Session 6:

Innovation and Economic Growth

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Outline: Innovation and Economic Growth

- Prelude: Population growth in the Solow Model
- The Romer Model of long-run growth
- Combining Solow and Romer
- Discussion of ideas and economic growth

Prelude: Population Growth in the Solow Model

- Suppose the population grows at 1% per year in Solow
  - What is the long-run growth rate of GDP per person?
  - What is the long-run growth rate of GDP?
- Why?

Prelude: Population Growth in the Solow Model

- Suppose the population grows at 1% per year in Solow
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- Why?
  - In a Constant Returns to Scale world such as Solow, scale = population does not matter.
  - We can have a billion people or one person, and the results for GDP per person are essentially the same
    $\rightarrow$ each farmer with more seed to plant still runs into diminishing returns ($y = k^{1/3}$)
  - But since L grows at 1% and Y/L is constant, Y grows at 1% also

The Romer Model

The Romer Model: Our Corn Farm Again

- Farmers can use their labor (and capital) to produce corn

  $\sim$ Or... they can use their labor to invent new technologies for growing corn more productively

  - New tractors and combines
  - New fertilizer, irrigation systems, and drought-resistant seed

  The nonrivarly of ideas can sustain exponential growth
  in a way that capital accumulation could not.

- Model here is somewhat different from that in textbook
  - A better, more intuitive understanding of growth
- Focus on ideas versus objects; drop capital to keep simple

The Key Insight: Nonrivalry

- Production function for goods

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- Dividing by L_t, output per person is

$$y_t \equiv \frac{Y_t}{L_t} = A_t^{\beta}$$

The Key Insight: Nonrivalry

- Production function for goods

$$y_t = A_t^{\beta}$$

- Because of nonrivalry, output per person depends on the total stock of ideas, not on "ideas per person" — contrast with capital!
    - If you add one new computer, you make one worker more productive
    - If you add one new idea (e.g. better spreadsheet or the internet itself), you can make any number of workers more productive.

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$$g_{At} = \frac{\Delta A_{t+1}}{A_t} = \frac{L_t}{A_t}$$

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$$g_{At} = \frac{\Delta A_{t+1}}{A_t} = \frac{L_t}{A_t}$$

- Now solve for A_t to get

$$A_t = \frac{1}{g_{At}} L_t$$

More people means more ideas

What is the long-run growth rate of A_t?

- In the LR, $g_{At} = g_A$ is constant. Apply our growth rules to

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- In the LR, $g_{At} = g_A$ is constant. Apply our growth rules to

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- Obviously A_t and L_t will grow at the same rate when g_A is constant:

$$g_A = \bar{n}$$

The growth rate of ideas equals
the growth rate of researchers = population growth

Growth in the Romer Model

- Recall:

$$y_t = A_t^{\beta} \quad \text{and} \quad g_A = \bar{n}$$

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  - Growth in per capita GDP is proportional to the growth rate of ideas.
  - People produce ideas, so the growth rate of ideas equals the growth rate of people!

The long-run growth rate is the product of β — the strength of increasing returns — and $\bar{n}$ the growth rate of “scale”.

From IRS to Growth

Why does the Solow model fail to deliver growth whereas the Romer model successfully grows per capita income in the long run?

- Objects (Solow): Add 1 computer $\Rightarrow$ make 1 worker more productive.

  Output per worker $\sim$ # of computers per worker **(diminishing returns)**

- Ideas (Romer): Add 1 new idea $\Rightarrow$ make unlimited # more productive.
  - E.g. cure for lung cancer or drought-resistant seeds

  Income per person $\sim$ the aggregate stock of knowledge, not on the number of ideas per person.

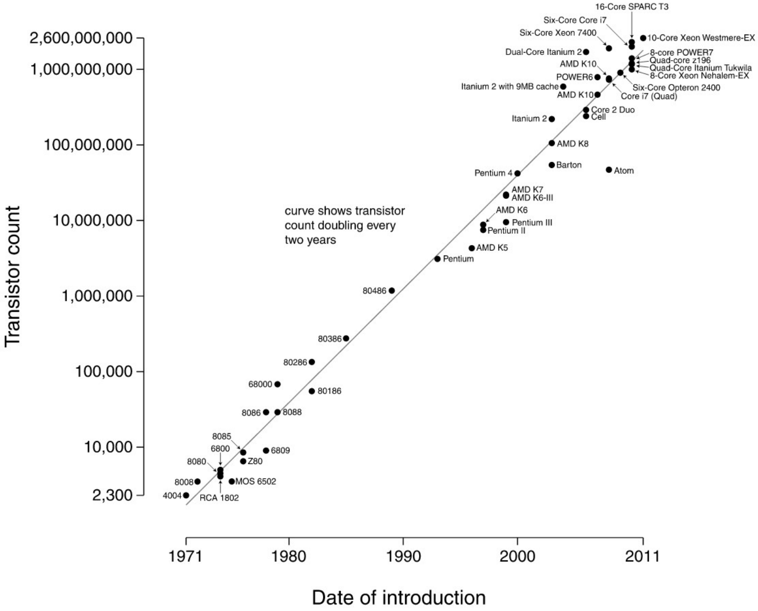
But it is easy to make aggregates grow: population growth!

IRS $\Rightarrow$ bigger is better.

Discussion

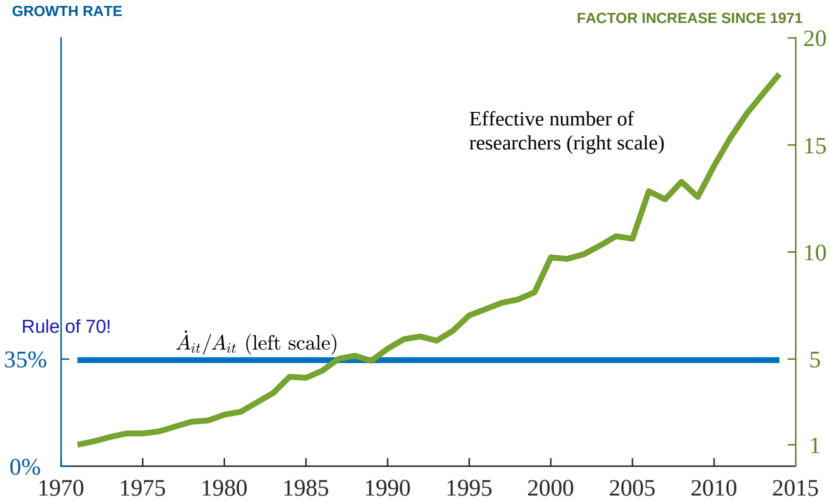
- Why does U.S. income per person grow at 2% per year for last 100+ years?
- China versus Hong Kong?
- OECD versus Africa?
- Robust to more elaborate idea production functions
  - Can distinguish researchers versus other workers/people
  - Past ideas can make current researchers more productive ("standing on shoulders")
  - Or past ideas can make current research harder ("fishing out")
  - $\Delta A_{t+1} = L_t A_t^{\phi}$; $\phi = 0, \phi > 0, \phi < 0$

The Steady Exponential Growth of Moore's Law



Evidence on Moore's Law

Research effort: 18x (+6.8% per year)



Bloom, Jones, Van Reenen, and Webb (2020)

The Ultimate Resource

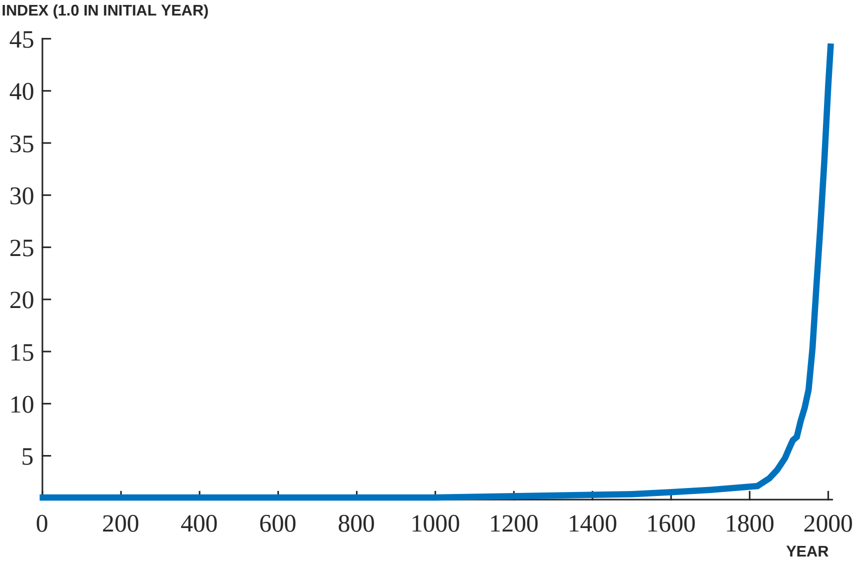
- Why are we richer today than in the past?

  More people $\Rightarrow$ more new ideas $\Rightarrow$ higher income / person

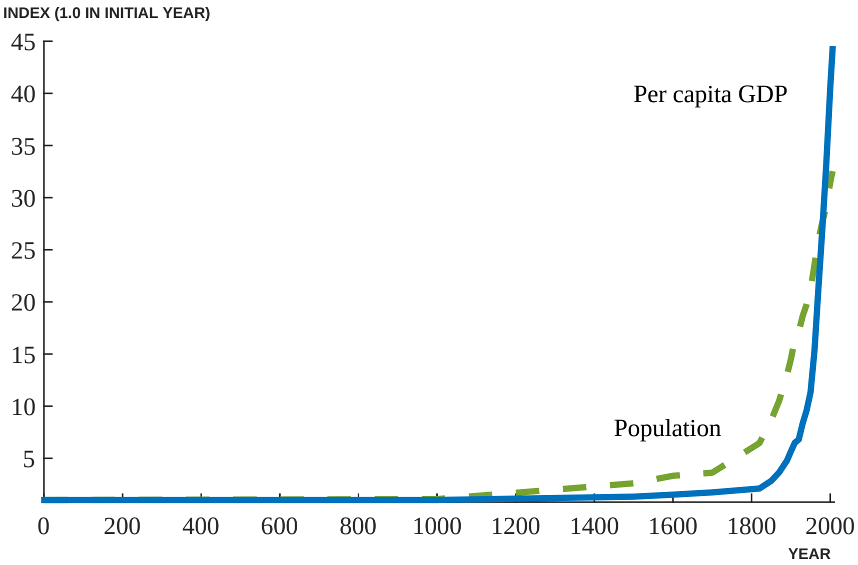
- Population growth is a historical fact.
  - If we take it as given, then growth in per capita income is not surprising

- Two applications:
  - Growth over the last 100,000 years (now)
  - The future of economic growth (in Discussion section)

What is graphed here?



World Growth over the Very Long Run



Growth in the Really Long Run

- Population growth and per capita GDP growth over 10,000 years
  - Overcoming Malthus

What differs here versus in the textbook?

- The textbook model assumes a strong (and arbitrary) degree of increasing returns in the idea production function
- What is different in these slides is that we connect the growth rate of ideas to the rate of population growth.
    - It's okay if you find this surprising, counterintuitive, and even a little strange
    - A broader discussion is in Chad's tribute "Paul Romer: Ideas, Nonrivalry, and Endogenous Growth"
- If you are interested: To see an obvious problem with the textbook model, ask yourself what happens in that model if the population grows...
    - Textbook: $\Delta A_{t+1} = L_t \, A_t$

Combining Solow and Romer

Combining the Solow and Romer Models

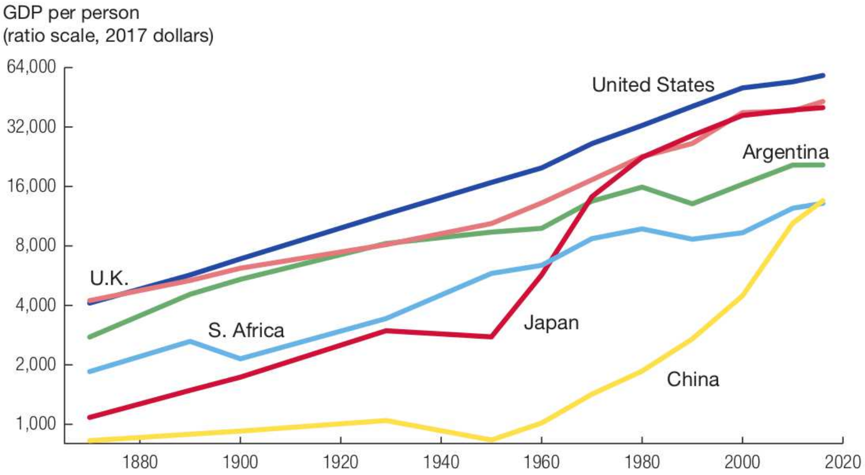
Romer: Explains the trend growth of the world frontier
(e.g. the United States)

- The world frontier grows through the discovery of new ideas

Solow: Countries grow “around” the Romer trend

- Principle of transition dynamics explain why countries grow at different rates for long periods of time
- Each country has a steady state relative to the world frontier
- Steady state is determined by TFP, openness to ideas, institutions, misallocation, investment rates, etc.

Per capita GDP in Seven Countries



Example: China and India

- Production function including institutions (I) and ideas (A)

$$Y = \underbrace{I A^{\beta}}_{TFP} K^{1/3} L^{2/3}$$

- Growth accounting

World idea growth	2%	U.S./frontier growth
Input catch-up	4%	Solow factor accumulation (better rules?)
Idea catch-up	1%	TFP growth greater than U.S.
Less misallocation	1%	Additional TFP growth via better rules
Total	8%	

Questions for Discussion

Is China's growth good or bad for the U.S.?

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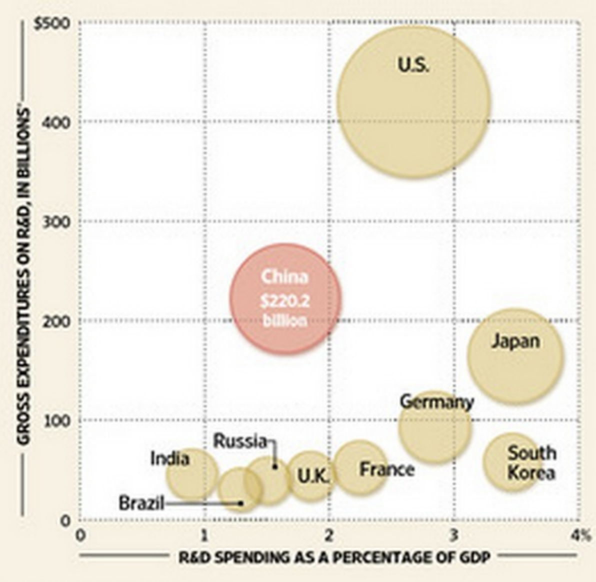
- When Intel, California invents a faster computer chip, is that good or bad for people living in New York?
- **Scale effect:** the development of China & India means the number of people around the world producing new ideas may quadruple
  - Ratio $\frac{\text{New Chinese PhDs in Sci/Eng}}{\text{New U.S. PhDs in Sci/Eng}}$: 1978 $<$ 5%, 2010 = 125%!
  - In 2013-16, Tsinghua University: more of the 10 percent most highly cited papers in STEM than any other university
  - In 2000, 47% of people with PhDs in Sci/Eng in US were immigrants
  - How many latent Jennifer Doudnas and Thomas Edisons are waiting to realize their potential?

R&D Spending by Country



The Future of Growth

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- Reading: "America's Best Days May Be Behind It"
  Reading: "One Economics Sickness, Five Diagnoses" (Mankiw)

- What might growth look like in the future?

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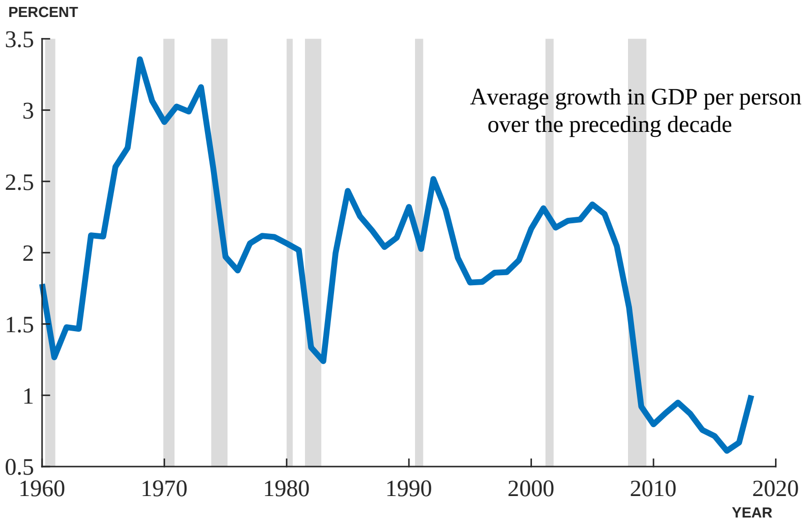
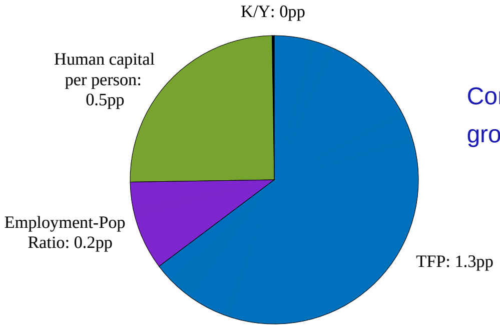
- What might growth look like in the future?
  - Bob Gordon “The Rise and Fall of American Growth”
  - Brynjolfsson and McAfee “Race Against the Machine” and “The Second Machine Age”

The Future of Growth? The U.S. TFP Growth Slowdown



U.S. Historical Growth Accounting



Components of the 2% growth in GDP per person

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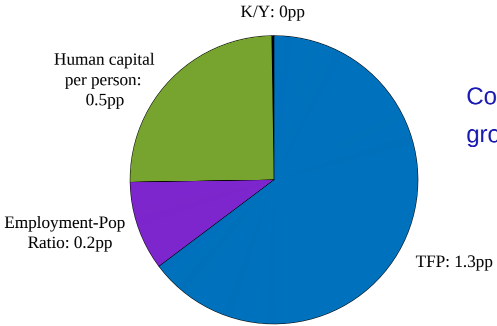
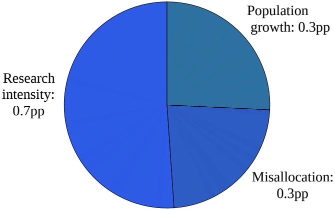


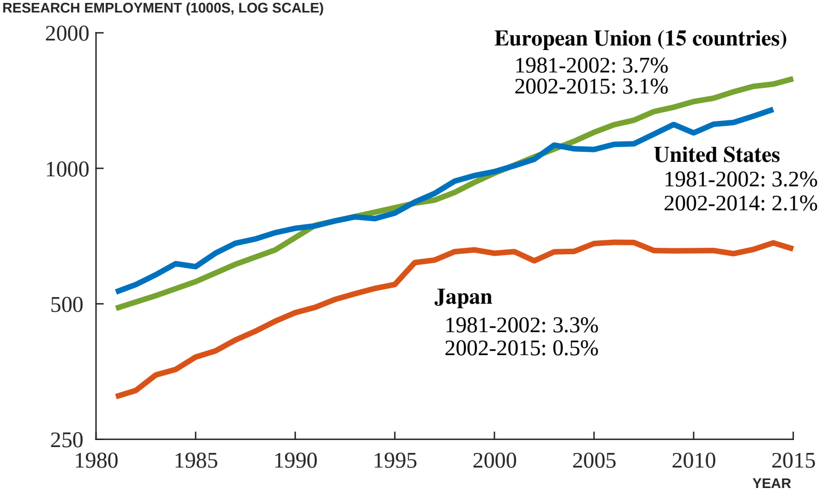
Components of the 2% growth in GDP per person

The long-run component of growth is only 15% of historical growth = 0.3pp!

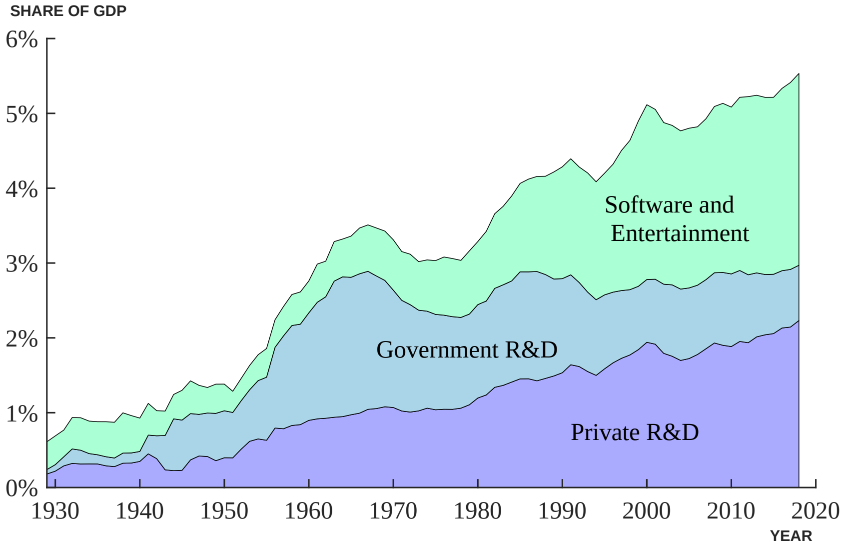


Components of the 1.3% TFP growth

Slowdown in Research Employment



Intellectual Property Products in the U.S.



The Future of Growth?

- Headwinds
  - Ideas are getting harder to find
  - Educational attainment is leveling out
  - Population growth slowing in advanced countries
- Tailwinds
  - China and India (each as populous as US/Japan/Europe)
  - How many future Thomas Edisons and Jennifer Doudnas are waiting to realize their potential?
- Uncertainties
  - To what extent can machines/AI substitute for labor/researchers?
  - The shape of the future idea production function?

Is there too much or too little research?

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- Think about the overall benefit to society from the creation of
  - Penicillin, oral rehydration therapy
  - Electricity
  - Eyeglasses
  - The internet
- Did the inventor capture anything close to the social returns from the invention?
- Is this a problem?
- Did Bill Gates add more value to the world by giving away his fortune or by selling Microsoft's products?

Questions for Review

- Why does the nonrivalry of ideas make growth possible?
- What role does population play in helping us understand long-run growth?
- How do the combined Solow and Romer models help us to make sense of economic growth in a country like China?
- What considerations affect the future of economic growth?