Economic Growth   Lecture Note 18

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Natural resources and economic growth

In this course we discuss three subjects concerning the relationship between economic growth, natural resources, and the environment. The catchwords are:

I. Renewable resources.

II. Non-renewable resources.

III. Social cost-benefit analysis with an application to the climate change problem.

This lecture note briefly deals with subject I. But first we need to establish a common terminology for these matters.

1 The concept of sustainable development

The Brundtland Commission (1987) defined sustainable development as “development that meets the needs of present generations without compromising the ability of future generations to meet theirs”.

In more standard economic terms we will here define *sustainable economic development* as a time path along which per capita welfare remains non-decreasing across generations forever. Here “forever” should not be taken literally, but as equivalent with “for a very long time horizon”; we all know that the sun will eventually (in some billion years) burn out and consequently life on earth will become extinct. Note also that the definition emphasizes *welfare,* which should be understood as more or less synonymous with “well-being” (the term used in Smulders (1995)). That is, what may matter is not only the per capita amount of marketable consumption goods, but also such things as health, life expectancy, and enjoyment of services from the ecological system.

To clarify this, suppose two variables enter the period utility function of a typical individual, consumption, c, of a standard produced good and the quality, q, of services from the eco-system. Suppose further that the period utility function is of CES form:[1]

$$u(c,q)=\left[\alpha c^{\beta}+(1-\alpha)q^{\beta}\right]^{1/\beta}, \qquad 0<\alpha<1, \beta<1. \tag{1}$$

The parameter β is called the *substitution parameter.* The elasticity of substitution between the two goods is $\sigma=1/(1-\beta)>0$, a constant. When $\beta\rightarrow 1$ (from below), the two goods become perfect substitutes (in that $\sigma\rightarrow\infty$). As β decreases, the goods become less and less substitutable (more and more complementary). When $\beta<0$, $\sigma<1$, and as $\beta\rightarrow-\infty$, the indifference curves become near to right angled.[2] According to many environmental economists, there are good reasons to believe $\beta<0$, since water, basic foodstuff, clean air, absence of catastrophic global warming, etc. cannot be replaced by produced goods and services. In this case there is a limit to the extent to which rising c can compensate for falling q. And the techniques by which the ordinary consumption good is currently produced may pollute and thereby lower the quality of the services from the eco-system.

A requirement of sustainable economic development is thus a requirement that the economic activity of current generations does not spoil the environmental conditions for future generations. Living up to this requirement necessitates economic and environmental strategies consistent with the planet's endowments. This means recognizing the role of limited natural resource and environmental constraints for economic development.

Along with this, we may define *sustainable economic growth* as a time path along which per capita welfare is forever *growing.* Note that the concept of sustainable economic growth emphasizes growth in a per capita *welfare* sense, not in a material sense. Permanent (exponential) per capita output growth in a *physical* sense is impossible with limited natural inputs (matter or energy). The sustainable growth issue is about whether, by combining man-made inputs (human capital and knowledge) with the natural inputs, an output stream of increasing quality, and therefore increasing *economic value,* can be maintained.

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[1] CES stands for Constant Elasticity of Substitution.

[2] By L'Hôpital's rule for "0/0" it can be shown that, for fixed c and q,

$$\lim_{\beta\rightarrow 0,\beta\neq 0}\left[\alpha c^{\beta}+(1-\alpha)q^{\beta}\right]^{1/\beta}=c^{\alpha}q^{1-\alpha}.$$

So the Cobb-Douglas utility function, which has elasticity of substitution between the goods equal to 1, is an intermediate case, corresponding to $\beta=0$.

Given the scarcity of natural resources and the pollution problems caused by economic activity, key questions are:

a. Is sustainable development possible?

b. Is sustainable economic growth (in a per capita welfare sense) possible?

c. What is the relationship between sustainable economic growth and optimal economic growth?

d. How can environmental policy be designed so as to enhance the prospects of optimal economic growth?

2 Classification of means of production

We may distinguish between different categories of production factors or means of production. First the two broad categories:

1. *Producible* means of production, also called man-made means of production.
2. *Non-producible* means of production.

The first category includes:

1.1 *Physical inputs* like machines, buildings, intermediate goods.

1.2 *Human inputs* like knowledge and human capital.

The second category includes:

2.1 Human inputs of a non-produced character, sometimes called "raw labor".[3]

2.2 Natural resources.

Natural resources can be sub-divided into:

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[3] Outside a slave society, biological reproduction is usually not considered as part of the economic sphere of society even though formation and maintainance of raw labor requires child rearing, health, food etc.

2.2.1 *Non-renewable resources*, that is, natural resources the amount of which on earth is finite and which has no natural regeneration process (at least not within a relevant time scale). Hence, the stock of a non-renewable resource is depletable. Examples: fossil fuels, many non-energy minerals, virgin wilderness, endangered species, ozone layer.

2.2.2 *Renewable resources.* A renewable resource is also available only in limited supply, but its stock is replenished by a natural self-regeneration process. Hence, if the stock of a renewable resource is not over-exploited, it can be sustained in a more or less constant amount. Examples: ground water, fertile soil, fish in the sea, clean air.

The climate change problem (CO_2 in the air) can be seen as belonging to somewhere between category 2.2.1 or 2.2.2 in that the atmosphere *has* a natural self-regeneration ability, but the speed of regeneration is very slow.

3 A renewable resource

Here I give a brief outline of the simplest model of the stock dynamics associated with a renewable resource.

Let $S_t \geq 0$ denote the stock of the renewable resource and $R_t \geq 0$ the extraction of the resource per time unit, both at time t :

$$\dot{S}_t = G(S_t) - R_t, \tag{2}$$

where $G(\cdot)$ is the *self-regeneration function.* If for instance the stock refers to the number of fish in the sea, the flow variable, R_t, is the number of fish harvested per time unit. And if, in a pollution context, the stock refers to "cleanness" of the air in cities, R_t measures, say, the emission of SO_2 per time unit.[4]

Until further notice, we stick to the first interpretation, that of S indicating the size of a fish population. The self-regeneration function is often assumed to have a bell-shape as illustrated in the upper panel of Fig. 1. There is a lower threshold, $\underline{S}(0) \geq 0$, below which even with $R = 0$ there are too few female fish to generate offspring, and

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[4] Even if S represent the stock of a *non-renewable* resource, the equation (2) will still valid if we impose that there is no self-regeneration, i.e., $G(S) \equiv 0$.

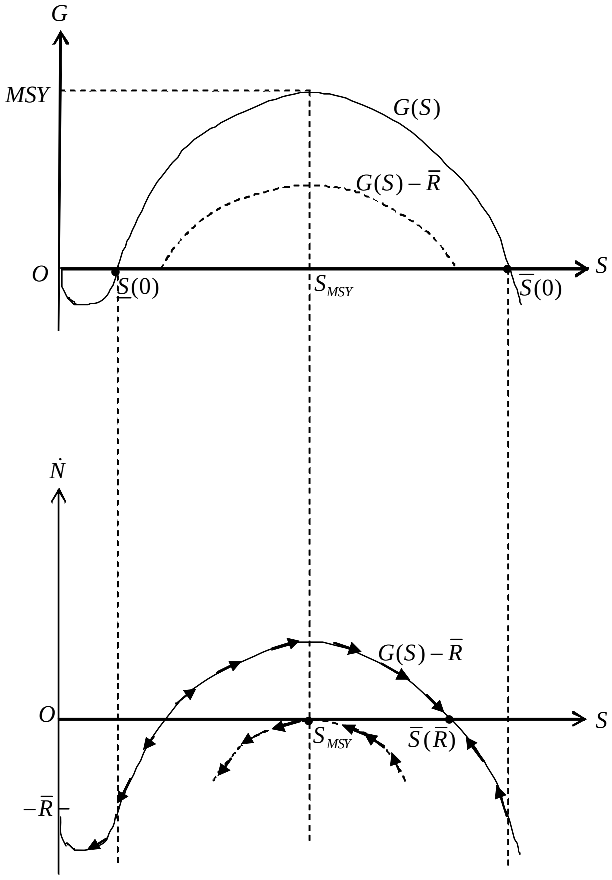

Figure 1: The self-generation function and stock dynamics for $R = \bar{R} \in (0, MSY)$.

the population necessarily shrinks and eventually reaches zero. We may call $\underline{S}(0)$ the *minimum sustainable stock.*

At the other intersection with the horizontal axis, $\bar{S}(0)$ represents the *maximum sustainable stock.* The eco-system cannot support further growth. The reason may be food scarcity or spreading of diseases because of high population density.[5] The value MSY, indicated on the vertical axis, in the upper panel equals $= \max_S g(S)$. This value is thus the maximum sustainable harvest level. It is sustainable, presupposing the size of the fish population is initially at least of size $S_{MSY} = \arg\max_S g(S)$ which is that value of S where $G(S) = MSY$. This size of the fish population is consistent with maintaining the harvest MSY forever in a steady state.[6]

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[5] Popular mathematical specifications of $G(\cdot)$ include the logistic function $G(S) = \ \alpha S(1 - S/\beta)$, where $\alpha > 0$, $\beta > 0$, and the quasi-logistic function $G(S) = \alpha S(1 - S/\beta)(S/\gamma - 1)$, where in addition $\gamma > 0$. In both cases $\bar{S}(0) = \beta$, but $\underline{S}(0)$ equals 0 in the first case and γ in the second.

[6] This is an ecological maximum and not necessarily in any sense an economic optimum. Indeed, since the search and extraction costs may be a decreasing function of the fish density, hence of the stock, it

The lower panel in Fig. 1 illustrates the dynamics in the $(S, \dot{S})$ plane, given a fixed level of $R = \bar{R} \in (0, MSY)$. The arrows indicate the direction of movement. In the long run, if $R = \bar{R}$ for all t, the stock will settle down at the size $\bar{N}(\bar{R})$. The stippled curve in the upper panel indicates $G(S) - \bar{R}$, which is the same as $\dot{S}$ in the lower panel, given $R = \bar{R}$. The stippled curve in the lower panel indicates the dynamics in case $R = MSY$.

4 Pollution

As hinted at above, the concern that certain production methods involve pollution is commonly incorporated into economic analysis by subsuming environmental quality into the general notion of renewable resources. In that context S_t in Fig. 1 will represent the "level of environmental quality" and R_t will be the amount of dirty emissions per time unit. Since the level of environmental quality is likely to be an argument in both the utility function and the production function, again some limitation of the "extraction" (the pollution flow) is motivated. Pollution taxes may help to encourage abatement activities and induce technical change towards cleaner production methods.

5 Literature

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Smulders, S., 1995.

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may be worthwhile to increase the stock beyond S_{MSY}, thus settling for a smaller harvest. Moreover, a microeconomic calculation will maximize the sum of discounted expected profits taking into account the expected evolution of the market price of fish, the cost function, and the dynamic relationship (2).

In a macroeconomic context, S possibly has amenity value, thus entering the period utility function. Then again some conservation of the stock over and above S_{MSY} will be motivated.

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