The Romer Model

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Issues

- We study models where **intentional innovation** drives productivity growth.
- **Romer model**:
  - The standard model of R&D goes back to **Romer** (1990).
  - Innovations are produced like any other good using R&D labor as input.
- **Policy effects**
  - Policies, such as R&D subsidies, can change the rate at which innovations are produced.
  - Surprisingly, it turns out that **policies** have **no effect on long-run growth**.

- Production of goods works exactly like in the Solow Model
- Aggregate production function:

$$Y_t = K_t^{\alpha} \ (A_t L_{Yt})^{1-\alpha} \tag{1}$$

- **Capital accumulation** as in the Solow model

$$\dot{K}_t = s_K Y_t - dK_t \tag{2}$$

- **Labor input** grows at a constant rate

$$g(L) = n \tag{3}$$

Solow Block

What has changed?

Final goods production function has:

- constant returns to rival inputs: K and L_Y.
- has **increasing returns** to all inputs (including A)

Labor is divided into production (L_Y) and R&D (L_A).

R&D Block

- Ideas are produced just like other goods.
- The input is labor (L_{At})
  - not much changes if capital is an input, too.
- The output is a number of new ideas.
  - A_t is the number of ideas that have been invented up to t.
  - $\dot{A}_t$ is the number of ideas discovered today (or the rate at which they are discovered).

R&D Block

- The **ideas production function**:

$$\dot{A}_t = \bar{\delta} L_{At}^{\lambda} \tag{4}$$

- λ determines returns to scale.
- $\bar{\delta}$ is a productivity parameter.

Ideas are inputs to innovation

- How easy it is to produce a new idea depends on how much has already been discovered.

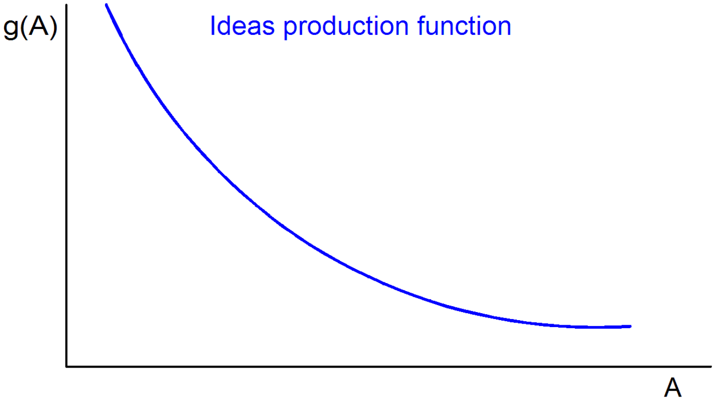
$$\bar{\delta} = \delta \ A^{\phi} \tag{5}$$

- If ideas help produce new ideas: $\phi > 0$: $A \uparrow \Longrightarrow \bar{\delta} \uparrow$.
- If there is "fishing out:" $\phi < 0$.
- Assume $\phi \leq 1$. (If $\phi > 1$ odd things happen...).
- The ideas production function is then

$$\dot{A} = \delta \ L_A^{\lambda} \ A^{\phi} \tag{6}$$

$$g(A) = \delta \ L_A^{\lambda} \ A^{\phi - 1} \tag{7}$$

Ideas production function



Even though ideas foster innovation $(\phi > 0)$, more ideas imply **slower** $g(A)$.

- So far we have described technologies.
- To describe behavior, we make a **Solow assumption**:
  - A constant saving rate

$$S/Y = I/Y = s_K$$

  - A constant labor allocation:

$$L_R = s_R \ L \tag{8}$$

$$L_Y = (1 - s_R) \ L \tag{9}$$

Model summary

The Solow block:

$$Y = K^{\alpha} \ (A \ L_Y)^{1-\alpha} \tag{10}$$

$$\dot{K} = s_K \ Y - \delta \ K \tag{11}$$

$$L_t = L_0 \ e^{nt} \tag{12}$$

Production of ideas:

$$\dot{A} = \delta \ L_A^{\lambda} \ A^{\phi} \tag{13}$$

Constant behavior:

$$L_Y = s_Y \ L; \quad L_A = s_A \ L \tag{14}$$

The growth rate of ideas:

$$g(A) = \delta \ (s_A \ L)^{\lambda} \ A^{\phi - 1} \tag{15}$$

Does the Model Make Sense?

- The production functions are arbitrary.
  - But what matters are certain qualitative features, not the exact functional form.
  - We wil get back to this.
- There is only one input. Only one good.
  - All of this can be relaxed without changing anything too important.
- Where are the households, consumption, population growth ...
  - We can add those - it does not make any difference.
- The labor allocation is fixed.
  - This is important.
  - The literature does not make this assumption. It can talk about patents, policy, ...
- Ideas are produced like goods.

Balanced growth path

Definition

A BGP is a path along which all variables grow at **constant rates**.

- Law of motion: $g(k) = s\ y/k - d$.
  - Constant $g(k)$ requires constant k/y.
  - Therefore: $g(k) = g(y)$.
- Production function: $y = k^{\alpha}\ A^{1-\alpha}$.
  - Take growth rates: $g(y) = \alpha\ g(y) + (1-\alpha)\ g(A)$.
  - Therefore: $g(y) = g(A)$.

Growth rate of ideas

$$g(A) = \frac{\lambda \ n}{1 - \phi} \tag{16}$$

Proof:

Ideas production:

$$g(A) = \delta \frac{L_A^{\lambda}}{A^{1-\phi}} \tag{17}$$

Take growth rates of that

$$g(g(A)) = \lambda g(L_A) - (1 - \phi) g(A) \tag{18}$$

With constant time allocation, s_R: $g(L_A) = n$.

Balanced growth means: $g(A)$ does not grow:

$$0 = \lambda \ n - (1 - \phi) \ g(A) \tag{19}$$

Summary: Balanced growth

Balanced growth in the Romer model is characterized by:

$$g(y) = g(k) = g(A) \tag{20}$$

$$g(A) = \frac{\lambda \ n}{1-\phi} \tag{21}$$

All growth is due to innovation.

Why is this true?

Balanced growth: Intuition

$$g(A) = \frac{\lambda \; n}{1-\phi} \tag{22}$$

Growth is simply a multiple of population growth

Behavior does not matter: s_K and s_R do not appear in (22).

Intuition

- Consider the case $\phi = 0$.
- Ideas production is then

$$\dot{A} = \delta \ L_A^{\lambda} \tag{23}$$

- If the population is **constant**, L_A is constant.
- In each period, the economy produces a constant number of ideas.
- The growth rate of ideas, $g(A) = \delta \ L_A / A$, falls to zero over time.
- A fixed number of people cannot produce a growing stream of ideas.

Population growth is necessary for sustained innovation (at a constant rate).

Intuition
Case: Phi = 1

- With $\phi = 1$, idea production becomes

$$g(A) = \delta \ L_A^{\lambda} \tag{24}$$

- This is the case studied by Romer (1990).
- The model has exploding growth, unless the population is constant.
- This is clearly contradicted by post-war data: L_A rose dramatically, while $g(y)$ was at best constant.

Reality check

1. The model says: constant population - no growth.
   - But we are still producing new ideas all the time.
   - How can we reconcile this?
2. What if the population shrinks over time?
   - Is the long-run growth rate negative?

Policies have level effects

- What are the effects of government policies?
- We may expect policies to affect saving (s_K), R&D (s_R), or population growth (n).
- Consider the case of $\phi < 1$, where growth is

$$g(A) = \frac{\lambda \ n}{1 - \phi} \tag{25}$$

- Main result: Policies that affect only saving or investment in R&D (s_R) do not affect long-run growth.
- Note: For policies that do not affect R&D the model behaves exactly like the Solow model.

R&D Subsidies

- Consider a permanent increase in s_R.
- We must consider two equations:

$$g(A) = \delta \ (s_R L)^{\lambda} \ A^{\phi-1} \tag{26}$$

$$\dot{K} = s_K \ Y - d \ K \tag{27}$$

- Note: Behavior of A is independent of K and Y.
- Simplify by assuming $\lambda = 1$ and $\phi = 0$ so that

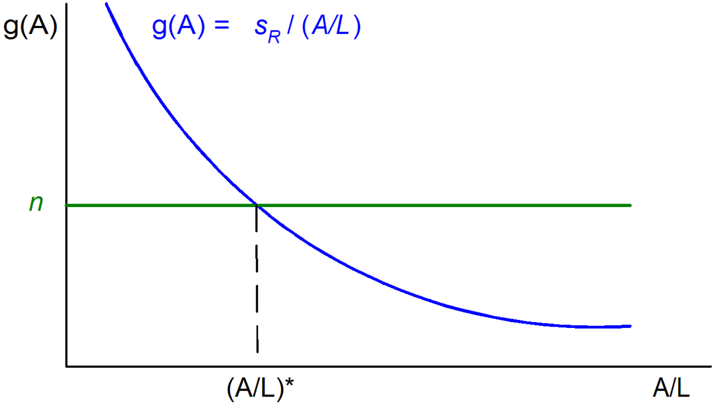
$$g(A) = \delta \ s_R \ L \ / \ A \tag{28}$$

- Balanced growth rate:

$$g(A) = n$$

R&D Subsidies

Steady state and stability



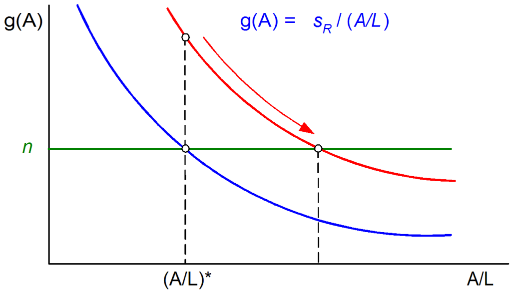
R&D Subsidies

- On a BGP, (28) determines A/L:

$$(A/L)^* = \frac{\delta \ s_R}{g(A)} = \frac{\delta \ s_R}{n} \tag{29}$$

- As long as L/A is above BGP, $g(A) > n$ is above BGP.
- Therefore, $g(A)$ declines over time until it reaches n.

Transition path after an increase in sR



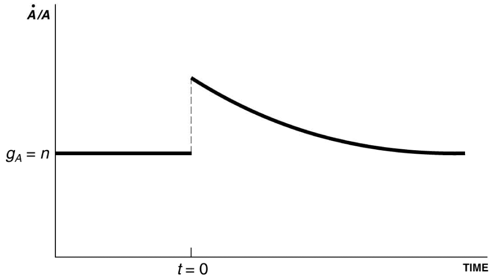
Start in BGP with $L/A = \frac{n}{\delta \ s_R}$.

Raise s_R. That reduces steady state L/A (more ideas per capita).

L/A is initially above steady state.

Growth rate increases (more R&D), but falls over time.

Time path of the growth rate of ideas



5.2 $\dot{A}/A$ OVER TIME

A period of faster innovation builds up more ideas.

Time path of A

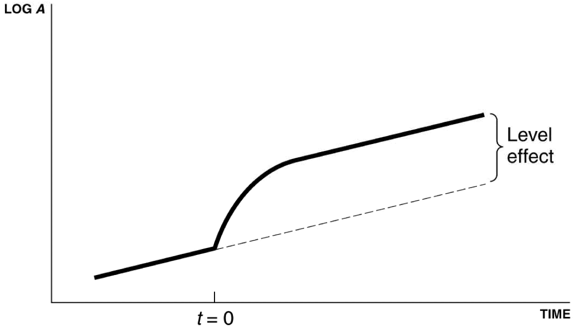


FIGURE 5.3 THE LEVEL OF TECHNOLOGY OVER TIME

Eventually growth levels off, but the higher level of A remains forever.

Policy Implications

Policy implications

- Patent protection, R&D subsidies, and other policies affect s_R.
- These policies can raise the growth rate of output, although not in the long run.
- Policies do affect long-run levels of Y/L.

Gains From Openness

- Traditional trade theory implies that gains from trade are small.
- The Romer model has a new channel for gains from trade.
- The idea:
  - each firm invests in technology capital A
  - closed economy: A can be used in all domestic locations
  - open economy: A can be used in more locations
  - productivity rises due to increasing returns to scale

Evidence: Gains From Openness

Idea: do countries that open up grow faster?

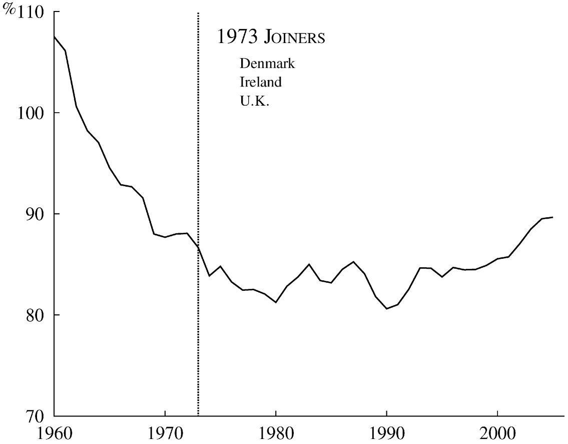


Fig. 2. 1973 joiners' labor productivity as a percentage of EU-6 (1960–2005).

McGrattan and Prescott (2009)

Evidence: Gains From Openness

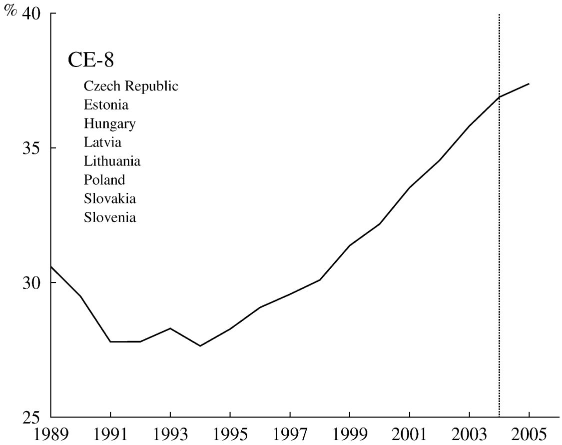
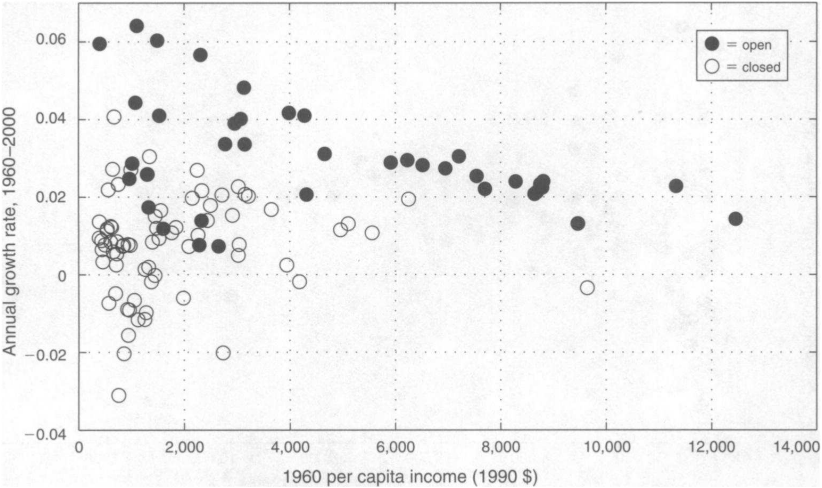


Fig. 5. CE-8 labor productivity as a percentage of EU-6 (1989–2005).

McGrattan and Prescott (2009)

Evidence: Gains From Openness



Lucas (2009): open economies converge to the frontier country.

Efficiency

- There is no reason to believe that "the market" chooses the optimal level of R&D.
  - R&D is only profitable if the innovator earns rents. This requires patents (government intervention).
  - Innovators are monopolists for some time (patents). Monopoly pricing is not efficient.
  - Innovation has knowledge spillovers - other innovators benefit.
- Which policies induce efficient innovation is an easy question in theory, but hard in practice.

Free Riding

- Most countries seem to invest almost nothing in R&D.
  - They free-ride on innovations in the leading countries (U.S., Japan, Germany).
- One implication: it is not clear how much an increase in U.S. R&D would increase U.S. productivity.
- In the long-run, the effect could be quite small.

Policy implications
The main trade off

Patents induce firms to invest in R&D.

- Pay a fixed cost up front.
- Receive profits from the patent over time.

Better patent protection implies:

- more ideas (higher s_R and A);
- fewer resources available for producing output (lower L_Y);
- more **monopoly distortions** (high prices of goods covered by patents).

Summary

- Innovations are produced just like regular goods, but they are non-rival.
- Therefore, we have scale effects: larger markets support more rapid innovation.
- The growth rate of Y/L is proportional to the population growth rate.
- A one-time increase in R&D effort (higher L_A) raises the rate of innovation permanently.
  - But this is not enough to sustain higher long-run growth.
- Policies only have level effects.

Final Example

What is the effect of a permanent increase in

1. research productivity
2. population?

Reading

- Jones, Introduction to Economic Growth, ch. 5.
- Romer, Advanced Macroeconomics, ch. 3.1-3.4.
- Jones, Macroeconomics, ch. 6

Advanced Reading

- Jones, Charles (2004). "Growth and Ideas." [Can be downloaded from Chad Jones's web page at Stanford]
- Lucas, R. E., & Jr. (2009). Trade and the diffusion of the industrial revolution. American Economic Journal: Macroeconomics, 1(1), 1-25. http://www.jstor.org/stable/25760258
- McGrattan, E. R., & Prescott, E. C. (2009). Openness, technology capital, and development. Journal of Economic Theory, 144(6), 2454 - 2476. doi:10.1016/j.jet.2008.05.012