Lecture 7: The New Growth Theory: Romer Model

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Outline

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- Endogenising technological progress
  - The nature of knowledge/idea
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Introduction to New Growth Theory (1 of 2)

- In the neoclassical growth models we have discussed so far, the long run growth of output per worker is determined by a mystery variable, the "effectiveness of labour" (A), whose exact meaning is not specified and whose behavior is taken as exogenous.
- New growth theory, also known as endogenous growth theory, developed since 1980s, aims to overcome this shortcoming. (i.e. to endogenise long run growth in output per worker)
- Competing models have been developed by various economists. Crucial importance is given to the "production" of new technologies and human capital.

Introduction to New Growth Theory (2 of 2)

- One class of endogenous growth models aims to endogenise technological progress (i.e. to identify A and endogenise its evolution).
- Romer (1986, 1987, 1990), Grossman and Helpman (1991), Aghion and Howitt (1992) etc.
- Another approach to generate endogenous growth is to assume that all production factors are reproducible. In particular, incorporating human capital and model its evolution.
- Uzawa (1965), Lucas (1988), Rebelo (1991) etc.
- We will briefly review one model from each literature, discuss its main implications, and directions for future research.

Endogenising Technological Progress (1 of 2)

- In this strand of endogenous growth literature, sustained growth is driven by sustained growth in technology where the latter is somehow chosen by the agents in the economy.
- The main challenge for this literature is to identify what A is and how it evolves over time. (i.e. the nature of knowledge/idea)
- We have simply described A as knowledge. But knowledge/idea come in many forms, ranging from the highly abstract to the highly applied. Different types of knowledge play different roles in economic growth.
- How knowledge/idea accumulate over time? There are many channels through which societies accumulate knowledge: formal education, on-the-job training, basic scientific research, learning-by-doing, process innovations, and product innovations.

Endogenising Technological Progress (2 of 2)

- Nonrivality of knowledge/idea: All types of knowledge share one essential feature: they are nonrival. The use of a piece of knowledge in one application makes its use by someone else no more difficult. Conventional private economic goods, in contrast, are rival.
- Although all knowledge/idea is nonrival, it is heterogenous along a second dimension: excludability. A good is excludable if it is possible to prevent other from using it.
- Excludability depends both on the nature of knowledge/idea itself and on economic institutions governing property rights.
- Major forces governing the allocation of resources to the development of knowledge/idea: support for basic scientific research, private incentives for R&D and innovations, alternative opportunities for talented individuals, and learning-by-doing etc.

Challenges to Model the Growth of A

- Identify what A is and what role it plays in the production of final goods.
- Through what channel is A accumulated? What factors are important to its accumulation process?
- The markets for knowledge may deviate from perfect competition.
- Due to the nonrivality nature of knowledge, if some types of knowledge has a low degree of excludability by nature, then incentives are needed for agents to create such knowledge, such as patent law and copyright law. This may imply a deviation from perfect competition.

Revisit Our Standard Production Function (1 of 2)

- Suppose Pfizer is developing a new medicine for treating COVID-19 (affects about 50% of the population).
  - Coming up with the successful, new chemical formula is the hard part – rough estimates suggest an average cost of $800 million to develop a new medicine.
  - Once developed, just an object, subject to standard CRS production.
  - Example: $800 million R&D cost, then $10 per dose in manufacturing costs
- Constant returns after invention implies increasing returns including invention.
  - $800 million dollars ⇒ 1 dose
  - $1600 million dollars ⇒ about 80 million doses
  - Doubling inputs far more than doubles output!

Revisit Our Standard Production Function (2 of 2)

- Familiar notation, but now let A_t denote the "stock of knowledge" or ideas:

$$Y_t = F(K_t, L_t, A_t) = A_t K_t^{\frac{1}{3}} L_t^{\frac{2}{3}}$$

- Constant returns to scale in K and L holding knowledge fixed.

$$Y_t = F(2K_t, 2L_t, A) = 2F(K_t, L_t, A)$$

- But therefore increasing returns in K, L and A together!

$$F(2K_t, 2L_t, 2A_t) > 2F(K_t, L_t, A_t)$$

- Economic interpretation is quite straightforward:
  - Replication argument + Nonrivalry ⇒ CRS to objects
  - Therefore there must be IRS to objects and ideas.

Problems with Perfect Competition

- Adam Smith's fundamental invisible hand result
  - Under perfect competition, markets lead to the best of all possible worlds (Pareto optimality at least).
  - Marginal benefits = marginal costs via the price system and prices allocate scarce resources to their best uses.
- There must be a wedge between price and marginal cost, so that firms can recover the fixed cost of inventing new ideas.
- A single price cannot simultaneously provide the appropriate incentives for research and allocate scare resources efficiently.
- We no longer live in the best of all possible worlds there is an important role for institutions beyond free markets.

Basic Setup of Romer Model (1 of 3)

- The nonrivarly of ideas can sustain growth in a way that capital accumulation could not.
- Focus on ideas versus objects.
- **Production function for the consumption good**: output is produced using the stock of existing knowledge, labour and capital

$$Y_t = A_t K_t^{\alpha} L_{y,t}^{1-\alpha}$$

- **Production function for ideas**: the new ideas produced during period t (change in stock of ideas) depend on existing ideas and number of workers in R&D sector

$$A_{t+1} - A_t = \bar{z} A_t L_{a,t}$$

where $\bar{z}$ is a productive parameter; therefore, new ideas are produced using existing ideas

Basic Setup of Romer Model (2 of 3)

- Resource constraint

$$L_{y,t} + L_{a,t} = \bar{L}_t$$

- How labour is allocated to these two sectors? Constant fraction $\bar{l}$ of the population works in research and $1 - \bar{l}$ work in producing output

$$L_{a,t} = \bar{l}\bar{L}_t \quad \text{and} \quad L_{y,t} = (1 - \bar{l})\bar{L}_t$$

- Capital accumulation as in the Solow-Swan model

$$K_{t+1} - K_t = sY_t - \delta K_t$$

Basic Setup of Romer Model (3 of 3)

- Output per person, $y_t \equiv \frac{Y_t}{\bar{L}_t}$ can be written as:

$$\frac{Y_t}{\bar{L}_t} = \frac{A_t K_t^{\alpha} L_{y,t}^{1-\alpha}}{\bar{L}_t} = A_t \left(\frac{K_t}{\bar{L}_t}\right)^{\alpha} \left(\frac{L_{y,t}}{\bar{L}_t}\right)^{1-\alpha} = A_t \left(\frac{K_t}{\bar{L}_t}\right)^{\alpha} (1-\bar{l})^{1-\alpha} \qquad (1)$$

- Therefore, a new idea that increases A_t will raise the output of each person in the economy.
- Nonrivalry of ideas means that per capita GDP depends on the total stock of ideas.
- For simplicity, assume no population growth, $g_{\bar{L}} = 0$. Thus, $\bar{L}_t = \bar{L}$ for all t.

Finding Growth Rates (1 of 3)

$$Y_t = A_t K_t^{\alpha} L_{y,t}^{1-\alpha} \tag{2}$$

$$K_{t+1} - K_t = sY_t - \delta K_t \tag{3}$$

$$A_{t+1} - A_t = \bar{z} A_t L_{a,t} \tag{4}$$

$$L_{y,t} + L_{a,t} = \bar{L}_t$$

$$L_{a,t} = \bar{l}\bar{L}_t$$

$$g_L = 0$$

- Find g_Y, g_K and g_y

Finding Growth Rates (2 of 3)

- The formulas on growth rates (see Appendix 1), applied to Eq.(2), we get:

$$g_Y = g_A + \alpha g_K + (1-\alpha) g_{L_y}$$

- From Eq.(4), we have:

$$g_A = \frac{A_{t+1} - A_t}{A_t} = \bar{z} L_{a,t} = \bar{z}\bar{l}\bar{L}$$

- From Eq.(3), we have:

$$g_K = \frac{K_{t+1} - K_t}{K_t} = s\frac{Y_t}{K_t} - \delta$$

  This equation still has two endogenous variables on the right hand side. But it is helpful:

$$\frac{Y_t}{K_t} = \frac{g_K + \delta}{s}$$

Finding Growth Rates (3 of 3)

- $\frac{Y_t}{K_t}$ is constant, hence:

$$g_Y = g_K$$

- Finally, we need g_{L_y}. We assumed that population growth is zero.

$$L_{y,t} = (1 - \bar{l})\bar{L}_t = (1 - \bar{l})\bar{L}$$

- Therefore $g_{L_y} = 0$ and we have:

$$g_Y = \bar{z}\bar{l}\bar{L} + \alpha g_Y + 0$$

- Hence,

$$g_Y = \frac{\bar{z}\bar{l}\bar{L}}{1 - \alpha}$$

- The growth of output per person is:

$$g_y = g_Y - g_L = g_Y - 0 = \frac{\bar{z}\bar{l}\bar{L}}{1 - \alpha}$$

Steady State (1 of 2)

- From the production function we have:

$$Y_t = A_t K_t^{\alpha} L_{y,t}^{1-\alpha} = A_t K_t^{\alpha} (1-\bar{l})^{1-\alpha} \bar{L}_t^{1-\alpha} = A_t K_t^{\alpha} (1-\bar{l})^{1-\alpha} \bar{L}^{1-\alpha}$$

- Thus,

$$\frac{Y_t}{K_t} = A_t K_t^{\alpha-1} (1-\bar{l})^{1-\alpha} \bar{L}^{1-\alpha}$$

- We have:

$$\frac{Y^*}{K^*} = A_t \left(\frac{K^*}{\bar{L}}\right)^{\alpha-1} (1-\bar{l})^{1-\alpha}$$
$$\frac{g_K + \delta}{s} = A_t \left(\frac{K^*}{\bar{L}}\right)^{\alpha-1} (1-\bar{l})^{1-\alpha}$$

- The steady state capital per capita therefore is:

$$k_t^* = \frac{K^*}{\bar{L}} = \left(\frac{s}{g_K + \delta}\right)^{\frac{1}{1-\alpha}} A_t^{\frac{1}{1-\alpha}} (1-\bar{l})$$

Steady State (2 of 2)

- The steady state output per capita is derived from Eq.(1):

$$y_t^* = A_t(\frac{K^*}{\bar{L}})^{\alpha}(1-\bar{l})^{1-\alpha}$$

- Finally, we have:

$$y_t^* = A_t[(\frac{s}{g_K+\delta})^{\frac{1}{1-\alpha}} A_t^{\frac{1}{1-\alpha}}(1-\bar{l})]^{\alpha}(1-\bar{l})^{1-\alpha}$$
$$y_t^* = A_t(\frac{s}{g_K+\delta})^{\frac{\alpha}{1-\alpha}} A_t^{\frac{\alpha}{1-\alpha}}(1-\bar{l}) = (\frac{s}{g_K+\delta})^{\frac{\alpha}{1-\alpha}} A_t^{\frac{1}{1-\alpha}}(1-\bar{l})$$

Solow-Swan vs. Romer

- Why does the Solow-Swan model fail to deliver growth whereas the Romer model successfully grows per capita income in the long run?
- Solow-Swan: capital is rivalrous, therefore it is capital per person that matters for growth, and capital per person runs into diminishing returns
- Romer: ideas are nonrivalrous, therefore it is the total stock of ideas that matters for growth
- More people produce more ideas, just like more autoworkers produce more trucks.
- But since ideas are nonrivalrous, growth in the total stock of ideas can sustain growth (whereas in Solow-Swan we require growth in capital per person).

Insights from R&D-based models (1 of 3)

- Policy implications suggested by these models: economics policies with respect to trade, competition, education, taxes and intellectual property will all affect the costs and benefits of doing R&D and hence will affect the rate of technological progress.
- These models, however, are vulnerable to the critique by Jones (1995a): long-run trends in economic growth in the U.S. are not correlated with long-run trends in the various determinants of growth suggested by endogenous growth theories. (i.e. R&D intensities, government spending and taxation, subsidies etc.)
  - The growth rate of per-capita GDP in the U.S. has been virtually constant since 1880.
  - Therefore, the only way that long run growth is correlated with a combination of various determinants would be if their effects on growth offset each other by coincidence.

Insights from R&D-based models (2 of 3)

- This critique has not led to great modification of endogenous growth theory. One reason is that the critique has been effectively countered with subsequent empirical findings.
- For example, Kocherlakota and Yi (1997) find that there is indeed such a combination of government policies, tax rates and public capital: an increase in public capital tends to raise growth, but the increase in growth is nullified by the increase in tax rates needed to finance the capital expenditure.

Insights from R&D-based models (3 of 3)

- Another critique by Jones (1995b): The evidence on productivity growth and R&D inputs in the U.S. and other OECD countries refutes the "scale effect" of R&D-based models.
  - According the theory, an increase in the size of population should raise long-run growth, through two channels.
    - First, by providing a larger market for a successful innovation.
    - Second, by providing a larger stock of potential innovators.
  - This critique has motivated some researches to get ride of the scale effect while maintaining other features of the R&D-based models (not very successful yet). (e.g. Paretto, 1998; Young, 1998; Howitt, 1999)

Implications for the Central Questions of Growth Theory (1 of 3)

- Recall that the central questions of growth theory is what accounts for the substantial variations in real per capita GDP over time (worldwide growth) and across countries?
- If we think of this line of research as modeling worldwide economic growth, it seems plausible.
- The growth of knowledge appears to be the central reason that output and standards of living are so much higher today than in previous centuries.
- The fact that growth rate of world GDP per capita and growth rate of world population move together is broadly consistent with the theory.

Implications for the Central Questions of Growth Theory (2 of 3)

- The literature has not reached a conclusion yet what types of knowledge are most important for growth, their quantitative importance, and what forces determining how knowledge is accumulated. But the general directions of research seem promising for understanding worldwide growth.
- With regards to cross-country differences in real incomes, relevance of these models is mixed.
- First, there is no strong empirical evidence that supports the "scale effect": growth rate of output per worker is not on average higher in countries with larger population or higher R&D input.
- Quantitatively, if one believes that economics are described by something like the Solow-Swan model but do not have access to the same technology, then the lags in the diffusion of knowledge from rich to poor countries that are needed to account for the observed differences in incomes are extremely long – on the order of a century or more.

Implications for the Central Questions of Growth Theory (3 of 3)

- Conceptually, technology is nonrival: its use by one firm does not prevent its use by others. This naturally raises the question of why poor countries do not have access to the same technology as rich countries.
- One may argue that the difficulty poor countries face is not lack of access to advanced technology, but lack of ability to use that technology. Then the main source of differences in standards of living is not different level of knowledge or technology, but differences in whatever factors that allow countries to take advantage of advanced technology. (i.e. infrastructure, legal system, policy etc.)

Appendix 1: Formulas on Growth Rates

- Suppose two variables x and y have average annual growth rates of g_x and g_y. Then the following rules apply:
  - If $z = \frac{x}{y}$, then $g_z = g_x - g_y$.
  - If $z = x \times y$, then $g_z = g_x + g_y$.
  - If $z = x^{\alpha}$, then $g_z = \alpha g_x$.

Appendix 2: A Brief Review of Endogenous Growth Literature (1 of 4)

- This appendix briefly reviews other related endogenous growth literature. It is for you knowledge and it is NOT included in the problem set.
- Learning by doing: Arrow (1962)
  - Arrow (1962) was motivated by the empirical observation that after a new airplane design is introduced, the time required to build the aircraft is inversely related to the number of aircraft of the model that have already been produced; this improvement in productivity occurs without any evident innovations in the production process.
  - This type of knowledge accumulation in known as **learning by doing**, which occurs as a side effect of conventional economic activity.

Appendix 2: A Brief Review of Endogenous Growth Literature (2 of 4)

- The AK approach to endogenous growth
  - Diminishing returns to the accumulation of capital (the only reproducible factor in production) plays a crucial role in limiting growth in neoclassical growth models.
  - A class of growth models assume that one factors other than capital grow in a way that allows output to grow in proportion to capital, and hence result in a production function of the form $Y = AK$ with A a constant.
  - These models are generally referred to as AK models, which is viewed as the first wave of endogenous growth theory.

Appendix 2: A Brief Review of Endogenous Growth Literature (3 of 4)

- Romer (1986): Externality from spillover
  - Romer (1986) presents an endogenous growth model where the accumulation of capital by individuals is associated with a positive externality on the available technology.
- Romer (1987): Research and monopolistic competition
  - Romer (1987) constructs a model where agents can choose to engage in research that produces technological improvement.
  - Each innovation represents a technology for producing a new type of intermediate input that can be used in the production of final goods.

Appendix 2: A Brief Review of Endogenous Growth Literature (4 of 4)

- R&D-based model
  - Following Romer (1986, 1987), R&D based (or innovation based) theory has gained significance in the endogenous growth literature, in which long run growth is driven by technological change that results from the research and development efforts of profit-maximising agents.
  - Important contributions to this literature include Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992, 1998), Howitt (2000, 2004).
  - We discussed Romer (1990) in the class.