Growth, Capital Accumulation, and the Economics of Ideas

PRINCIPLES OF ECONOMICS (ECON 210)

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Immediate causes of growth

• In this lecture we advance a model of the production function of an economy and of how accumulation of inputs and technological innovation lead to growth of output per capita.

• This analysis takes the ultimate causes of growth from the previous lecture (institutions and incentives) as given.

• It focuses instead on accounting for the immediate causes of growth per capita, i.e., in
  • physical capital and
  • technology.
Immediate causes of growth

This allows economists to study questions such as:

• “Is it possible for an economy to enjoy positive growth forever by simply saving and investing in its stock of capital (machines and tools)?”

• “Will the incomes of various countries converge over time?” and “Under what conditions?”
  • “Absolute convergence”

• “Will the growth rates of various countries converge?” and “Under what conditions?”
  • “Conditional convergence”
“Catch up” growth

• The model implies convergence of the incomes of economies with the same savings rate, technology level, and production function (also population growth rate, though I ignore population growth here).
  • Differences in growth rates among these economies, then, results from differences in their capital stocks, with the lower-capital economies growing faster and “catching up” to the higher-capital ones.
  • This also implies that the level of capital will converge to an equilibrium or “steady state” level.

• Income growth diminishes toward zero as the economy approaches the steady state.
  • Since “rich” countries continue to grow and invest, however, “catch up” growth is not the only kind.
“Cutting edge” growth

• Technological innovation ("better ideas"), that increases output for all levels of labor and capital, can explain why economies on the “cutting edge” continue increasing their investments in capital and their incomes per capita.

• Innovation has peculiar properties that distinguish it from capital accumulation.
  • E.g., an idea can be used by many firms simultaneously (where a machine cannot).

• The conclusion of this lecture will explore these peculiar properties and their implications for the future of economic growth in more detail.
The model

• The following is the starting point for virtually all discussion of macroeconomic growth theory, and it was first written by economist Robert Solow in 1956.
The heart of this model is a production function, i.e., a set of mathematical rules that maps the quantities of inputs to the quantity of output (denoted $Y$). The inputs are grouped into 3 categories: capital ($K$), labor ($L$), and technology ($A$). The notation for the production function is:

$$Y = F(K, L, A),$$

i.e., “output is a function of capital, labor, and technology,” or “you tell me how much of each input you have, and the function will tell you how much output is produced.”
Inputs

• Capital: durable physical inputs, e.g., machines, buildings, pencils, that are rival in production (cannot be used by several users at the same time).

• Labor: the number of workers and the time they work, as well as their physical strength, skills, and health.
  • Labor is also rival in production because workers’ time can only be devoted to one activity at a time.

• Technology: the “blueprint” or “formula” for how to combine given amounts of capital and labor most effectively.
  • Crucially technology is non-rival in production; many firms can simultaneously use the same ideas.
Non-rivalry of ideas

“If nature has made any one thing less susceptible than all others of exclusive property, it is the actions of the thinking power called an idea, which an individual may exclusively possess as long as he keeps it to himself; but the moment it is divulged, it forces itself into the possession of everyone, and the receiver cannot dispossess himself of it. Its peculiar character, too, is that no one possesses the less, because every other possesses the whole of it. He who receives an idea from me, receives instruction himself without lessening mine.”

-Thomas Jefferson, letter to Isaac McPherson, 12 August, 1813 (my emphasis).
The model (continued)

- K, L, and A in an economy can all change over time, resulting in different levels of output.

- Population growth (↑ in L) presents a challenge. Though it increases output, it is dubious that population growth increases *per capita* output, ceteris paribus, and that is how standards of living are measured.
  - There is a more difficult version of this model that allows for population growth (without disrupting the key predictions), but a simpler way to handle it is to assume zero population growth.
  - Thus any increase in Y will also be an increase in (Y/L), the per capita income.
  - This has the added advantage of focusing our attention on increases in K and A.

- Temporarily assuming that A is also fixed, focuses on the relationship between K and Y.
The model (continued)

• Solow’s model assumes the relationship between output and capital is positive but with diminishing returns,
  • i.e., capital increases output, but at a decreasing rate.

• This means the marginal product of capital \((MP_K)\) is positive but diminishing.
Diminishing returns

- The function graphed here is an example of one with positive and diminishing returns to capital (holding A and L constant).

- The function is upward sloping, but as you go from left to right, the slope gets flatter, i.e., closer to zero.
The model (continued)

• Capital accumulates because of saving and investment. After output is produced each period, individuals decide how to allocate it between consumption and saving.

• Anything that is saved is invested and becomes part of the capital stock in the next period.

• Solow’s model assumes a constant fraction $\gamma$ ("gamma": $0 < \gamma \leq 1$) of output is saved and invested.
  • The remainder $(1 - \gamma) \times Y$ is consumed.

• So investment ($I$) is:

$$I = \gamma Y = \gamma F(K|A,L),$$

and the investment function has the same shape as the production function.
Investment

• Any amount of output can be divided into 2 parts.

• Investment is the height of the lower blue line.

• Consumption is output minus investment (the gap between the blue lines).
The model (continued)

- There is one last factor that changes the capital stock over time: **depreciation**.
  - Capital is durable but not everlasting; it wears out or “depreciates”.

- The Solow model assumes that depreciation also occurs at a constant rate of $\delta$ (“delta”).
  - Without any new investment, the capital stock next period ($t + 1$) equals a fraction of the capital stock in the present period:
    \[
    K_{t+1} = (1 - \delta)K_t
    \]
    \[
    \Leftrightarrow \text{(the proportional decrease in } K) = \frac{K_{t+1} - K_t}{K_t} = -\delta,
    \]
  i.e., the proportional decrease in capital stock from depreciation is $\delta$. 

The model (concluded)

• Investment and depreciation are opposing forces acting on the capital stock (investment ↑ and depreciation ↓).

• The change in capital stock from one period to the next is then:

$$\Delta K = K_{t+1} - K_t = \gamma * F(K_t) - \delta K_t.$$
Solow model’s implications

• An economy’s standard of living (per capita output) increases if Y increases.

• Since K is the only variable input right now, Y increases if K increases.

• Investment tends to increase K, but it is “fighting against” the force of depreciation, which tends to decrease K.

• There is a level of capital at which investment is exactly offset by depreciation, and the capital stock is not changing, i.e., in a steady state.
Steady state: $\Delta K = 0$

- This graph shows the investment and depreciation functions together.
- Investment increases with the capital stock, but at a diminishing rate (because of the production function).
- Depreciation increases linearly: the larger the capital stock, the more there is to depreciate.
- When both have equal magnitude (at the intersection), the economy is in its steady state.
Steady state output

- Putting the previous graph back together with the production function, shows the steady state rate of output.
  - Recall that when the capital stock ceases changing, $Y$ ceases changing as well.
Summary

• Let’s review what we know now:
  • If Investment > Depreciation → K and Y grow.
  • If Investment < Depreciation → K and Y fall.
  • If Investment = Depreciation → K and Y are constant.
Conclusions

• Steady state equilibrium occurs when investment equals depreciation.

• When $K$ is in steady state equilibrium, $Y$ is in steady state equilibrium.

• The further the economy is from its steady state, the faster it should grow (scatterplot, right).

*Conditional Convergence* The poorer the OECD country in 1960, the faster growth was between 1960–2000.

Source: Penn World Tables
Note: Data includes 18 of the 20 original OECD countries, excluding Germany and Turkey.
What happened here?
“One more for the road”

• Once you get to the steady state, the only things that can increase growth are:
  • the savings rate (↑ 𝛾 →↑ 𝑌) and
  • the depreciation rate (↓ 𝛿 →↑ 𝑌).

• But even countries with a lot of capital that have been growing for decades invest a lot and continue growing . . .
Better ideas drive long-run growth

• Now we examine technological change as a source of persistent economic growth.

• Adding it back into the model is fairly simple. So far we have assumed that production follows a power function such as

\[ Y = \sqrt{K}, \]

which one can think of as the function

\[ Y = A\sqrt{K} \]

with \( A = 1 \) (technology level normalized to 1).

• Increasing \( A \) higher than 1 has the same overall effect as raising the saving rate:
  • it increases the height of the production function for all values of \( K \).
Cutting edge growth: growth in the steady state output

- Point (a) is the original steady state.
- Better ideas, e.g., discovery of electricity, the internal combustion engine, or the computer chip, move the production function from the blue line to the red line.
- Investment and capital stock increase until a new steady state is reached at point (c).
  - Determined by where the new investment function intersects depreciation.
The economics of ideas

• We have “invested” much energy in modeling how capital accumulates.

• One ought to ask a similar question about technology.
  • One easy answer is to assume “exogenous” progress, e.g., $A$ grows at a constant rate over time.

• Endogenous technical progress is more satisfying to economists because then we can ask,
  • “who has an incentive to innovate?” and
  • “what are the costs and benefits of technological progress?”

• Also “is there enough incentive to innovate?”
The economics of ideas (conclusions)

• Technological innovation is the result of research and development by profit-seeking firms (or individuals).

• Since ideas are non-rival, some of their benefits spill over to others that did not perform the R&D to discover them.
  • While this sounds like a healthy phenomenon, it also gives firms the incentive to “free ride” off of others instead and do less R&D themselves.
  • Consequently government has a role in encouraging R&D and the production of ideas.

• Larger markets for ideas increase the incentives to do R&D.
Research and development

• Innovation is a probabilistic endeavor.
  • When you set out to make something that no one yet knows how to make, it is uncertain whether you will succeed.
  • It becomes more likely the more smart people you have and the longer they work on it, though!

• Smart people and the complementary physical capital are costly to employ, regardless of whether R&D is successful or not.
Research and development (continued)

• A successful innovation usually means a patent and a stream of future revenue from producing goods with the new idea.

• Unsuccessful R&D means you get no revenue and have to pay the costs anyway.
  • (you lose money).

• The net gain (G) of R&D looks schematically like this:

\[
G = [\Pr(\text{success}) \times \text{prize}] + [\Pr(\text{failure}) \times 0] - (\text{salaries paid to smart people}).
\]
Increasing the number of smart people has marginal benefits and costs:
- It increases the probability of innovating and getting the “prize”;
- It also increases the costs paid.

The “optimal” amount of R&D is the level at which the marginal benefit equals the marginal cost and $G$ is maximized.
- Optimal is in the sense of maximizing the gains to the firm doing the R&D.

Things that affect the optimal R&D:
- Cost of smart people (and apparatus that complements them) → less R&D.
- Size of the “prize” → more R&D.
Spillovers from R&D

• A central question is how successful innovators are rewarded when an idea’s use is non-rival.

• Once the innovation is made, it may be nearly costless to diffuse it to everyone on earth:
  • think of a software program that can be copied ad infinitum by downloading it from the internet.
  • When’s the last time you paid for digital music? That’s what I thought.

• Even if patents nominally protect intellectual property, like a monopoly on each idea, it may not be difficult to “reverse engineer” or imitate the original once competitors see the new product.
Spillovers from R&D (continued)

• Furthermore one good idea may inspire other inventions.

• This is especially true of “basic” research—the kind typically done at Universities like Purdue—that does not lead directly to any patentable product but is nonetheless vital to the people who do apply it to commercial R&D.

• The ease of diffusing innovations is a good thing, but there would be even more innovations to share if researchers considered all of the benefits including spillovers.
Spillovers (continued)

• The larger the size of the spillovers from R&D the further the realized level will be from the optimal level.

• I.e., “not enough good ideas”.
Government’s role in innovation

• So how do innovators make their R&D pay off when so many of the benefits escape to rival producers? Government can help.

• Several options:
  • Stricter patent enforcement,
  • Subsidize R&D expenditures directly, or
  • Subsidize the inputs to R&D (smart people).

• Target industries and fields where the spillover benefits are the largest.
  • STEM fields tend to produce a lot of valuable basic research from which the researchers receive only a small share.
  • For examples see the “Research News” section of any “Purdue Today” newsletter.
Patents vs. subsidies

• Stricter patent enforcement.
  • Enforcement is costly, restricts ideas instead of encouraging.
  • Side effect: encourages speculation over patents and “trolling”.

• Subsidies for R&D, directly or for inputs (more smart people).
  • Make tuition cheaper in fields where R&D has a lot of spillover.
  • Shift the supply of smart people outward, decrease the price.
Market size

• An obvious way of increasing the “prizes” for innovations is to open up new markets to their diffusion,
  • e.g., shift the demand curve out by selling them in many countries.

• As other countries grow and become richer, the market for a successful innovation increases even more.
The future of economic growth

• The “cutting edge” is the future of growth.

• Many economies still have “catching up” to do.

• Better ideas in the “rich” world make this faster because of international spillovers (Nordhaus 2004 NBER paper).
Could growth actually be accelerating?

- Most of the world does not have easy access to education and employment in R&D.
  - Many more talented researchers from developing countries will get opportunities from more investment in education.

- Growth begets more growth because markets for innovation increase in size.

- Non-diminishing (maybe increasing?) returns to ideas.
  - “More good ideas make it even more likely I will discover one.”

- Isaac Newton: “If I have seen further it is by standing on the shoulders of giants.”
Conclusions (1)

• Output grows by accumulation of inputs.
• A model of growth requires a production function relating inputs to output.
• Growth in the model comes from the assumptions governing
  • capital accumulation (investment and depreciation) and
  • technological advances (R&D).
Conclusions (2)

• Even after reaching a steady state, in terms of capital accumulation, the steady state can grow as a result of technology.

• Technological innovation results from individuals and firms that aim to gain from research and development.

• Innovation has positive spillovers, and consequently we do not have “enough” good ideas.
  • Subsidies from government may be necessary to achieve the optimal level of R&D.

• The nature of ideas may make “cutting edge” growth self-sustaining and accelerate over time.