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**.

Learning Objectives

In this section you will learn:

1. how to analyze the Romer model
2. why R&D policies do not change the long-run growth rate of the economy

The Romer model

Solow block

- 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

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

- **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**:

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

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

Ideas are inputs to innovation

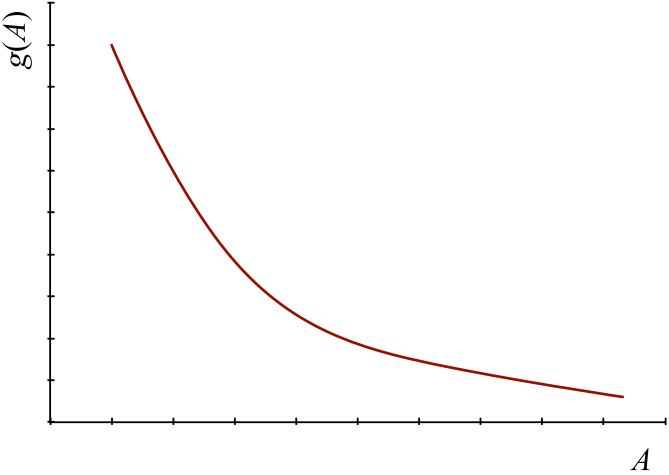
- How easy it is to produce a new idea depends on how much has already been discovered.

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

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

$$\dot{A} = B\ L_A^{\lambda}\ A^{\phi} \tag{6}$$
$$g(A) = B\ L_A^{\lambda}\ A^{\phi-1} \tag{7}$$

Ideas production function



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

Ideas production function

Note how similar this is to the law of motion for capital in the Solow model

Model			Productivity	"Capital"	Labor	Depreciation
Solow	$\dot{K}_t$	$=$	A_t	K_t^{α}	$L_t^{1-\alpha}$	$-\delta K_t$
Romer	$\dot{A}_t$	$=$	B	$A_t^{\phi-1}$	L_{At}^{λ}	-0

The Romer model
Behavior

- 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:

$$L_A = s_A L \tag{8}$$
$$L_Y = (1 - s_A)\ L \tag{9}$$

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:

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

Constant behavior:

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

The growth rate of ideas:

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

Model summary

- This looks complicated, but isn't.
- We have tricked the model such that Y and K don't matter for how A evolves.

$$\dot{A} = B\ L_A^{\lambda}\ A^{\phi} \tag{16}$$

- This would change, if we let $\dot{A}$ depend on K
  - but that would not affect the results
  - only the algebra would be more complicated (see **?**)

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**.

Why might this be interesting?

Balanced growth path

At what rates do the endogenous objects grow on the BGP?

Result 1: $g(k) = g(y)$

Proof:

Balanced growth path

Result 2: $g(y) = g(A)$

Proof:

Result

All long-run growth is due to R&D.

Growth rate of ideas

$$g(A) = \frac{\lambda\ n}{1-\phi} \qquad (17)$$

Proof:

Ideas production:

$$g(A) = B\frac{L_A^{\lambda}}{A^{1-\phi}} \qquad (18)$$

BGP: $g(A)$ is constant $\Longrightarrow L_A^{\lambda}A^{\phi-1}$ is constant

Take growth rates of that

$$g(g(A)) = \lambda g(L_A) - (1-\phi)g(A) = 0 \qquad (19)$$

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

Solve for $g(A)$. Done.

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?

Why is all growth due to innovation?

Solow model:

Romer model:

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_A do not appear in (22).

Intuition

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

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

- 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, $g(A) = B\, L_A / A$, 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

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

- 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?

Policy Implications

Policies have level effects

- What are the effects of government policies?
- We may expect policies to affect saving (s_K), R&D (s_A), 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_A) 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_A.
- We must consider two equations:

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

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

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

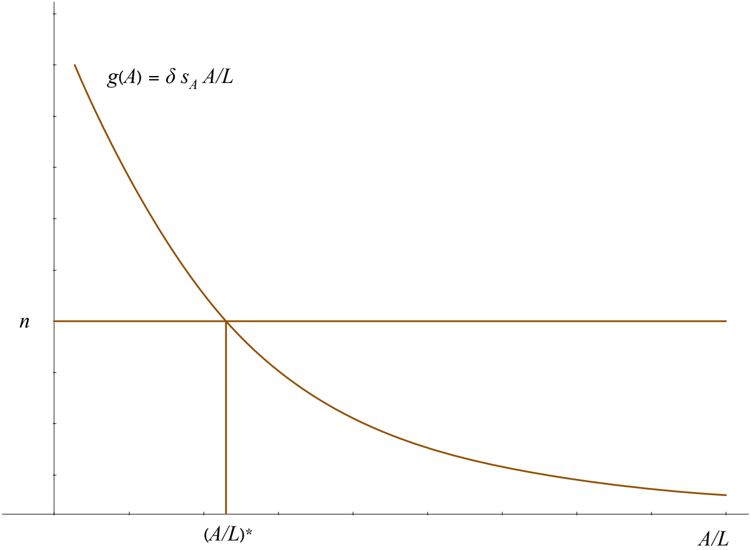
$$g(A) = B \ s_A \ L \ / \ A \tag{28}$$

- Balanced growth rate:

$$g(A) = n$$

R&D Subsidies

Steady state and stability



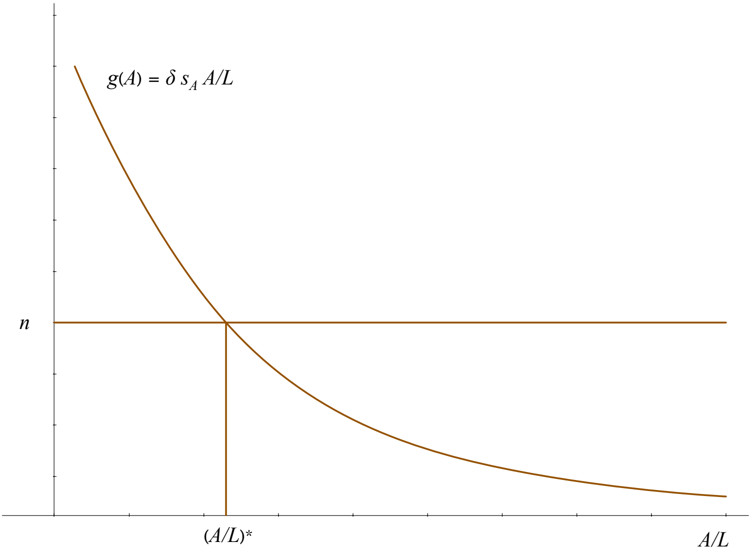
R&D Subsidies

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

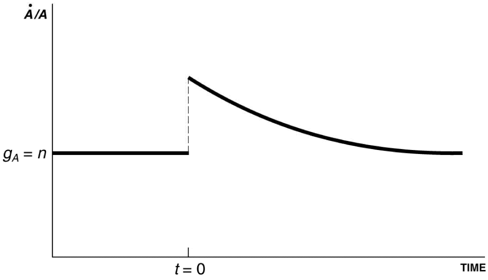
$$(A/L)^* = \frac{B\ s_A}{g(A)} = \frac{B\ s_A}{n} \tag{29}$$

- 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 s_A



Time path of the growth rate of ideas



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

Economic Growth,

A period of faster innovation builds up more ideas.

Time path of A

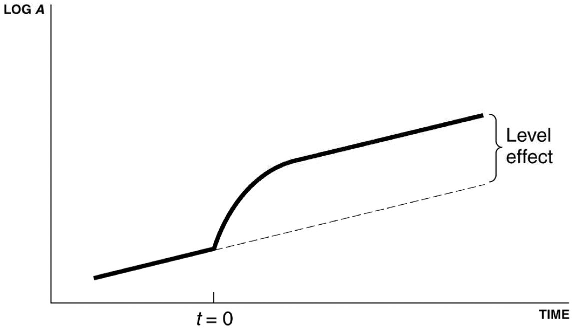


FIGURE 5.3 THE LEVEL OF TECHNOLOGY OVER TIME

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

Policy implications

- Patent protection, R&D subsidies, and other policies affect s_A.
- 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?

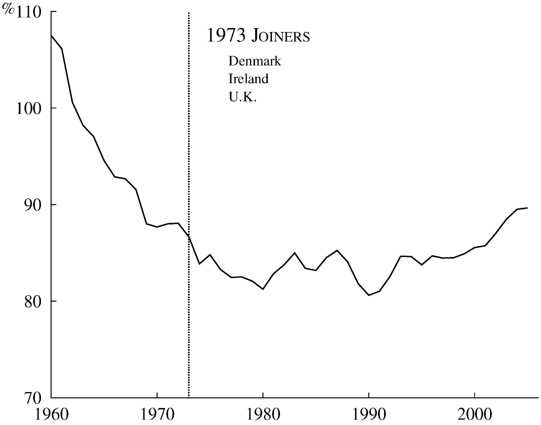


Fig. 2. 1973 joiners' labor productivity as a percentage of EU-6 (1960–2005).

Source: ?

Evidence: Gains From Openness

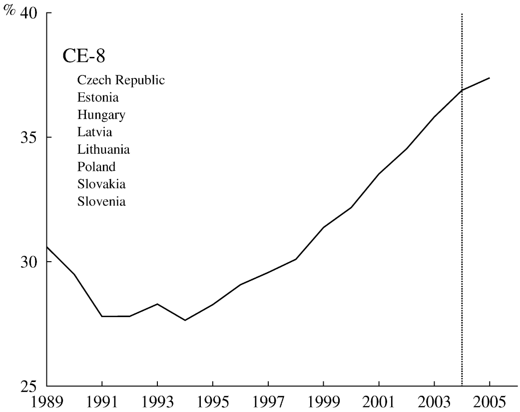
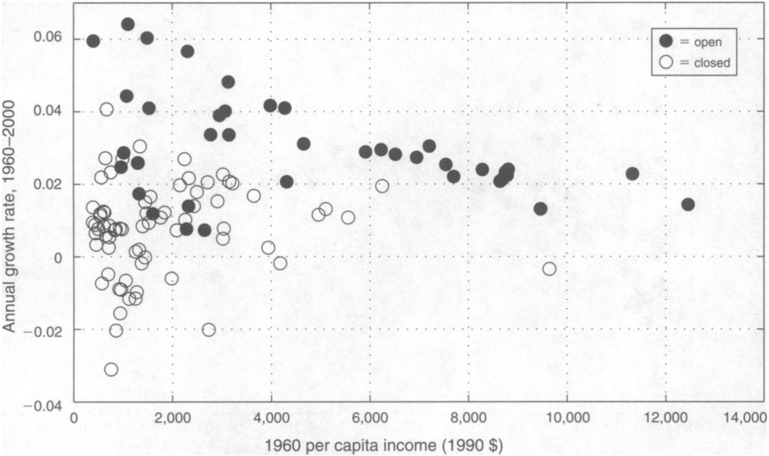


Fig. 5. CE-8 labor productivity as a percentage of EU-6 (1989–2005).

Source: ?

Evidence: Gains From Openness



?: open economies converge to the frontier country.

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.

Optional:

- **?**, ch. 3.1-3.4
- Jones, Macroeconomics, ch. 6

Advanced Reading

- ? talks in some detail about the economics of ideas.
- ? and ? on openness and growth

References I