Knowledge creation as a remedy against environmental degradation

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Plan of the lecture

- Knowledge as a remedy against environmental degradation
- Homer-Dixon arguments: Environment and violence
- Romer-Stiglitz model of growth and environmental impact on knowledge: Barbier (1999)

Knowledge creation

- Knowledge might be:
  - non-rival
  - non-degradable
- It can grow forever without limits
- Thus it is the only option for everlasting economic growth (**growth engine**)

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  - non-rival
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- It can grow forever without limits
- Thus it is the only option for everlasting economic growth (**growth engine**)
- Nature is:
  - not growing (exhaustible)
  - bounded
- Only knowledge may cope with bounded nature!

Minimal working example

The simplest model to include both environment and non-rival knowledge creation:

- Includes natural resources growth/degradation:

$$\dot{N} = E(N, R_0) - R;$$

- Knowledge creation mechanism:

$$\dot{H} = Y(N, R, H) - C;$$

- And social welfare function:

$$W = \int_0^\infty U(C, N, H)\mathrm{e}^{-\nu t} dt.$$

Feasibility and sustainability

- Assume constant (non-diminishing) returns to knowledge:

$$Y(N, R, H) = y(N, R)H;$$

- Constant fraction of output devoted to knowledge creation:

$$C = (1 - s_H)Y;$$

- The sustainable ($\dot{N} = 0$) solution is **feasible**:

$$\dot{H}/H = s_H y(\bar{N}, R)) = \dot{C}/C = \dot{Y}/Y,$$

- So economy may grow at a constant rate without harming the environment.

Main points

- The world is facing **increasing resource scarcity**
- The substitutability of natural resources is limited
- Even with substitutable resources greater amount of 'capital' is needed for this substitution
- Thus resource scarcity may lead to decrease in social welfare in a non-symmetric way
- The poorer the country is, the more it is going to be hurt by this scarcity

Asymmetry sources

- Poor countries has lower capital to output ratio:
  1. Lower possibilities to substitute resource for capital
  2. Greater decrease in GDP and social welfare from exhaustion
- Poor countries **export** the majority of their resources
  1. Local population may lack these (essential) resources
  2. Scarcities may stem from the degradation of **renewable**, rather than exhaustible resources (water)
  3. Further increasing social tensions and divergence in income levels.
- The environmental degradation is hurting **more** the less developed the country is.

Human capital and scarcity

- Increased social instability may lead to:
  1. Increase in violence level
  2. Decrease in social security level
  3. Deepened poverty
  4. Large-scale **migrations**.
- Decreased income leads to:
  1. Decreased government spending on social welfare
  2. Decreased R&D spending
  3. Degradation of infrastructure

R&D and Environment

- Human capital slows down the degradation
- Technique effect: increases substitutability of resources and capital
- Effect on GDP:
  1. Progress of technology drives resources prices down, decreasing income
  2. Increased scarcity may increase income giving resources for modernization.
- Environment degradation has negative effect:
  1. Slows down human capital growth (low income)
  2. Slows down productivity growth (damage functions)
  3. Increases social violence.

Overview

- The standard model of Romer (1990) with scarce natural resource as a factor
- The model amounts to optimal extraction rate of this resource
- Technology influences the extraction rate
- The state of environment may also influence technology
- **Resource-dependent** technological change!

Setup

- Production technology:

$$Q = Ax^{\alpha_1} L^{\alpha_2} R^{\alpha_3} H_Q^{\alpha_4}, \tag{1}$$

  is homogeneous with $\sum_1^4 \alpha_i = 1$ except for A

- Capital is accumulated through savings:

$$\dot{K} = Q - C \tag{2}$$

  with **endowment** $K(0) = K_0$

- Romer-type machines:

$$K = \eta A x \tag{3}$$

- Knowledge spillover

$$\dot{A} = \sigma H_A A \tag{4}$$

Exhaustible resource

- Environment in the model is represented by the stock of some exhaustible resource:

$$\int_{0}^{\infty} R dt \leq S_0, \dot{S} = -R. \tag{5}$$

- R is **a flow** of resource stock S into production Q
- Resource is **essential**, $R > 0$
- This is alternative way of representing environment

Output evolution

- Output may be rewritten as:

$$Q = \eta^{\rho-1} A^{1-\alpha_1} K^{\alpha_1} L^{\alpha_2} R^{\alpha_3} (H - H_A)^{\alpha_4} \tag{6}$$

where $\rho = (1 - \alpha_1) = \alpha_2 + \alpha_3 + \alpha_4$,

- The growth rate of output is thus:

$$g_Q = \rho g_A + \alpha_1 g_K + \alpha_2 n + \alpha_3 g_R - \alpha_4 g_H. \tag{7}$$

- Given by total differentiation of expression above

Dynamic problem

The social optimum problem is to maximize social welfare:

$$\max_c W = \int_0^\infty L_0 \mathrm{e}^{-(\delta - n)t} \frac{c^{1-\theta}}{1-\theta} dt \tag{8}$$

subject to dynamics of capital, technology, resource stock and labour:

$$\begin{aligned} \dot{K} &= Q - cL \\ \dot{A} &= \sigma H_A A \\ \dot{S} &= -R \\ \dot{L} &= n. \end{aligned} \tag{9}$$

Optimal growth conditions

Optimality conditions Derivations may be transformed into conditions for growth rates of the economy:

1. Ramsey rule for optimal savings:
$$g_c = \frac{\alpha_1\beta - \delta}{\theta}; \quad (10)$$
2. Hotelling's rule for resource extraction:
$$g_R = g_Q - \alpha_1\beta; \quad (11)$$
3. Romer's rule of human capital accumulation:
$$g_{H_Q} = -\alpha_1\beta + \frac{(1-\alpha_1)\sigma(H - H_A)}{\alpha_4} + g_Q; \quad (12)$$
4. Production rule
$$g_Q = (1-\alpha_1)\sigma H_A + \alpha_1(\beta - \beta z) + \alpha_2 n + \alpha_3 g_R + \alpha_4 g_{H_Q}. \quad (13)$$

Growth rates

Denote $\beta = Q/K, \beta_z = cL/K, \gamma = R/S$ (rate of resource utilization):

$$g_{\beta_z} = \frac{\alpha_1 \beta - \delta}{\theta} + n - \beta + \beta_z; \tag{14}$$

$$g_\beta = g_Q - \beta(1-z) = \frac{\alpha_2 n + (1-\alpha_1)\sigma H + \alpha_2 \beta_z}{\alpha_1 + \alpha_2} - (1-\alpha_1)\beta; \tag{15}$$

$$g_\gamma = g_Q - \alpha_1 \beta + \gamma = \gamma + \frac{\alpha_2 n + (1-\alpha_1)\sigma H - \alpha_1 \beta_z}{\alpha_1 + \alpha_2}; \tag{16}$$

$$g_{H_Q} = -\frac{\alpha_1 \beta_z + \alpha_2 n + (1-\alpha_1)\sigma H}{\alpha_1 + \alpha_2} + \frac{(1-\alpha_1)\sigma(H - H_A)}{\alpha_4}. \tag{17}$$

BGP

In this model the balanced growth is defined as:

1. Constant structure of the economy:

$$g_{\beta} = g_{\beta z} = g_{\gamma} = 0, \tag{18}$$

2. Constant consumption per capita growth rates:

$$g_c = g_K - n = g_Q - n = g; \tag{19}$$

3. Constant capital accumulation rate:

$$g_K = g_A + g_x. \tag{20}$$

Illustration Romer-Stiglitz model

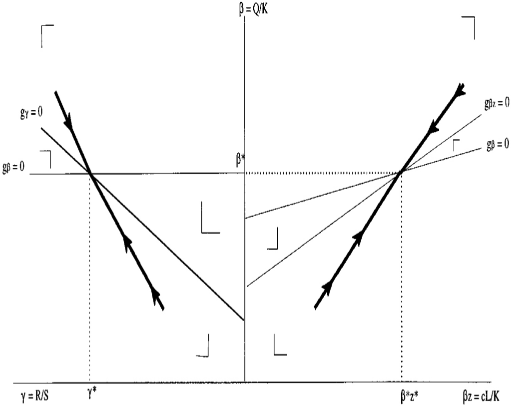

Figure 1. The long run equilibrium of the basic Romer–Stiglitz model.

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Equilibrium growth rates

- Per capita balanced growth rate of the economy is:

$$g^* = \frac{(1-\alpha_1)\sigma H^* - (\alpha_3+\alpha_4)\delta}{\alpha_2 + (\alpha_3+\alpha_4)\theta}, \tag{21}$$

- It defines the rate of resource utilization:

$$\gamma^* = (\delta - n) - (1-\theta)g^* = (\delta - n) - (1-\theta)\frac{(1-\alpha_1)\sigma H^* - (\alpha_3+\alpha_4)\delta}{\alpha_2 + (\alpha_3+\alpha_4)\theta}, \tag{22}$$

- and technology growth rate:

$$g_A^* = \frac{(\alpha_2 + (\alpha_3+\alpha_4)\theta)g^* + (\alpha_4+\alpha_3)\delta}{1-\alpha_1} - \sigma(H^* - H_A^*) = \sigma H_A^*. \tag{23}$$

Comments

- In this basic model long-run growth is possible;
- The rate of growth does not depend on resource extraction;
- For growth to be positive, there must be sufficient human capital H^* and productive R&D sector;
- Technical innovation may be sufficient to overcome decreasing resource stock **and** growing unskilled population;
- However, failure to boost innovations and/or conserve resources (slow down extraction rates) may result in **negative** consumption dynamics.

ERGO: In the basic model the generation of new intermediaries may overcome degradation of the resource.

Preliminaries

- The conclusions of the basic model may be too optimistic;
- Technical change, being endogenous, yields the same qualitative conclusions as neoclassical resource-augmenting technical change;
- In this setup consumption may grow indefinitely high despite limitedness of the resources;
- Resource exhaustion and consumption decrease may be postponed indefinitely (but eventually have to happen);
- The reason is that resource scarcity has no negative feedback on innovations generation.

Motivation

The increased resource scarcity may disrupt innovations because:

- Bad state of environment may negatively affect productivity of research (as in Gradus&Smulders for human capital);
- In low income economies resources extraction is the main drive of social welfare (Homer-Dixon arguments);
- Thus the degradation of this resource would disrupt national income, cause social conflicts;
- Social instability would, of course, disrupt research efforts;
- Fact: poorer economies invest less into R&D.

This is modelled by the negative relationship between γ and $\dot{A}$.

Setup

- The knowledge accumulation is now assumed to be affected by resources extraction:

$$\dot{A} = \sigma H_A A - \omega\gamma \tag{24}$$

with $\omega = const$,

- The modified Hamiltonian is F.O.C.s, Co-states:

$$\mathcal{H}^* = \frac{c^{1-\theta}}{1-\theta} + \lambda(Q - \mathbf{c}\mathbf{e}^{nt}) + \mu(\sigma H_A A - \omega\gamma) - \psi R, \tag{25}$$

with $\psi(t) > 0, \mu(t) > 0$.

Growth rates

1. Ramsey rule is the same;
2. Hotelling's rule for resource extraction:

$$g_R = g_Q - \alpha_1\beta + \frac{(1-\alpha_1)\omega\gamma}{\alpha_3 A}(1+\alpha_4 h); \tag{26}$$

3. Romer's rule of human capital accumulation:

$$g_{H_Q} = -\alpha_1\beta + \frac{(1-\alpha_1)\sigma(H-H_A)}{\alpha_4} + g_Q + \frac{\omega\gamma}{A}; \tag{27}$$

4. Production rule

$$g_Q = (1-\alpha_1)\sigma(H_A - \frac{\omega\gamma}{A}) + \alpha_1(\beta - \beta z) + \alpha_2 n + \alpha_3 g_R + \alpha_4 g_{H_Q}. \tag{28}$$

Steady state

is characterized by two conditions:

- Constant (increasing) consumption is possible if

$$g_C = g_Q \gtreqqless 0 \leftarrow \alpha_1 \beta^* = \delta \gtreqqless \frac{(1-\alpha_1)\sigma(H^* - H_A^*)}{\alpha_4} + \frac{\omega\gamma^*}{A^*} \tag{29}$$

- Constant (decreasing) rate of resource utilisation is possible if:

$$g_\gamma \gtreqqless 0 \leftarrow \gamma \gtreqqless \gamma^* = \frac{(1-\alpha_1)\sigma(H^* - H_A^*)}{\alpha_4} - \frac{(\alpha_2 + \alpha_4(1+h^*))}{\alpha_3}\sigma H_A^*. \tag{30}$$

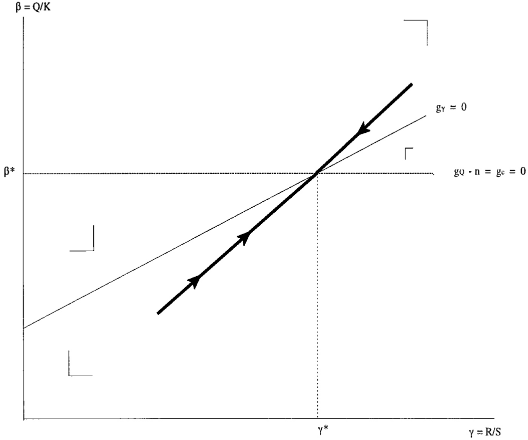
Sustainable resource usage

Substituting (29) into (30) and utilizing $g_A = 0$ in equilibrium we get the central point:

$$\gamma^* = \delta - \frac{1 - \alpha_1 + \alpha_4 h^*}{\alpha_3} \sigma H_A^* \tag{31}$$

- Higher opportunity costs of holding on resources, δ, increase resource exploitation;
- Higher emphasis on research rather than production, h slows down degradation;
- Higher efficiency of research, σ has the same effect.

Modified Romer-Stiglitz: illustration



The steady state of the constrained Romer-Stigliz model.

Policy implications

- In the Romer's framework postponing total exploitation indefinitely is possible;
- For that government has to increase the share of R&D sector (h);
- Through (possibly) institutional reforms it has also to increase efficiency of R&D;
- This model is particularly suitable for developing resource-dependant countries;
- R&D efficiency may be increased through appropriate trade agreements?

Conclusions

- Depending on the way of specifying knowledge creation, effect on environment is different;
- Non-rival fundamental knowledge creation is beneficial;
- However, variety expansion per se has to use natural resources of a kind;
- What is the **optimal direction and type** of technical change?

References

- Smulders S. (1995) Enthropy, Environment and Endogenous Economic Growth. *International Tax and Public Finance, 2*, pp. 319-340;
- Homer-Dixon T. (1995) The Ingenuity Gap: Can Poor Countries Adapt to Resource Scarcity? *Population and Development Review, Vol. 21, No. 33*;
- Barbier E. (1999) Endogenous Growth and Natural Resource Scarcity. *Environmental and Resource Economics, 14*, pp. 51-74;

Next time

- We consider another dimension of technical change
- It is given by quality increases rather than taste-for-variety concept
- It employs the notion of creative destruction
- Paper: *A Model of growth through creative destruction*. Aghion&Howitt (1992)

Solution for (8)-(9)

This dynamic problem is solved with the help of (current-value) Hamiltonian:

$$\mathcal{H} = \frac{c^{1-\theta}}{1-\theta} + \lambda(Q - c\mathbf{e}^{nt}) + \mu(\sigma H_A A) - \psi R. \tag{32}$$

Which yields F.O.C. and costate equations:

$$\begin{aligned}
&\frac{1}{c^{\theta}} - \lambda \mathbf{e}^{nt} = 0 \\
&\dot{\lambda} = (\delta + n)\lambda - \lambda Q_K \\
&\dot{\mu} = (\delta + n)\mu - \mu\sigma H_A \\
&\dot{\psi} = (\delta + n)\psi + \psi
\end{aligned} \tag{33}$$

Back

F.O.C.s for (25)

- Optimal consumption per capita:

$$\frac{\partial \mathcal{H}^*}{\partial c} = 0 \rightarrow \lambda = \frac{c^{-\theta}}{L} \tag{34}$$

- Optimal human capital in research:

$$\frac{\partial \mathcal{H}^*}{\partial H_A} = 0 \rightarrow \mu\sigma A = \frac{\lambda\alpha_4 Q}{H - H_A} \tag{35}$$

- Optimal resource exploitation:

$$\frac{\partial \mathcal{H}^*}{\partial R} = 0 \rightarrow \psi = \frac{\lambda\alpha_3 Q}{R} - \frac{\mu\omega\gamma}{S} \tag{36}$$

Back

Shadow prices for (25)

- Growth of marginal capital 'price':

$$\dot{\lambda}/\lambda = (\delta - n) - \frac{\partial \mathcal{H}^*}{\partial K} = (\delta - n) - \alpha_1 \frac{Q}{K}; \qquad (37)$$

- Growth of marginal technology 'price':

$$\dot{\mu}/\mu = (\delta - n) - \frac{\partial \mathcal{H}^*}{\partial A} = (\delta - n) - \frac{\lambda}{\mu}(1 - \alpha_1)\frac{Q}{A} - \sigma H_A; \quad (38)$$

- Growth of marginal resource 'price':

$$\dot{\psi}/\psi = (\delta - n) - \frac{\partial \mathcal{H}^*}{\partial R} = (\delta - n) - \frac{\mu}{\psi}\omega\gamma S^{-1}. \qquad (39)$$

Back