (1992), easily recognizable as the father of the capability approach, who stated clearly that the idea of development must not be confused with the increase in quantity of goods available within an economy. Pearce and Warford (1993) stress that being development a process that leads to improvement or progress, a society which follows this process of economic development will obtain a combination of three effects: first of all, an advance in utility (in terms of per capita income, quality of the environment, and general social well-being); secondly, advances in education, health, and quality of life (in this exposition they use the same classification adopted by Goulet, 1971); and third, growth of self-esteem and self-respect, which leads to independence and capacity of choice.

Economic systems are made by several variables, and they can be defined as developed when they have some attributes[1]. The more a region is developed, the greater and the deeper are components of its welfare. It means that after primary needs, there comes a series of other and higher qualifications which express goodness of quality of life. Then, economic development appears clearly as a much wider concept than economic growth, being the latter defined as just an increase in the level of the per capita gross national product over time. The way in which the progress is pursued puts in evidence the match against the environmental constraint; sustainability assumes a crucial relevance because considered the world today, and given characteristics of mankind and nature, it may not be possible anymore to define development without placing it within a sustainability framework.

It is difficult to give a unique definition of sustainability and/or of sustainable development because of the availability of alternatives that it is possible to find in the literature. Pearce *et al.* (1989) offer more than thirty possible definitions. These definitions can be divided into two groups (Beltratti 1996): the first group refers to sustainability in physical terms, looking at the limitations imposed by

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[1] For example the *World Bank Development Indicators* include the eradication of extreme poverty and hunger, the achievement of universal primary education, the promotion of gender equality, the reduction of children mortality, the improvement of maternal health, the struggle against HIV/AIDS, malaria and other diseases, and the environmental sustainability. According to some other authors (Pearce, Barbier, Markandya 1989), development would involve an increase in real income per capita, improvements in health, nutrition, and education, a fairer distribution of resources and income and an increase in what they call "basic freedoms".

scarcity of natural resources on the growth process; the second group describes sustainability on the basis of the comparison among utility levels of different generations. Summing up, a broad definition of sustainability would include the preservation of human wellbeing by the maintenance of natural, social, and economic systems. Following Kunte *et al.* (1998), it is possible to define wealth as the per capita stock of assets.

$$W = \frac{K_m + K_n + K_h}{POP}$$

where K_m is the stock of man-made capital, Kn is the stock of natural capital, K_h is the stock of human capital, and *POP* is the population. This composition allowed the distinction between strong and weak sustainability: the idea of weak sustainability, based on the studies of Solow (1974) and Hartwick (1977), allows the substitution between natural capital and man-made capital because it is based on the assumption that welfare is not dependent on a specific form of capital and that there is a near perfect substitutability between man-made capital and natural resources. If such a substitution is possible, an economy is recognized as sustainable even if it draws down its stock of natural capital, provided that it creates enough manufactured capital to compensate for the loss of natural capital so that the constancy of the total stock of capital is ensured (Neumayer 1999). Instead, the strong sustainability criterion requires maintaining different kinds of capital intact separately; therefore it refers to the case in which substitutability is not allowed[2]: according to the strong sustainability view, at least some natural capital is non-substitutable and should be maintained at or above some threshold levels. Natural capital that is not substitutable by any other form of capital is called critical natural capital[3] and its preservation assumes a great relevance. Determination of criticality depends on ecological, as well as economic, political and social criteria (Mac Donald *et al.* 1999) and critical levels depend not only on ecological standards, but are also related to standards of living and relative affluence of a particular group, region or nation (Pearce, and Warford 1993), in the sense that the degree to which a function is considered important (i.e. critical) may vary from place to place, from population to population.

From what has been said, sustainability is not only an attribute for development, but also a qualification for the path which allows reaching it. If development were a ladder, growth would be the progress that a system does from the first to the higher steps. For this reason it is possible on one hand to agree with the part of the literature which refers to growth as a path made by stages (see, for example, Rostow 1952), and on the other hand to deepen the strength of sustainability inside of the meaning of

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[2] Some authors do not admit either substitution or compensation (Sen 1982; Barry 1991; Spash 1994; Azar 2000); furthermore, there are some resources so important that substitutability is not even practicable, as for example the ozone layer. Muradian (2001) puts in evidence how surpassing some critical levels in the depletion of some resources can imply unknown and important transformations. Finally, Page (1983) states that opportunities of the next generations will not be threatened if they will inherit the same resource base that the present generation has inherited; while Bromley (1989) finds the intergenerational justice in the case in which every generation can receive undiminished resource stock and environmental quality.

[3] In literature, several definitions for ‘critical’ natural capital have been given:

“Vital parts of the environment that contribute to life support systems, biodiversity and other necessary functions denoted as ‘keystone species and processes” (Turner 1993).

“Critical natural capital consists of assets, stock levels or quality levels that are: (1) highly valued; and (2) essential to human health; or (3) essential to the efficient functioning of life support systems; or (4) irreplaceable or non-substitutable for all practical purposes (e.g. because of antiquity, complexity, specialization or location)” (English Nature 1994).

“That set of environmental resources which performs important environmental functions and for which no substitutes in terms of human, manufactured or other natural capital currently exist” (Ekins 2003).

Mac Donald *et al.* (1999) underlines how more comprehensive definitions of critical natural capital focus on two main aspects: the “functional” aspect of the natural capital referred to those ecological assets that are essential to human wellbeing or survival (*see* also: Pearce, and Warford 1993) and the “primary” aspect of ecosystems for general biosphere functioning which requires to maintain population or resource stocks within bounds thought to be consistent with ecosystem stability and resilience (*see* also: Turner 1993). Thus, the latter preserves the eco-centric stability (in the sense of maintaining environmental integrity looking mainly at the maintenance of “habitat functions”); and the former, based on an anthropocentric perspective, basically defends those natural equilibria that are indispensable to human survival and cannot be substituted.

economic growth. This will lead to development, whose definition has no more sense whether it is not sustainable, given that all the dimensions of the sustainability concept enter into utility functions of humans and therefore contribute to define welfare. This approach is pursued by Costantini (2006) who deepens the analysis about quality in economic systems also referring to the *Human Development Index* (HDI), establishing a relationship between human development and sustainability. Her conclusion shows that sustainability is a multidimensional concept based on economic growth, wealth, and natural capital. Coherently also with Biondo (2004), she underlines how a sustainable growth path can be followed starting from a sufficient human development level – which evidently implies satisfaction of basic needs. The higher is the starting-level of development, the easier is sustainable growth.

There are a lot of contributions in growth literature dealing with sustainability and how economic growth (production, technology, and population) influences the environment, receiving at the same time constraints from it. It is not possible to survey them all here, but it is possible to assess a rapid overview at least to recall some of recurring topics: first of all, at least implicitly, literature almost always refers to well-known environmental functions (highlighted by Pearce and Turner, 1990): support to life, input to production, and waste recovery. For example, Dasgupta and Heal (1974) is perhaps the first rigorous consideration of the optimal path for consumption in a representative agent single-commodity model, where the agent maximizes discounted utility and production uses inputs of capital and environmental non-renewable resource; many other models used that framework since then. The environment is seen as input also in Stiglitz (1974), where the author seeks the optimal rate of utilization for resources and builds up a model where environment is a necessary input for production. This kind of analysis opens another important stream of literature, in terms of intergenerational opportunities, as in Solow (1974), who tried to establish proof of intergenerational equity finding the optimal depletion of natural resources. The intergenerational issue, present also in Howarth and Norgaard (1992), who focused on the topic of justice between generations and proposed intergenerational transfers, is strictly connected to the idea of sustainability. A number of papers dealt with sustainability concept, and Pearce *et al*. (1989) listed more than thirty different definitions of it. Other important contributions came from Redclift (1992), Pezzey (1992 and 1997), Barbier and Markandya (1990), and Lele (1991); Pearce and Atkinson (1993) tried to give a measure of sustainability, as in Hamilton *et al*. (1998), and in Hamilton and Clemens (1999) where the path for sustainability passes through stimulating savings. Weitzman (1997) looked at technical progress in relation to sustainability, and similarly Jaffe *et al*. (2000) presented an analysis focused on the impact of technology on the environmental economic field. Seeking for “sustainability rules”, many papers gave important ideas; for example, Hartwick (1977) showed that constant consumption is warranted for an economy with a constant returns to scale Cobb-Douglas production function with capital and non-renewable resource as inputs, equalling resource depreciation to investment in reproducible capital, and defined and generalized his homonymous rule for an optimal resource use in subsequent contributions; Beltratti *et al*. (2000) proposed the Green Golden Rule; Chambers *et al*. (2000) built an indicator for sustainability; Smulders (2000) defined his concept of balanced growth; Pittel (2002) surveyed endogenous growth theory in sight of sustainability. In between streams of intergenerational and sustainability issues, Farmer and Randall (1997) analyzed sustainability through an overlapping generations framework while Pezzey (2004) traced a distinction between environmental policy and sustainability policy referring to intergenerational equity. More broadly, Beltratti (1996) deepened the matter of inserting environment in growth models, and van den Bergh and Hofkes (1999) wrote an interesting review of sustainable-development economic models. Another stream of literature deals with human development, as for example Anand and Sen (2000) where human development is related with sustainable development, while, less specifically, Ranis (2004) reported the evolution of development debate.

The trade-off between growth and environment is not easy to be described, because it is multidimensional; Grossman (1995) suggests that growth affects the environment through three effects: the “scale effect”, the “composition effect”, and the “technique effect”. The “scale effect” simply refers to the augmented quantity of produced output that leads per se to a greater exploitation of the environment, in terms of both resource consumption and polluting emissions. The “composition effect” is the consequence of higher income on the economic activity and life of the system, in the sense that the more the income increases, the more cleaner activities and less pollutant technologies will be preferred: in Grossman’s view, the composition effect is oriented toward the supply side, where industries substitute agriculture at first, and then the service sector substitutes the industrial one. At the same time, this composition effect will automatically stimulate the "technique effect", because innovation and progress assume more relevance: in fact, the cleaner the process of production, the stronger must be the innovation and the capacity of the R&D sector at social level. Not only does innovation improve efficiency, but also it reduces usage of environment and allows natural capital to be maintained and, if necessary, reintegrated over time. Only if innovation reduces the use of environmental inputs, a weak sustainability framework can be possible. This point is particularly important in sight of the model presented here. It constitutes a theoretical perspective which successfully describes economic environmental interaction, making the important differentiation between expenditure in innovation and expenditure in recovery and substitution of natural capital; furthermore, it derives the sustainability condition for economic growth (taking into account the grade of consciousness of people), and finally it gives the theoretical structure for future quantitative analysis. Evidently, whether economic growth is good or not for the environment mostly depends on the presence of adequate policies: as Arrow *et al.* (1995) underline, given that all the activity of the economic system depends on the environmental resource base and that every misuse of these resources may reduce the capacity for generating material production for the future, there exists the need for the creation of institutions in order to pursue right policies and completeness of the markets. But this is a higher level of the problem; policies are possible if they are based on instruments which can actually tune variables in the economic system; therefore, the analysis of the relationship between growth and sustainability must at first pass through the exposition of a simple model which will try to show conditions for the economy can grow in a sustainable way. Section two will present the model, section three will conclude.

2. The Model

The model presented here, will derive a condition for a positive sustainable growth rate; in doing this attempt, it will represent a very simple two-sector-closed-economy framework, in which only one good is produced and consumed: one sector will be devoted to production of the unique good, while the other sector is used by policy-maker for environmental purposes as it will be explained later. An extensive literature has coped with environmental elements of production and consumption: there are models based on a dynamic optimization problem in which the utility of an infinitely lived representative agent is maximized within the framework of the optimal control theory, and models based on the endogenous approach with increasing returns to scale for the production function. Few examples of the first stream of models are in Tahvonen and Kuuluvainen (1993), where pollution enters both the production and the utility function, and in Lopez (1994), where environment plays directly the role of productive factor; whereas examples of the second kind of models are in Bovenberg and Smulders (1995), where an aggregate stock of environmental services can be found in both production and utility, and Stokey (1998) where pollution is a function of output and enters the utility function. As in Bovenberg and Smulders (1995), the model here will consider an aggregate set of services that the environment delivers to social and economic activities: it simply shows that in order to produce and to consume the unique good X, the economic system uses environmental resources (for example in terms of raw materials, waste disposal, recreational reasons, just to mention a few); as a result, this "production–consumption cycle" of X depletes environment and generates polluting wastes (W) which can be reasonably assumed as a growing function of the amount of produced–consumed output. Let the relation between W and X be expressed by the following function:

$$W = \alpha(\bullet)X \tag{1}$$

At this stage, α will be considered simply as a positive parameter, but later this assumption will be relaxed and it will be described as a function, in order to explain elements which can affect it; however will be assumed[4] that $\partial W/\partial X > 0$. Put in this way, α represents how much each unit of X is polluting both to be produced and to be consumed, and the greater it is, the more X pollutes. Over time, while production and consumption go on, wastes follow an accumulation process which results in the

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[4] The basic idea that must be taken in mind is that the positive variation of X implies a positive variation in W. With the assumption of α as a simple positive parameter, the equation (1) could be written as:

$$W = \alpha X,\ \alpha > 0 \tag{2}$$

total amount of pollution *P*, as in Tahvonen and Kuuluvainen (1993), who basically built up on Brock (1977), considering recycling capacities of environment, which absorbs part of pollution and wastes and converts them into resources again:

$$\dot{P} = W - \beta P \qquad 0 < \beta < 1 \tag{3}$$

Such an equation of motion is quite standard in models which deal with sustainability; it is worth to notice, Smulders (2000) uses a very similar one, but he refers just to production in his accumulative process which explains environmental quality evolution, whereas here *W* includes consumption contribution to pollution. In fact, not only consumption of any good implies creation of wastes, but environment itself is consumed for health, fun, and lots of recreational issues by agents. As it is easily understandable, β represents the capacity of the environment to absorb pollution and wastes; it is $\beta \in (0, 1)$, because it can be hypothesized that the "carrying capacity" of the environment may vary between two theoretical extremes: the impossibility to absorb ($\beta = 0$) and the capacity to recycle all the pollutants ($\beta = 1$). β could be assumed as a function of natural capital stock (NK): $\beta = \beta(NK)$, $d\beta/dNK > 0$. Many times in literature the capacity of environment to absorb pollution is depicted as a natural renewable resource (*see* for example: Pearce, and Warford 1993).

For any value of β, it is important to underline here that the model describes a path which links unavoidably continuous production and consumption of *X* to growing pollution and wastes (asymptotically infinite if the realistic assumption made here, that $\alpha > \beta$, holds true[5]).

Considering now the growth rate of eq.(1)[6], the growth rate of wastes results:

$$\hat{w} = \hat{\alpha} + \hat{x} \tag{4}$$

In order to demonstrate sustainability, the model must accounts for what will happen whenever the absorption capacity of the environment is completely saturated. In that moment, $\beta = 0$ in (3) and the economy reaches the maximum quantity of pollution and wastes which saturates nature totally. In this extreme case, the idea of environmental sustainability arises clearly: for the system to be sustainable, since that moment on, pollution cannot increase anymore. That is: if

$$\beta = 0 \quad \Leftrightarrow \quad \dot{P} = W \tag{5}$$

Then sustainability implies:

$$\hat{p} \leq 0 \Leftrightarrow W \leq 0$$

That, in turn implies:

$$\hat{w} = \hat{\alpha} + \hat{x} \leq 0 \tag{6}$$

The production–consumption of *X* will be sustainable if it grows at a rate which can satisfy the condition in (6). In order to let production–consumption continue at a positive rate, it is necessary that $\hat{\alpha}$ is negative (and greater than or at least equal to $\hat{x}$, in absolute value). In other words, R&D expenditure in technology and innovation would be compulsory to ensure correspondent reductions of α : this should lead to a new (higher) level of development in which W and x are linked by a different function – i.e. $\partial W/\partial X$ decreased. Define now:

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[5] In a certain way, $\alpha > \beta$ is *obvious* in sight of model, because the case in which $\alpha \leq \beta$ would imply a production-consumption process whose wastes were completely absorbed by the environment without increasing pollution; therefore the interest in studying the environmental sustainability of such a production-consumption cycle would be extremely scarce.

[6] All of the growth rates will be indicated with the same name of the corresponding variables but in lower case and with a superscript.

$$NI = NI(\pi; X) \ and \ \pi = \pi(NK) \tag{7}$$

as the investment expenditure to obtain environmental-related technical progress; in other words, it is the R&D expenditure devoted to discover new technologies which can save natural capital (*NK*). This function is particularly relevant in sight of the meaning of this model; in fact, its role is twofold: by one side it represents the R&D expenditure for innovative investments (*NI* depends positively on *X* because the more the good is produced and consumed, the more R&D expenditure is required, therefore $\partial NI / \partial X > 0$), and by the other it indirectly indicates the amount of natural services required by production[7] and the quality of the actual consistency of natural capital. π represents here the consciousness of the policy-maker about environmental conditions and expresses therefore the preference for innovative investment in terms of expenditure in R&D focused to reduce wastes and polluting emissions. It depends negatively on *NK*, because the more *NK* is exploited, greater is the importance of the environmental problem, the more *NI* is necessary: therefore $d\pi / dNK < 0$ and $\partial NI / \partial \pi > 0$ [8].

Let now *NC* be the total amount of other expenditures and costs (different from R&D) necessary to clean nature and recover natural capital. This function behaves exactly like *NI*: everything has been explained for *NI* holds for *NC*. Then it can be written:

$$NC = NC(\rho; X) \ and \ \rho = \rho(NK) \tag{8}$$

where ρ has the same role that π does[9], but referred to cleaning and recovery expenditures. The model, then, takes in account the "weak sustainability" perspective in a certain way, but underline a very important difference between *NI* and *NC*: they differ in terms of timing, amount and applicability. Environmental protection does not rely solely on substitution between natural and man-made capital (*NC*), but especially on innovative expenditure which actually reduces usage of environment.

The motion of *NK* is then given by:

$$N\dot{K} = NI + NC - P \tag{9}$$

The accumulation process for *NK* in (9) shows the source of the idea that policy should deal with maintaining a non-declining natural capital; it was first developed in Pearce and Turner (1990) and gives in this model the idea of what sustainability can be at the point where $\beta = 0$: in order to have non-decreasing (critical) natural capital, $(NI + NC) \geq P$ must hold.

The rationale underneath the model is that the "generic" good *X* is exactly the domestic product of the economy. In this broader perspective, the problem is revealed: the sustainability of further production–consumption of *X* is the problem of the sustainability of economic growth. Given elements which have been used into the model, and in the shape of the important part of literature dealing with new national accounting systems[10], the traditional fundamental closed-economy income equality,

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[7] This will be immediately clarified when α will be presented as a function.

[8] It is easily understandable why π is function of *NK*. It is evidently related to sensitivity of people to the environmental problem and to actual wealth: briefly it can be said that the more the system approaches the critical level of natural capital, the more π will increase, and this will in turn imply increasing *NI*. The definition of a proper function form for π is not the main goal of this paper, but it is extremely interesting to deepen just one aspect about its elasticity: the consciousness of the environmental problem is not identical everywhere. Then, the function will behave differently from place to place, according to preferences of people, being more rigid where the environmental impact is not deeply considered, and more elastic where people is more sensitive.

[9] Then it is: $\partial NC / \partial X > 0$, $d\rho / dNK < 0$, $\partial NC / \partial \rho > 0$.

[10] Particularly relevant in this field are: UN (1992, 1993), where first UNSTAT proposals for satellite accounts can be found, Lutz (1993), Bartelmus (1994), Wackernagel and Rees (1997) for a simple introduction to ecological footprints which describes methods of calculation, Vitousek *et al*. (1997) for a review of lots indicators, Neumayer (1999), Hamilton (2000) who reviewed theory of genuine savings, and Field (2001).

$$X = C + I + G$$

Adding terms here presented, can be rewritten as:

$$Y = X + NI + NC \tag{10}$$

This more complete definition of GDP includes the "traditional" components (*X*) plus *NI* and *NC* as they have been just defined: (10) reveals that the model presents a second sector, *N*=*NI*+*N*C, dedicated to environment, whose activities are aimed both to develop new technologies in order to substitute natural capital with man-made capital and to recover natural system; the *N* sector is not pollutant by virtue of assumption. On the basis of what has been expounded up to now, it is finally possible to go back to *α*, to deepen its determination and factors which influence it[11]:

$$\alpha = h(NI; NC) \tag{11}$$

Coherently with all the rest of the model it must be assumed that:

$$\frac{\partial \alpha}{\partial NI} < 0 \quad and \quad \frac{\partial \alpha}{\partial NC} < 0 \tag{12}$$

Differentiating (11) w.r.t. time, one obtains:

$$\dot{\alpha} = \frac{\partial \alpha}{\partial t} = \frac{\partial \alpha}{\partial NI}\frac{\partial NI}{\partial t} + \frac{\partial \alpha}{\partial NC}\frac{\partial NC}{\partial t} =$$

$$= \frac{\partial \alpha}{\partial NI}\frac{\partial NI}{\partial t}\frac{NI}{NI} + \frac{\partial \alpha}{\partial NC}\frac{\partial NC}{\partial t}\frac{NC}{NC}$$

Then

$$\hat{\alpha} = \frac{\dot{\alpha}}{\alpha} = \frac{\partial \alpha}{\partial NI}\frac{\partial NI}{\partial t}\frac{NI}{NI}\frac{1}{\alpha} + \frac{\partial \alpha}{\partial NC}\frac{\partial NC}{\partial t}\frac{NC}{NC}\frac{1}{\alpha}$$

Rearranging

$$\hat{\alpha} = \frac{\partial \alpha}{\partial NI}\frac{NI}{\alpha}\frac{1}{NI}\frac{\partial NI}{\partial t} + \frac{\partial \alpha}{\partial NC}\frac{NC}{\alpha}\frac{1}{NC}\frac{\partial NC}{\partial t}$$

And, defining

$$\eta_{\alpha,NI} = \frac{\partial \alpha}{\partial NI}\frac{NI}{\alpha} \; and \; \eta_{\alpha,NC} = \frac{\partial \alpha}{\partial NC}\frac{NC}{\alpha} \tag{13}$$

It results

$$\hat{\alpha} = \eta_{\alpha,NI}\hat{NI} + \eta_{\alpha,NC}\hat{NC} \tag{14}$$

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[11] In presenting next relationship, (12), it is necessary to focus on technology. Building up from a distinction made by Pemberton and Ulph (2001), two cases must be distinguished, according to the way by which technology could enter the model. As a first solution, technology can be considered completely endogenous: in this way it is considered implicitly in R&D activities, and the model still preserves capacity to take it in account; the second solution would imply an exogenous technical progress which does not arise from R&D: it would add in the model a time-dependent production possibility set. For a matter of simplicity the first solution has been used here.

The growth rate of α is the weighted sum of the growth rate of NI and NC; weights are $\eta_{\alpha,NI}$ and $\eta_{\alpha,NC}$ which are, as shown in (13), elasticity coefficients of the α function respectively to NI and to NC. It is easy to notice that these elasticity coefficients are both negative given that, by virtue of assumption, conditions (12) hold. Recalling now (6), it is possible to write:

$$\hat{x} \leq -\hat{\alpha} \tag{15}$$

This means that for any positive growth rate of X there must be an (at least) equal reduction rate in α. It follows immediately from (14) and (15) that:

$$\hat{x} \leq -\eta_{\alpha,NI} N\hat{I} - \eta_{\alpha,NC} N\hat{C} \tag{16}$$

Which can be finally written, as

$$\hat{x} \leq \mathrm{H}_{NI} N\hat{I} + \mathrm{H}_{NC} N\hat{C} \tag{17}$$

Posing

$$\mathrm{H}_{NI} = -\eta_{\alpha,NI} \quad and \quad \mathrm{H}_{NC} = -\eta_{\alpha,NC} \tag{18}$$

Inequality (17) gives the first result of the model. In order to be sustainable, the growth rate of the economy must be less than (or at maximum equal to) a weighted sum of the growth rate of NI and NC, representing weights the efficacy of environmental expenditure in R&D and cleaning in reducing α. This brings to a weak sustainability idea implicitly: when the environment goes to collapse, the model explains that NI and NC substitute and rebuild destroyed natural capital. The effectiveness of this passage depends mostly on the level of development; in fact in developed economies elasticity coefficients will be higher and while X can be produced at acceptable growth rates, substitution and recovery of environment will be easier than in less developed economies. One important topic is to check whether $\hat{x}$ can be always positive; in looking for demonstrating it, consider that because of conditions in (12), and given the (16), the R.H.S. of (17) is always positive, as $H_{NI} > 0$ and $H_{NC} > 0$.

In order to show that $\hat{x}$ can be always positive, it is necessary to analyse values of elasticity coefficients in (13) as done in Table 1, where the first column brings values for H_{NI}, the second column associates to each possible value for H_{NI}, every possible value for H_{NC}, the third column shows consequent results for R.H.S. of (17), and finally the fourth column shows sign of $\hat{x}$, $\forall N\hat{I}, N\hat{C} > 0$:

Table 1. The analyse of values of elasticity coefficients

	H_{NI}	H_{NC}	$H_{NI}N\hat{I} + H_{NC}N\hat{C}$	$\hat{x}$
a.	< 1	< 1	> 0	> 0
b.		= 1		
c.		> 1		
d.	= 1	< 1	> 0	> 0
e.		= 1		
f.		> 1		
g.	> 1	< 1	> 0	> 0
h.		= 1		
i.		> 1		

As it can be seen, X can continue to grow: therefore $\hat{x}$ is the wanted positive sustainable growth rate for the variable "production and consumption". Once the policy-maker uses (17) there will be the possibility for the economy to grow sustainably; of course, there is no need to wait the saturation of environment to apply it: (5) was an important hypothesis needed to obtain (6) which leads to (17), but government should apply it before the moment when $P = P_{MAX}$, saving a lot of natural capital and increasing wealth for citizens. In particular, it is useful to check how high $\hat{x}$ can be, in the sense that a sustainable economy would choose to produce and consume as much as it can, looking for the highest wellbeing; in this sense (17) holds as an equality because $\hat{x}$ will be pursued at its highest bounding value and following inequalities will hold:

1. in case a., if $H_{NI} \leq H_{NC} \Rightarrow \hat{x} \geq N\hat{I} + N\hat{C}$
2. in case b., $\hat{x} > N\hat{C}$
3. in case c., $\hat{x} > 0$
4. in cases d., g., and h., $\hat{x} > N\hat{I} + N\hat{C}$
5. in case e., $\hat{x} = N\hat{I} + N\hat{C}$
6. in case f., $\hat{x} > N\hat{I}$
7. in case i., if $H_{NI} \geq H_{NC} \Rightarrow \hat{x} \geq N\hat{I} + N\hat{C}$

The case 3 is the worst, α is rigid to *NI* and *NC*, but production and consumption can still grow; all of other cases show that $\hat{x}$ is at least higher that either *NI* or *NC*.

Finally, given that $\hat{x}$ is an environmentally sustainable growth rate, and that it has been assumed that the *N* sector (*NI*+*NC*) is not pollutant in any sense, recalling (10), it can be written that the sustainable growth rate for the two-sector-closed economy of the model will be

$$\hat{y} > 0 \tag{19}$$

That ensures a positive growth rate of GDP which is environmentally sustainable.

3. Concluding remarks

This paper introduced a qualitative perspective in approaching economic growth rate determination. The establishment of sustainability priority as an unavoidable ingredient of contemporary world's progress definition claims the check of possibilities which the actual system can pursue. Economic growth cannot remain just a quantitative expression and must share the qualitative fashion usually related solely to the development idea. The presented model demonstrates the existence of an always positive growth rate for the economy which can ensure however the sustainability of the progress through a weak-sustainability approach. Innovation and technological progress are presented in terms of the variable *NI*, i.e. the investment expenditure in R&D to discover new technologies in order to either improve environmental compatibility of the system or reduce the amount of natural resource exploited[12]. This conceptual difference between *NI* and *NC* is extremely important: innovation is not a simple substitution between natural capital and man-made capital. It is something more. Not only because the substitution is not always possible, but more clearly because innovation plays a unique role in reducing usage of environment in all of its forms. *NC* rebuilds, repairs, replaces natural capital, in the usual and well-known "weak sustainability" approach, but *NI*, i.e. innovation and discoveries in technology, also when not directly addressed to environmental protection, may mean improvement in environmental conditions if they imply increases in efficiency of the production function and therefore allow saving natural resources. Evidently, the model counts on equation (11) and on conditions (12). If the possibility for *NI* and *NC* to reduce α is removed from assumptions, admitting the existence of R&D expenditure and/or other expenditures to recover natural capital without reduction of $\partial W / \partial X$, then the model will not give same conclusions. This is the basis for a key role for the policy-maker, in terms of R&D expenditure and in terms of exogenous constraints which could be posed, as laws and regulations. For example, in order to warranty a constant effort by all agents, the government could establish a compulsory innovative expenditure per year. In this way a positive growth rate of *NI* and might be ensured. Mowery and Rosemberg (1989) confirm that policies voted to encourage R&D expenditure for innovation are extremely diffuse in actually all of industrialized countries. The model here hypothesizes that the *N* sector is an instrument for the policy-maker; this does not mean implicitly to accept that it must be (partially or exclusively) financed by the public sector. There are some contributions in

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[12] The model does not investigate about the natural resources management problem. Nonetheless, this matter has been considered in a way: the recycling capacity of nature and the transformation made by the environment of wastes in resources again is undoubtedly a renewable resource. This appears in the model giving the main starting step.

literature which find successful public intervention in financing R&D as Cohen and Noll (1991) and others which do not emphasize government expenditure, as Jaffe (1998); however a mixed system can easily be considered, where that the government can have a key role to enhance technological research. Policies could be addressed to reduce costs after-tax of R&D expenditure, or to provide subsidies to researchers, firms, and consumer, to respectively induce more innovation, adopt it, and choose innovative products. There is part of literature which successfully deals with these important topics, such as Hall and Van Reneen (2000), Klette *et al*. (2000), and Romer (2000). Moreover, private operators may have strong incentives to pursue innovative investments, firstly because Government could levy higher taxes for polluters and secondly because of competition, image marketing, actual saving in production, as highlighted by Dasgupta and Stiglitz (1980), Spence (1984), Levin and Reiss (1988), just to mention a few. Therefore the main force of the model here presented is not only to replace natural capital with man-made capital, but exactly the Schumpeterian incentive to reduce usage of environment. This will lead to sustainable growth, as stated by the model. Of course, the efficacy of NI and NC in reducing α is very difficult to measure, and depends on different factors. First of all, it depends on the degree of development in which the research is conducted (in this sense, all the model view can vary, being α, π, ρ, and their functions, possibly dissimilar in different contexts, *see* footnotes: n.9 and n.10); secondly it would probably rely very strongly on the cooperation among researches and on diffusion on innovations. Many authors wrote about economic diffusion of technology, studying its dynamic, its costs, and positive externalities arising from it; here it is very useful just recall the role that policy can have in enhancing also this particularly important process. Government could be the main actor in providing the most efficient patent protection, (giving the possibility to distribute knowledge) and in distributing information in order to reduce obstacles as uncertainty, which endogenously characterizes economic life.

Further research will be conducted in studying explicit functional form for equations of the model. These analyses will allow studying α, NI, NC, and all of their determinants; even if data are missing and not always available, econometric estimation could be able to set important results to give actual application to this theoretically meaningful model.

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