Environment and growth: endogenous sources of growth

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Plan of the lecture

- Environmental Kuznets Curve: An Overview
- Endogenous sources of growth
- Environment and endogenous growth: Gradus&Smulders (1993)

Preliminaries

- There is a **hypothesis** on inverted-U relationship between growth and environment
- It is far from being proved
- However, many policy debates are concentrated around it
- This idea evolved due to endogenous growth models being around
- Since growth is endogenous, it's effect on environment may be **nonmonotonic**.

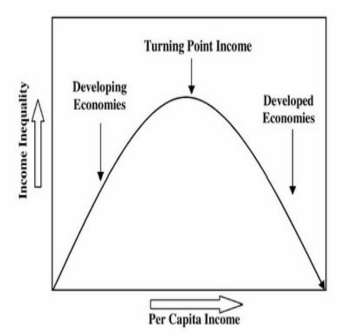
Intuition behind EKC

- Grow first clean up later
- Utility of clean environment increases with consumption growth
- Better technologies more feasible for advanced economies
- This is a counter-argument for Limits to Growth debate
- Includes technical change also as a factor

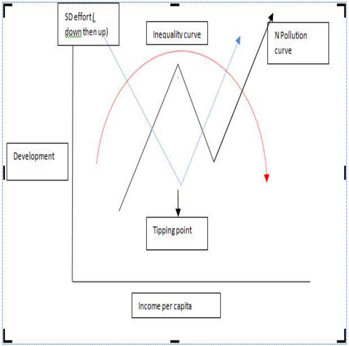
Effects of growth on the environment

- There are three main channels of growth' influence on environment:
  1. Scale effect ($-$): higher output leads to higher damages
  2. Composition effect ($+/-$): higher income leads to structural change towards cleaner industries
  3. Technique effect ($+$): with higher income more is spent on R&D, making cleaner technologies
- The inverted U-shape of EKC may be observed because of:
  1. Income elasticity of environmental demand is high enough
  2. Self-regulatory market mechanisms drive resource prices up
  3. Government interventions of bigger size (more resources at hand)

Illustration of debate



(a) EKC Hypothesis



(b) Limits to growth Hypothesis

Empirical evidence

- Air quality indicators show strong resemblance with EKC, but:
  1. Large standard errors for peak estimations;
  2. Only cross country studies of local concentrations;
  3. Global CO_2 concentration never decreases.
- Water quality indicators display both inverted-U and N-shaped curves:
  1. N-shape is consistent with Limits to growth analysis;
  2. If U-shape is found, it's peak is very high;
  3. N-shape is more likely since strong delays in water pollution (current ocean state?).
- For other indicators **there is no evidence of EKC at all**.

Cross-country vs Single-country studies

- The existence of EKC is mainly postulated by cross-country studies, but:
  1. This includes both developed and developing countries;
  2. Ergodicity fails.
- Single country studies do not find EKC even for developed economies:
  1. In four OECD countries air pollutant concentration increased within 1960-1993;
  2. Increment in even high income may worsen environment;
  3. Some studies still find reduction of pollution as income increases.
- ERGO: There is no evidence of EKC and deliberate regulation is necessary.

Conceptual overview

- Endogenous vs Exogenous growth
- AK-models
- Human capital

Conceptual overview

- Endogenous vs Exogenous growth
- AK-models
- Human capital
- **Variety expansion**
- **Quality ladders**
- **Directed technical change**

Exogenous vs Endogenous

Exogenous:

- Simple
- Unrealistic
- Growth from nowhere
- Models are similar
- Empirically fail always

Endogenous:

- Complex
- (a bit) More realistic
- Source pinpointed
- Many sources→many models
- Empirically valid sometimes

AK-models

- Considered to be the first endogenous growth model: Romer (1986)
- Idea: constant returns to scale are sufficient to generate ongoing growth (instead of decreasing in neoclassics)
- Not a 'true' endogenous growth model: technology is fixed
- Extremely simple, but dynamically inconsistent
- Constant ongoing growth causes infinite capital in finite time: How this looks like?

$$Y = AK,$$
$$\dot{k} = s \cdot A - n > 0 \quad (1)$$

Human capital

- Extension of AK-model to two sectors
- Capital and human capital grow independently
- Different from AK-model, human capital is endogenous
- The usual neoclassical dynamics is extended by human capital dynamics:

$$\dot{h} = (1 - u) \cdot h$$

  whereas u is controlled choice of time spent on education
- Control is as in R-C-K model (replace c by u there)

Technology in NGT

- Technology now serves as the main growth drive in theory
- It has **TWO** types:

Vertical:	**Horizontal**:
Simple	Complex
Applied research	Discoveries
No structural change	Dynamic structural change
Sustained growth	Growth is limited

- Two strands of literature
- Different impact on environment
- Some recent models combine both

Overview

- Studies the effects of environmental care on long-term growth and technology choices
- Comparison of three prototype growth models:
  - Neoclassical model with exogenous technology;
  - Romer's (1986) AK-model
  - Modification of Lucas (1988) model with dynamic human capital
- Pollution arises from production and enters social welfare function as disutility
- Environmental care is modelled as
  - Abatement efforts to clean up existing pollution
  - Switch to less-polluting technology of production

General model

The social planner is solving the optimization problem:

$$\max_{C} \int_{0}^{\infty} \mathbf{e}^{-\nu t} U(\frac{C}{L}, P) dt,$$

$$s.t.$$

$$P = P(K, A)$$

$$\dot{K} = Y(K, hL) - C - A \tag{2}$$

with

$$U_c > 0, U_{cc} < 0, U_P < 0, U_{PP} \leq 0, U_{cP} \leq 0, \quad P_K > 0, P_A < 0.$$

Optimality conditions

- **One** state K dynamical system
- **Two** controls: C, A yields two conditions: How to get them?

$$U_c = LU_P P_A; \tag{3}$$

$$\frac{\dot{c}}{c} = \left\{\left(Y_K + \frac{U_{cP}\dot{P} + LU_P P_K}{U_c}\right) - (\nu + \lambda)\right\}\eta \tag{4}$$

- The (4) is referred to as **Ramsey rule**

Condensing with $\lambda = \dot{L}/L,\ \eta = -U_c/cU_{cc}$

Social interest rate

- The Ramsey rule contains the so-called **social interest rate**:

$$r \stackrel{def}{=} Y_K + \frac{P_K}{P_A} - \xi \cdot \frac{\dot{P}}{P} \tag{5}$$

- It includes:

  relative productivity of investments
  utility loss from pollution
  physical marginal product

- Decentralised interest rate excludes the red term giving **larger** capital

Definition of social optimum

- The optimal consumption growth rate: Details

$$\frac{\dot{c}}{c} = \eta\left(Y_K + \frac{P_K}{P_A} - \xi \cdot \frac{\dot{P}}{P} - (\nu + \lambda)\right) \tag{6}$$

where $\xi = -PU_{cP}/U_c$;

- Positive growth thus requires

$$r \geq (\nu + \lambda); \tag{7}$$

- Implying market economy always grow **faster**

Neoclassical technology

Define

$$U(c, P) = \ln c - \frac{\varphi}{1+\psi} P^{1+\psi}; \tag{8}$$

$$P(K, A) = \left(\frac{K}{A}\right)^{\gamma}; \tag{9}$$

$$Y = K^{\beta} (hL)^{\alpha}. \tag{10}$$

This makes the R-C-K model with pollution.

- Technology is exogenous and constant;
- Human capital plays no role in the dynamics (constant h);
- Cobb-Douglas production.

Neoclassical BGP

The balanced growth path is characterized by:

$$g = \lambda + \nu; \tag{11}$$

$$g = r - \nu; \tag{12}$$

$$r = \beta \frac{Y}{K} - (\varphi\gamma)^{1/\mu} \cdot [\nu + (1-\beta)\frac{Y}{K}]^{1/\mu}. \tag{13}$$

where $\mu = 1 + \gamma + \gamma\psi$.

- The Eq. (11) provides the long-run attainable growth rate;
- The Eq. (12) provides the **desired** growth rate as a function of social preferences r;
- The last Eq. (13) gives output-to-capital ratio as a static allocation for any r.

Illustration Neoclassical model

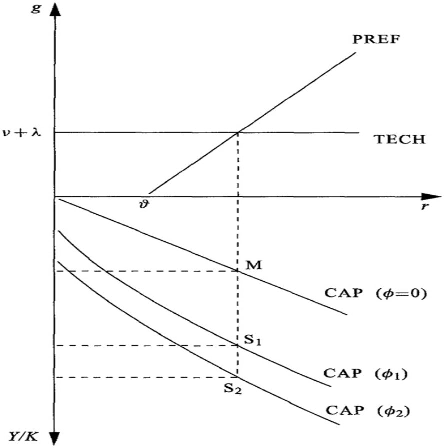


Fig. 1: Neoclassical case

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Comments

- With $\phi = 0$ the original Cass-Koopmans model is obtained with no internalization of pollution;
- The more weight the pollution has in the social welfare, the higher output-to-capital ratio has to be maintained;
- However, in the neoclassical framework the growth rate itself is unaffected;
- The social interest rate r is also constant;
- Pollution influences only the static allocation of capital!

Endogenous AK-growth specification

The simplest endogenous growth model assumes the production as:

$$Y = \alpha K; \tag{14}$$

Utility and pollution functions are defined by the same Eqs. (8), (9).

Then the consumption growth rate will be:

$$\frac{\dot{c}}{c} = \left\{ \alpha + \frac{P_K}{P_A} - \xi \cdot \frac{\dot{P}}{P} - (\nu + \lambda) \right\} \eta. \tag{15}$$

Where the marginal product of capital Y_K is replaced with constant α.

BGP for AK model with pollution

The BGP is defined by the set of conditions:

$$g = r - \frac{1}{\phi\gamma}(\alpha - r)^{\mu}; \tag{16}$$

$$g = r - \nu; \tag{17}$$

$$\frac{Y}{K} = \alpha. \tag{18}$$

- First Eq. (16) gives new technological constraints of growth;
- Eq. (17) is again the Ramsey savings rule;
- The last Eq. (18) gives (constant) output-to-capital ratio.

Illustration AK model

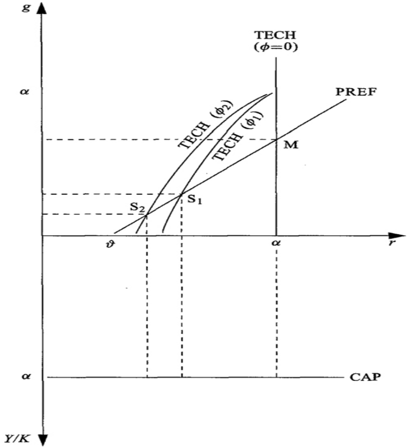

Fig. 2: "Rebelo case"

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Comments

- Point M corresponds to no pollution (no internalization);
- The higher the degree of internalization of pollution, the lower is the value of capital and growth rates;
- In market economy ($\phi = 0$) there are too much growth and too few cleaning activities;
- This model lacks factor substitution;
- The effect of **damages** from environment to production may counteract the lowering of growth rates;
- This raises the question of cleaner choice of factors for production.

Lucas model with human capital

This specification is given by production function and human capital dynamics:

$$Y = K^{\beta}(uhL)^{1-\beta}; \tag{19}$$

$$\dot{h} = \epsilon(1-u)h. \tag{20}$$

- The production function is of neoclassical type, allowing for factor substitution;
- However the efficiency of labour, h, is now dynamic;
- It grows proportionally to the time fraction, spent on eduction, $1-u$.

BGP conditions in Lucas model

With the same pollution and utility functions, the BGP of the economy is characterised by:

$$g = r - \nu; \tag{21}$$

$$g = \epsilon + \lambda; \tag{22}$$

$$r = \beta \frac{Y}{K} - (\phi\gamma)^{1/\mu} \cdot [\nu + (1-\beta)\frac{Y}{K}]^{1/\mu}. \tag{23}$$

Illustration for Lucas model

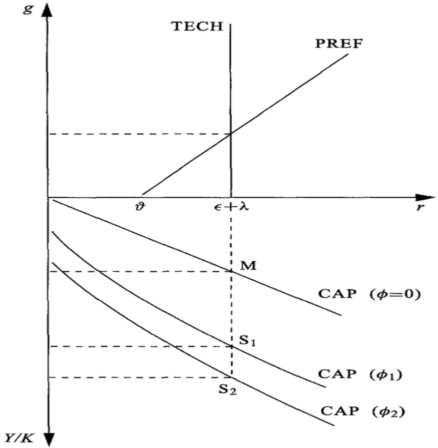

Fig. 3: "Lucas case"

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Comments

- The Lucas model exhibits independence of growth rate from the pollution;
- In the same way as in the neoclassical model, pollution affects only output-to-capital ratio;
- The reason for this is that environment affects only physical capital;
- Human capital accumulation, h, is unaffected and still this one governs the whole growth process;
- To allow for dependence of growth rate on pollution this h should depend on environment.

Modified Lucas case

Now include pollution as a factor into human capital dynamics:

$$\dot{h} = \epsilon(1-u)h - \xi(P)h. \tag{24}$$

where $\xi(P)$ is the influence of pollution on the learning process (?). Then the BGP Ramsey rule will depend on the steady state of pollution:

$$g - \lambda = \frac{\dot{c}}{c} = (\epsilon + \lambda - \xi(P^*) - (\nu + \lambda). \tag{25}$$

Illustration modified Lucas

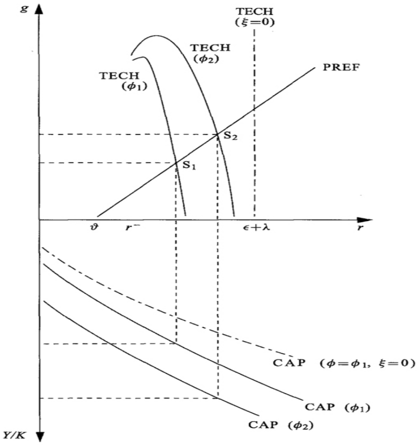

Fig. 4: Lucas case with health/education effects

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Comments

- This is the only version of the general model which allows both for output-to-capital ratio and growth depend on pollution;
- It is analytically difficult, since the technology requirement TECH now depends on the steady-state pollution;
- What is the "steady-state pollution" is not intuitive;
- The impact of environment on the learning is also not straightforward;
- The only conclusion is: market growth rate and capital are not optimal if to take care of environment.
- The human-capital type endogenous models are not the best choice for environmental analysis.

Conclusions

- Endogenous growth opened perspective for new kind of environmental modeling;
- First generation models mainly used AK-type or learning-by-doing frameworks;
- Internalization of environmental damage turned to slow down growth;
- Thus theoretically EKC fails;
- It fails empirically also, still widely discussed in the literature as an opportunity;
- Abatement from the government slows down capital accumulation,
- Thus the **only** channel for environmental care is technology..

References

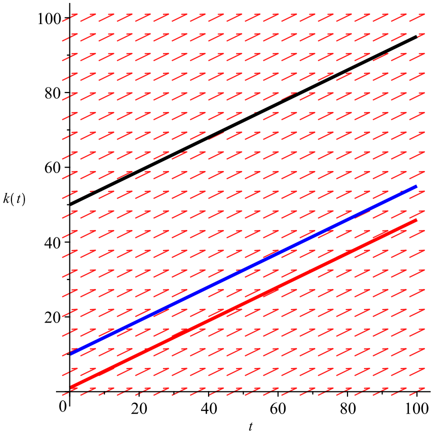
- Borghesi S. (1999) The Environmental Kuznets Curve:a Survey of the Literature;
- Gradus R., Smulders S. (1993) The Trade-off Between Environmental Care and Long-term Growth Pollution in Three Prototype Growth Models. *Journal of Economics, Vol. 58, No. 1, pp. 25-51*

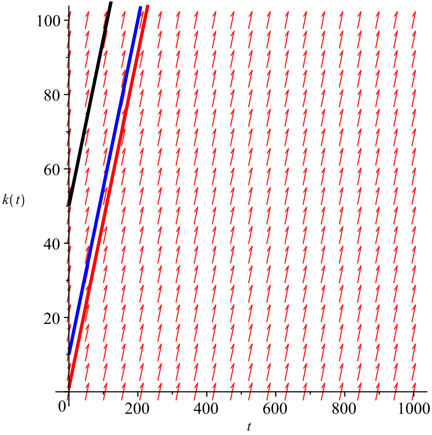
Next time

- We start with taste for variety concept
- The horizontal R&D as a source of growth
- Products variety definition and expansion
- Monopolistic competition and non-convexities
- Papers: Romer (1990), Grossman&Helpman (1991)

AK: inconsistency of capital accumulation given by (1)

Back





Necessary conditions I

Back Problem (2) yields (current value) Hamiltonian:

$$\mathcal{H}^{CV} = U(C(t)/L(t), P(K(t), A(t))) - \psi(t)(Y(K(t), hL(t)) - C(t) - A(t)$$

with 2 F.O.C.s and one co-state equation (suppressing t onwards):

$$\frac{\partial \mathcal{H}}{\partial C} = \frac{\partial U(c,P)}{\partial c} \cdot \frac{1}{L} - \psi = 0 \tag{26}$$

$$\frac{\partial \mathcal{H}}{\partial A} = \frac{\partial U(c,P)}{\partial P} \cdot P_A - \psi = 0 \tag{27}$$

$$\dot{\psi} = \nu \cdot \psi - \frac{\partial \mathcal{H}}{\partial K} \tag{28}$$

Necessary conditions II

Back Step 1: We use (26) and (27) to obtain (3):

$$\frac{\partial U(c,P)}{\partial c}\cdot\frac{1}{L}-\psi=\frac{\partial U(c,P)}{\partial P}\cdot P_A-\psi$$

Step 2: We use (28) and (26) to obtain (4):

$$\dot{\psi}=\nu\psi-\frac{\partial\mathcal{H}}{\partial K}\overset{\frac{d}{dt}(26)}{=}\frac{U_{cc}\dot{c}+U_{cP}\dot{P}}{L}-\frac{U_c}{L}\cdot\frac{\dot{L}}{L}$$

$$\dot{c}\overset{[\frac{\partial\mathcal{H}}{\partial K}=U_P P_K+\psi Y_K]}{=}\frac{(\nu\psi-U_P P_K-\psi Y_K+\frac{U_c\dot{L}}{L^2})L-U_{cP}\dot{P}}{U_{cc}}$$

$$\dot{c}/c\overset{[via(26)\ \psi=U_c/L]}{=}-\frac{U_c}{cU_{cc}}\left(\frac{U_{cP}\dot{P}}{U_c}-(\nu+\dot{L}/L)+\frac{LU_P P_K}{U_c}+Y_K\right)$$

with $\lambda=\dot{L}/L$, $\eta=-\frac{U_c}{cU_{cc}}$ finally giving (4)

BGP conditions

Back Start from (4)

$$(4) = \eta\left(Y_K - (\nu+\lambda) + \frac{P_K}{P_A} + \frac{U_{cP}\dot{P}}{LU_P P_A}\right) \overset{(3)}{=}$$

$$= \eta\left(Y_K - (\nu+\lambda) + \frac{P_K}{P_A} + \frac{U_{cP}\dot{P}}{U_c}\right) \overset{[\xi:=-PU_{cP}/U_c]}{=}$$

$$= (6)$$