Introduction to Economic Growth: Why are some countries poorer than others?

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Brown University, Summer School 2021

Lecture 3: Productivity, Innovations, and the Endogenous Growth Theories

Limitations of the Solow model

1. Explains the recent dynamics of developed countries well; performs worse in explaining growth in the developing world
2. The model does poorly in matching income differences quantitatively. More on that in the problem set!
3. The main driver of the 'cutting edge' growth - the rate of TFP growth, technological progress - is exogenous. The model is not designed to explain where it comes from.
4. The model is not designed to explain initial growth take-offs, industrialization, demographic change, and other crucial dynamics before the 2nd half of the 20th century.
5. The model predicts (conditional) convergence, while for most of the human history we saw either stagnation or divergence.
    - More recent evidence (post-MRW 1992) also finds evidence for 'club convergence', see Galor (1996) and Quah (1996) among others.

What has the Solow Model left unexplained? (a lot, including...)

Question 1 Where does productivity (TFP) growth come from? Where does technological progress come from? TFP growth in the data

Question 2 What incentives underlie investments in R&D, innovations, and entrepreneurship?

Question 3 Can government policy affect growth rates? The Solow model was not addressing policy at all.

Question 4 Are population growth and technological progress interrelated?

Question 5 How did technological progress evolve in the past? And will it stall in the future, or will it accelerate, and so will economic growth?

Several of the main concepts we cover in this lecture

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4. Scale (population) effects: more potential innovators means more innovations, other things equal.

Plan for this lecture

1. Increasing returns, profit incentives and innovations
   - Ideas and Technologies: increasing returns
   - Profit incentives and innovations
   - Profit incentives and innovations: government policies
2. A simple growth model with endogenous technological change
   - Basic structure
   - Steady state (or, 'balanced growth path') of the model
   - The (dual) role of population growth
3. The process of Creative Destruction
   - Shumpeterian framework of growth (simplified)
   - Predictions of the Shumpeterian model and the Data

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The idea behind increasing returns to ideas

The standard assumption in the growth theory (before Paul Romer's (1990) key paper) is that of "constant returns to scale":

- If you double all the 'rival' factors of production (K and L), you exactly double the output
- Think of a factory that produces machines using labor and capital. Build the exact same factory nearby, and you get double the output
- Solow Model has this property as well (with the Cobb-Douglas production function)

However, there is no need to re-invent an idea or technology for each next factory. The use of an idea by one factory or person does not affect it's availability for others. Ideas are ***nonrival***!

The idea behind increasing returns to ideas

Constant returns to scale mean that for $Y = F(K, L)$ we have:

$$F(\lambda \cdot K, \lambda \cdot L) = \lambda \cdot F(K, L) = \lambda \cdot Y \tag{1}$$

Meaning, if we increase all factors λ times, output also increases λ times. Romer, however, noted the following. If X are rival factors (K and L), and A is nonrival, by replicating all rival factors we get constant returns:

$$F(A, \lambda \cdot X) = \lambda \cdot F(A, X) = \lambda \cdot Y \tag{2}$$

But if we increase both rival factors and ideas (nonrival), then

$$F(\lambda \cdot A, \lambda \cdot X) > \lambda \cdot F(A, X) = \lambda \cdot Y \tag{3}$$

So, by doubling all factors, including ideas (technologies), we more than double output: ***increasing returns to scale***!

Increasing returns and profit incentives for researchers

With increasing returns, an invention by one researcher leads to benefits for everyone who can use a new idea or technology (so called 'positive externalities').

However, while ideas/technologies are nonrival, they are (at least partially) ***excludable***:

- patents and other property rights institutions may prevent others from using a new recent technology
- this is what brings incentives to innovators and researchers: opportunity to get profits
- in a perfectly competitive market, profits can't be sustained
- Paul Romer understood that at least some degree of monopoly power (maybe a temporary one) is desirable to stimulate innovation

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Profit incentives vs. nonrivalry of ideas

There is a fundamental conflict between two growth-promoting goals:

- to create new ideas (via innovations, R&D efforts, etc.)
- to spread new ideas as wide as possible (because they are nonrival, and the more people use them, the better)

The basic conflict is that spreading an idea (technology) widely means

- not having patents
- lowering the price for the use of idea (think of a formula for producing a pill)
  - if everyone can produce a new pill, it's supply becomes very high, and so it's price goes down
  - then the innovator cannot get much profit from it's efforts

If these conditions are met, there is little *incentive* to innovate in the first place...

What affects the incentives for innovations and R&D?

- How much of an advantage over competitors does the innovation convey:
  - Patents matter; the length of patents also matters (longer patents mean higher incentives - but also higher costs for the society)
  - What is the level of competition in the first place (more on that in the 'creative destruction' part)
- Product market size: the larger the market, the higher the profits.
  - Larger market $\rightarrow$ higher demand (simply because of more people) $\rightarrow$ higher price and quantity demanded
- Government policies, such as grants and prizes (especially when markets do not internalize benefits)
  - Fundamental science is one such example
- Risks of R&D investments: potential innovators weigh guaranteed costs against uncertain benefits.
  - Federal subsidies, venture funds, etc. - to spread the risks

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Government policies: patents

The United States of America

The Commissioner of
Patents and Trademarks

Has received an application for a patent for a new and useful invention. The title and description of the invention are enclosed. The requirements of law have been complied with, and it has been determined that a patent on the invention shall be granted under the law.

Therefore, this 5,860,492

United States Patent

Grants to the person(s) having title to this patent the right to exclude others from making, using, offering for sale, or selling the invention throughout the United States of America or importing the invention into the United States of America for the term set forth below, subject to the payment of maintenance fees as provided by law.

If this application was filed prior to June 8, 1995, the term of this patent is the longer of seventeen years from the date of grant of this patent or twenty years from the earliest effective U.S. filing date of the application, subject to any statutory extension.

If this application was filed on or after June 8, 1995, the term of this patent is twenty years from the U.S. filing date, subject to any statutory extension. If the application contains a specific reference to an earlier filed application or applications under 35 U.S.C. 120, 121 or 365(c), the term of the patent is twenty years from the date on which the earliest application was filed, subject to any statutory extension.

Government policies: patents

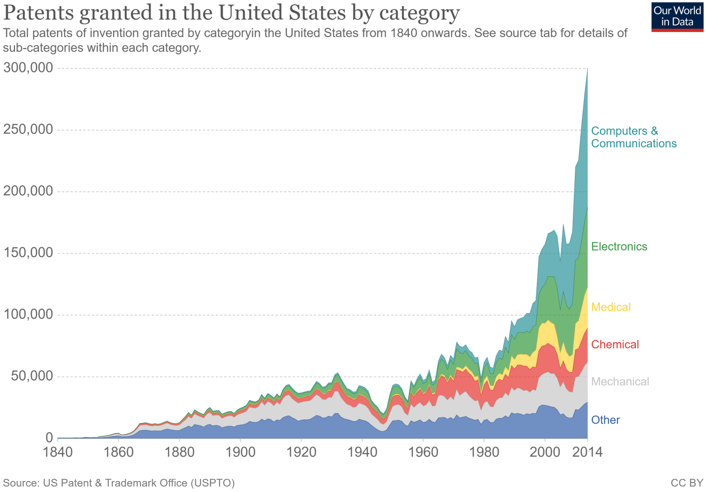

Figure 2: US patents by category. Source: ourworldindata.org

Government policies: subsidies, grants, prizes

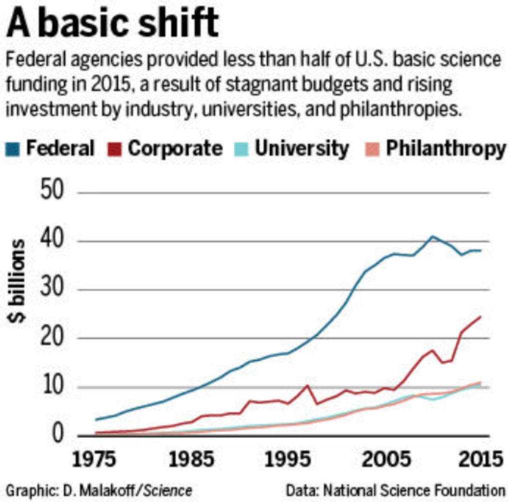

Figure 3: Basic Science Funding in the US, by Agency. Source: sciencemag.org

Government policies: subsidies, grants, prizes

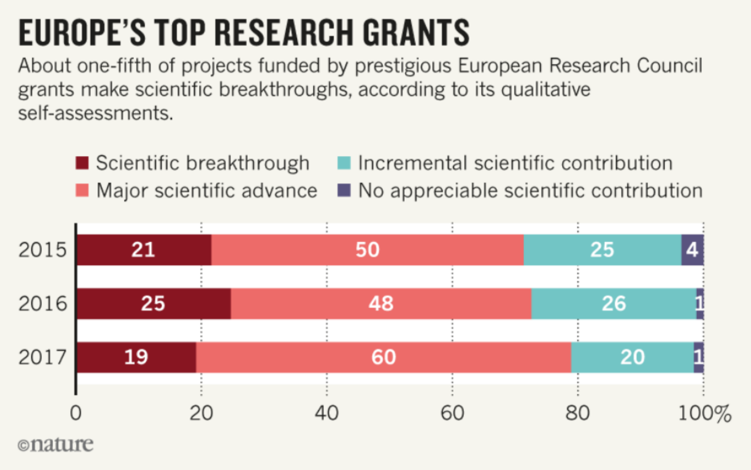

Figure 4: Projects Funded by the ERC, by Significance. Source: nature.com

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Two-sector model with (i) output production and (ii) idea production

The model consists of several parts:

- Output production (much like before, but even simpler here, only labor as an input)
- Idea production (where do ideas (technologies, etc.) come from?)
- Dynamics of the whole economy

We will look at these components one by one, then together, and then we'll see what our model can explain, and what testable predictions it has.

Producing output

We abstract from capital (both human and physical) in this version of the model.

Final output in period t is produced according to this production function:

$$Y_t = A_t^{\sigma} \cdot L_{Y,t} \tag{4}$$

where $L_{Y,t}$ - total amount of labor employed in producing final output; A_t - productivity, i.e., TFP.

We assume that of total labor force L_t, a share γ_Y is employed in producing final output, so $L_{Y,t} = \gamma_Y \cdot L_t$. Then, incomes per worker are just $y_t = Y_t / L_t = A_t^{\sigma} \cdot \gamma_Y$

- note that, because of increasing returns, incomes per worker depend on the total stock of ideas A_t - not on ideas 'per capita'.

Producing ideas

Inflow of additional ideas is given by the following production process for the amount of new ideas, ΔA_t :

$$\Delta A_t = \nu \cdot L_{A,t}^{\lambda} \cdot A_t^{\phi} \tag{5}$$

where $L_{A,t} = \gamma_A \cdot L_t$ is the amount of labor employed in R&D, $\lambda < 1$ reflects diminishing research productivity of additional labor employed in R&D, and ϕ reflects how much easier or harder it is to produce new ideas depending on how many ideas are already known. Finally, ν is research productivity per hour

- if $\phi < 0$, then there is a "fishing out" effect: the more ideas known, the harder to get new ones
- if $\phi > 0$, then there is a "standing on the shoulders of giants" effect: new ideas are getting easier to find
- note that David Weil assumes $\phi = 1$ and $\lambda = 1$ in his textbook

Dynamics of the economy

We assume for simplicity that the share of labor employed in ideas production (γ_A) is constant. Then, the growth rate of GDP per capita is

$$g_y = \sigma \cdot g_A \tag{6}$$

So, as before, incomes per capita growth is proportional to TFP growth (ideas, in this case).

Growth rate of ideas is given by

$$g_A = \frac{\Delta A_t}{A_t} = L_{A,t}^{\lambda} \cdot A_t^{\phi-1} \tag{7}$$

I got this by simply dividing equation (5) by A_t on both sides.

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Dynamic equilibrium: 'balanced growth path' of the economy

Definition: Balanced growth path

A ***balanced growth path*** (BGP) is reached when all of the main dynamic variables grow at a constant rate, unless a system is externally 'shocked'. In our case, the balanced growth path is reached when:

$g_A = L_{A,t}^{\lambda} \cdot A_t^{\phi-1}$ is constant[a]

[a] Note that we already had this BGP thing before: in the Solow model, when we introduced exogenous productivity growth

Applying again the rules of growth rates of a product (and of a power function), and requiring that growth rates are constant, we can find growth rate of TFP on the BGP:

$$g_{A,BGP} = \frac{\lambda \cdot n}{1-\phi} \tag{8}$$

Dynamic equilibrium: 'balanced growth path' of the economy

Now that we know the growth rate of TFP that the economy converges to, we can easily find the growth rate of incomes per capita (from (6)):

$$g_{y,BGP} = \frac{\sigma \cdot \lambda \cdot n}{1 - \phi} \tag{9}$$

- Growth rates (of technology and of GDP per capita) are increasing in population growth rate (n)
- Increasing in λ - how large are returns in terms of ideas to additional labor inputs in R&D
- Increasing in σ - how large are returns to final output from additional ideas/technologies
- Decreasing in ϕ (this is a bit harder to interpret, but give it a think)

Do we see this in the data?

Researchers and technological progress in the US

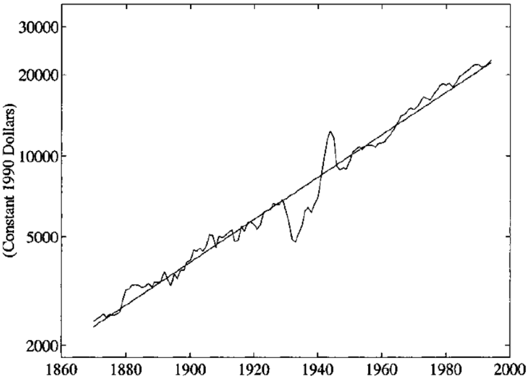

Figure 5: Very stable growth rates in the US. Source: Jones (2005)

Thus, the model should predict the stable growth rates as well. (it does, but...)

Researchers, R&D, and technological progress in the US

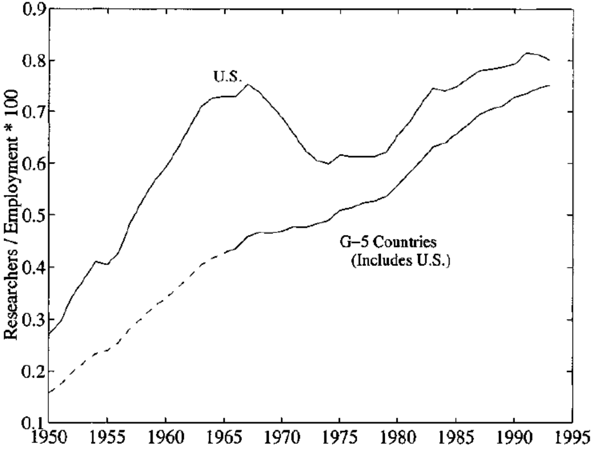

Figure 6: Dynamics of the US and G-7 research employment. Source: Jones (1995)

Researchers, R&D, and technological progress in the US

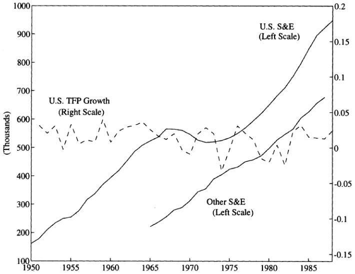

FIG. 1.—Scientists and engineers engaged in R & D and U.S. TFP growth. Source: The number of scientists and engineers engaged in R & D is taken from National Science Foundation (1989) and various issues of the *Statistical Abstract of the U.S. Economy*. TFP growth rates are calculated using the private business sector data in Bureau of Labor Statistics (1991). "Other S&E" is the sum of scientists and engineers engaged in R & D for France, West Germany, and Japan.

Figure 7: Dynamics of the US research employment and TFP. Source: Jones (1995)

Thus, the resources devoted to R&D were growing rapidly, while the TFP growth was not...

R&D effort and innovations (patents) across the world

FIGURE 3.
Total R&D Expenditures and High-Quality Patents Filed, by Country

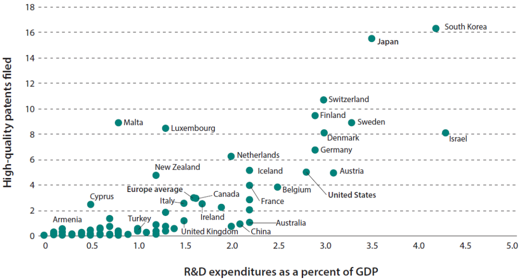

Figure 8: R&D Funding and Patents per Billion Dollar of GDP, by Country. Source: Shambaugh et al. (2017)

But it seems that across the (more or less) developed world, higher R&D effort translated into a higher level of patenting (not so clear with growth rates).

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The role of population in this model

- The very basic insight is that more researchers means higher technological (and hence GDP per capita) growth rates.
  - if we assume $\phi = 1$ (like in DW book), the prediction is that technological (and GDP per capita) growth is increasing in the size of population - this does not match modern data
  - for $\phi < 1$, it also does not seem that (at least in the US), a steady growth in research input translates into steady growth of TFP; however, cross-country, a larger R&D input does translate into more patents...
- Generally, higher growth rates of population are not necessarily a bad thing, however (as the Solow model has suggested).
- This model does not take a stance on whether the existing stock of ideas (current value of A_t) makes in easier or harder to produce new ideas...

The (dual) role of population growth

- In addition to the mechanical 'supply' of innovations effect of population growth, larger population also means a larger market size for potential innovators.
  - Larger market means higher demand for innovations, which pushes the market price of new products (hence, profits of innovators) upwards
- This brings us back to our key point of the lecture: profit incentives matter for R&D and innovations!
- We will talk more about the role of population size and population growth affecting innovations in Module 4, when look at the history of growth.
  - And we will see that, historically, the prediction of population size and growth rates leading to more innovations was much more accurate... Why would that be?

International transfer of technologies: 'innovation-based' vs 'imitation-based' growth

Generally, we do not see that today, countries with higher population or higher population growth produce more innovations.

One of the reasons is that 'technological followers' can benefit from importing technologies and ideas from abroad ('imitation-based' growth):

- This weakens the positive relationship between local population size and innovations
- This also means that countries further away from technological frontier can grow faster by engaging in less costly imitation, and only start innovating once they get closer to the frontier
- Interested folks, check out the David Weil's Chapter 8.3, section on "Two-Country Model" for a more detailed exploration of these ideas (optional).

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Basic ideas behind the Shumpeterian growth model

We have seen how (i) population (size and growth), (ii) number of researchers, (iii) returns to additional research effort, (iv) and other factors can affect the pace of technological progress.

However, what determines how much funding an economy puts into R&D? What determines how many new innovative firms are there, and how much do established firms innovate? (think of this as what determines γ_A in the previous model)

The 'Shumpeterian' growth theory by Aghion and Howitt (1992, 1998) explores these questions and relies on the basic idea by Joseph Shumpeter[1]:

New technologies and ideas do not just add to the existing stock, but often replace existing (older) technologies and ideas.

[1] Austrian economist of the 1st half of the 20th century.

Basic ideas behind the Shumpeterian growth model

The model works as follows:

- Innovations arrive at a rate $\lambda \cdot z_t$ per period, where λ is (as before) productivity of R&D effort, and z_t is the amount of R&D effort.
- Potential entrepreneurs choose between working for a wage w_t and engaging in R&D which generates future profits V_{t+1}.
- The equilibrium value of z_t is such that there is no incentive to switch from one activity to another.
- In this model, entrepreneurs invest more when R&D is more productive, and when market size is larger (because it increases future rents V_{t+1}) - as in Romer's model
- There are two very important additional effects of market competition that were ignored before

Basic ideas behind the Shumpeterian growth model

Escape competition effect

In industries where firms are of similar productivity ('neck-and-neck' industries), a higher competition (say, an entry of a new high-productivity firm) encourages more investment in innovation to escape this competition.

Shumpeterian effect

In industries where there is high disparity between laggard and leading firms ('unleveled' industries), a higher competition discourages innovation, because it decreases extra profits from innovations.

Intuition: example with students in a class

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Predictions of the model: firms turnover rates and economic growth

Turnover rates

Because innovations lead to firms turnover (replacement of firms using older technologies for firms using newer technologies), a higher turnover rate increases economic growth rate.

This prediction is supported, for example, in the work of Johansson (2005) for the IT industry in Sweden.

Predictions of the model: competition and innovations

Earlier theories of endogenous growth predicted that higher competition discourages innovations. Aghion et al. (2005, 2009) showed it's not true:

Competition and innovations

The combination of 'Shumpeterian' effects and 'escape competition' effects generates and inverted-U relationship between competition and innovations.

- when competition is low, an increase in competition forces leading firms in neck-and-neck industries to innovate, while profits are still quite high (so the escape competition effect dominates)
- when competition is already high, the Shumpeterian effect dominates: there is little incentive for laggard firms to innovate (because profits will not be high anyway), and overall, industries will be in the unleveled state, where innovations are low

Predictions of the model: competition and innovations

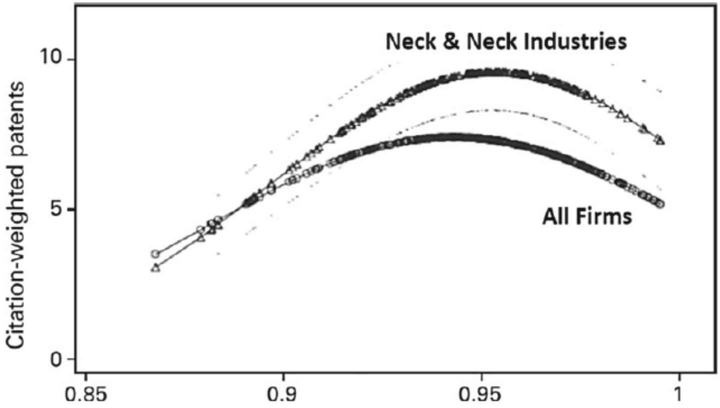


Figure 9: Innovations and competition: an Inverted-U relationship. Source: Aghion et al. (2005)

Predictions of the model: competition and innovations

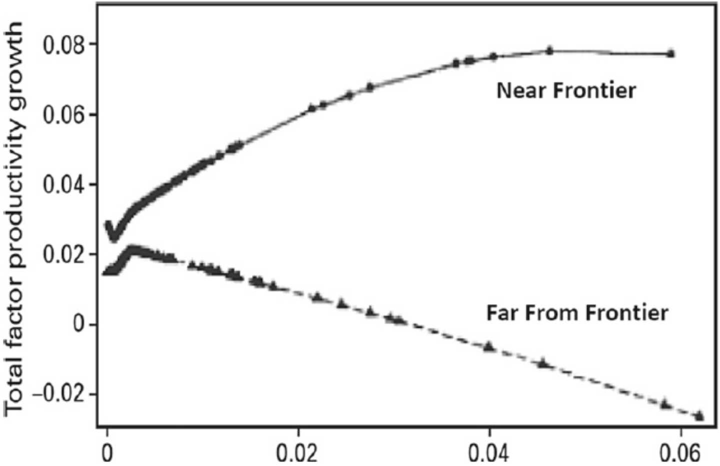


Figure 10: TFP growth and competition in leading and laggard firms. Source: Aghion et al. (2009)

Predictions of the model: Distance to Frontier and Institutions

Recall that innovations and R&D are not the only way to boost TFP: another way is imitation-based growth, when countries further from the frontier import technologies from abroad

Proximity to technological frontier and innovation vs imitation

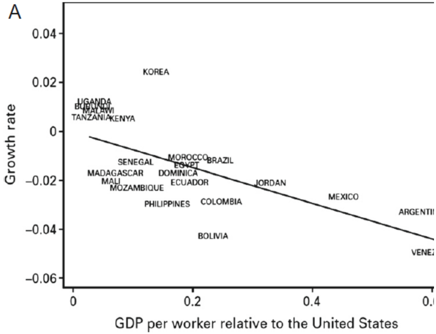
The closer the economy is to the world technological frontier, the more its growth driven by 'innovation-enhancing' policies and institutions, compared to 'imitation-enhancing'.

In particular:

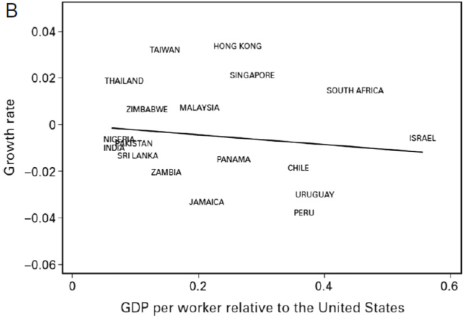
Market entry barriers and distance to frontier

High entry barriers become increasingly detrimental to growth as the country approaches the frontier

Predictions of the model: Distance to Frontier and Institutions



(a) Distance to frontier (the US) and growth rates: high entry barriers



(b) Distance to frontier (the US) and growth rates: low entry barriers

Figure 11: Distance to frontier (the US) and growth rates for countries with high entry barriers (left) and low entry barriers (right). Source: Aghion et al. (2014)

What have we learned in this lecture?

1. Innovations and ideas do not fall from the sky: they are the result of optimizing behavior that responds to incentives:
    - post-innovation profits and escape competition effects
    - larger market size
    - productivity of R&D effort
    - guarantees of property rights protection (patents, etc.), and lowered risks of R&D due to federal funding, etc.
2. Market competition is crucial in how it affects profit incentives for innovations (combination of 'escape from competition' and 'Shumpeterian' effects)
3. Population growth, especially when it translates into higher numbers of researchers and innovators, can help economic growth
4. Overall, long-run growth is the result of continuing innovations, which often times correspond to firms turnover ('creative destruction')
5. All these results are based on the concept of nonrivalry of ideas (and hence, increasing returns!)

Limitations of the EGT models

1. Explains the incentives behind innovations, technological progress, and R&D very well, but does not address the key questions of why certain places and countries have
   - higher or lower market competition
   - better patent systems and/or better universities and research centers
   - higher or lower firm entry and exit rates (entry barriers?)
   - higher share of population engaged in idea creation process, generally
2. Much as the Solow model and its extensions, the EGT models are not designed to explain
   - variation in the timing of initial growth take-offs and industrialization (recall, that innovations and R&D mostly happen in countries that were the first to industrialize)
   - demographic change, which is crucial for investments in human capital
   - other crucial dynamics before the 2nd half of the 20th century

Some 'growth accounting' results (David Weil, chapter 7)

'Growth accounting' shows that TFP growth is indeed crucial for understanding growth of incomes per capita.

If we assume a simple (per worker) production function with human capital: $y = A \cdot k^{\alpha} \cdot h^{1-\alpha}$, then

$g_A = g_y - \alpha \cdot g_k - (1-\alpha) \cdot g_h$

- For example, in the US economy, over the period 1975-2009, incomes per worker grew at a rate of 1.34% per year, capital grew at 2.2% per year, and human capital grew at 0.11% per year.
- Using the formula above (with $\alpha = 1/3$), it is clear that TFP must have grown at a rate of approx. 0.54% per year
- Thus, 2/5 of GDP per capita growth is explained by TFP growth (while 3/5 are explained by the accumulation of factors of production).
- But what is a broader, worldwide, picture?

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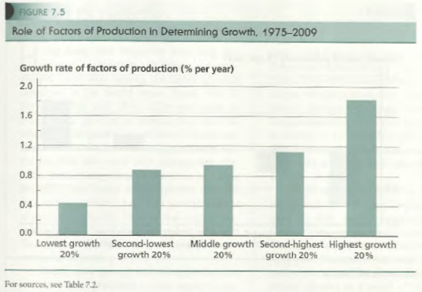
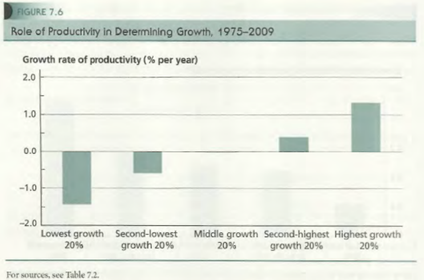
Some 'growth accounting' results (David Weil, chapter 7)



(a) Accumulation of factors of production and GDP per capita growth performance



(b) Growth of TFP and GDP per capita growth performance

Figure 12: Decomposing GDP per capita growth into growth of production factors and growth of TFP. Source: David Weil "Economic Growth" (3rd ed.)

Overall, 68% of the variation in GDP per capita growth rates is due to TFP growth differences, and 32% are due to factors accumulation.

Creative destruction and competition effects: classroom example

Imagine a class, where there are top students and students that are lagging behind.

Then, a new high-achieving student enters the class. (an increase in competition)

What will be the affect on top students and on students that are lagging behind? Works of Caroline Hoxby show that:

- Top students will increase their effort to remain at the top (escape competition effect)
- But students at the bottom of class will lower their effort because it becomes even harder for them to catch-up with the top

Quite strikingly (or not), firms behave just like students in a class :)

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