The Future of Economic Growth

Chad Jones

Stanford GSB

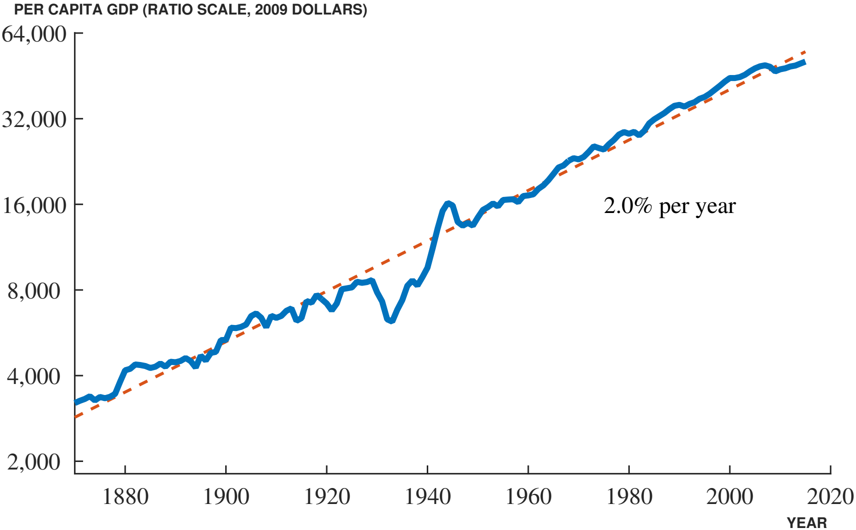
Simpson Lecture at Princeton University

October 15, 2018

Overview

- Why are we so much richer today than 100 years ago?
  - Paul Romer's Nobel Prize
  - The crucial role of the nonrivalry of ideas
- Are ideas getting harder to find?
- The future of economic growth?
- Other questions for which I'd like an answer

U.S. GDP per Person



Why?

- The average American is 15 times richer today than in 1870.
- How do we understand this fact?
- What does the future hold?

Growth Theory

- Conclusion of any growth theory:

$$\frac{\dot{y}_t}{y_t} = g \quad \text{and a story about g}$$

- Key to this result is (essentially) a linear differential equation somewhere in the model:

$$\dot{X}_t = \_\_ \, X_t$$

- Growth models differ according to what they call X_t and how they fill in the blank.

Catalog of Growth Models: What is X_t?

Solow	$\dot{k}_t = s k_t^{\alpha}$
Solow	$\dot{A}_t = \bar{g} A_t$
AK model	$\dot{K}_t = sAK_t$
Lucas	$\dot{h}_t = u h_t$
Romer/AH/GH	$\dot{A}_t = S A_t$
Variation on Romer (J/K/S)	$\dot{L}_t = n L_t$

The Linearity Critique

$$\dot{X}_t = sX_t^{\phi}$$

- To explain the U.S. 20th century, $\phi \approx 1$ is required
  - $\phi < 1$: Growth slows to zero
  - $\phi > 1$: Growth will explode
- Solow (1994 JEP) criticizes new growth theory for this: “You would have to believe in the tooth fairy to expect that kind of luck.”
  - But the same criticism applies to $\dot{A}_t = \bar{g}A_t$
  - Facts $\Rightarrow$ we need linearity somewhere. Where??

Solow and Romer

- Robert Solow (1950s)
  - Capital versus Labor
  - Cannot sustain long-run growth

- Paul Romer (1990s)
  - Objects versus Ideas
  - Sustains long-run growth
  - Wide-ranging implications for intellectual property, antitrust policy, international trade, the limits to growth, sources of “catch-up” growth

Romer’s insight: Economic growth is sustained by discovering better and better ways to use the finite resources available to us

Objects vs Ideas (Paul Romer, 1990)

- Objects: Almost all goods in the world
  - Examples: iphones, airplane seats, and surgeons
  - Rivalrous: If I'm using it, you cannot at the same time
  - The fundamental scarcity at the heart of most economics
- Ideas: They are different — nonrival
  - Examples: calculus, HTML, chemical formula of new drug
  - My use $\nRightarrow$ less of the idea is available to you

The Essence of Romer's Insight

- **Question:** In generalizing from the neoclassical model to incorporate ideas (A), why do we write the PF as

$$Y = AK^{\alpha}L^{1-\alpha} \qquad (*)$$

instead of

$$Y = A^{\alpha}K^{\beta}L^{1-\alpha-\beta}$$

- Does A go inside the CRS or outside?
  - The "default" (*) is sometimes used, e.g. 1960s
  - 1980s: Griliches et al put knowledge capital inside CRS

The Nonrivalry of Ideas ⇒ Increasing Returns

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

$$Y_t = F(K_t, L_t, A_t) = A_t K_t^{\alpha} L_t^{1-\alpha}$$

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

$$F(\lambda K, \lambda L, A) = \lambda \times F(K, L, A)$$

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

$$F(\lambda K, \lambda L, \lambda A) > F(\lambda K, \lambda L, A)$$

- Economics is quite straightforward:
  - Replication argument implies CRS to objects
  - Therefore there must be IRS to objects and ideas

A Simple Model

Production of final good	$Y_t = A_t^\sigma L_{Yt}$
Production of ideas	$\dot{A}_t = L_{At} A_t^\phi$
Resource constraint	$L_{Yt} + L_{At} = L_t = L_0 e^{nt}$
Allocation of labor	$L_{At} = \bar{s} L_t, \quad 0 < \bar{s} < 1$

A Simple Model

Production of final good	$Y_t = A_t^\sigma L_{Yt}$
Production of ideas	$\dot{A}_t = L_{At} A_t^\phi$
Resource constraint	$L_{Yt} + L_{At} = L_t = L_0 e^{nt}$
Allocation of labor	$L_{At} = \bar{s} L_t, \quad 0 < \bar{s} < 1$

$$y_t \equiv \frac{Y_t}{L_t} = A_t^\sigma (1 - \bar{s})$$

A Simple Model

Production of final good $$Y_t = A_t^{\sigma} L_{Yt}$$

Production of ideas $$\dot{A}_t = L_{At} A_t^{\phi}$$

Resource constraint $$L_{Yt} + L_{At} = L_t = L_0 e^{nt}$$

Allocation of labor $$L_{At} = \bar{s} L_t, \quad 0 < \bar{s} < 1$$

$$y_t \equiv \frac{Y_t}{L_t} = A_t^{\sigma}(1 - \bar{s})$$

$$g_y = \sigma g_A$$

$$\frac{\dot{A}_t}{A_t} = \frac{L_{At}}{A_t^{1-\phi}}$$

$$g_A = \frac{g_{L_A}}{1 - \phi}$$

$$g_y = \gamma n$$

Long-Run Growth	=	Degree of IRS, $\gamma \equiv \frac{\sigma}{1-\phi}$	$\times$	Rate at which scale grows

From IRS to Growth

- Objects: Add 1 computer ⇒ make 1 worker more productive.

  Output per worker ∼ # of computers per worker

- Ideas: Add 1 new idea ⇒ make unlimited # more productive.
  - E.g. computer code for 1st spreadsheet or the software protocols for the internet itself

  Income per person ∼ the aggregate stock of knowledge, not on the number of ideas per person.

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

IRS ⇒ bigger is better.

The Ultimate Resource

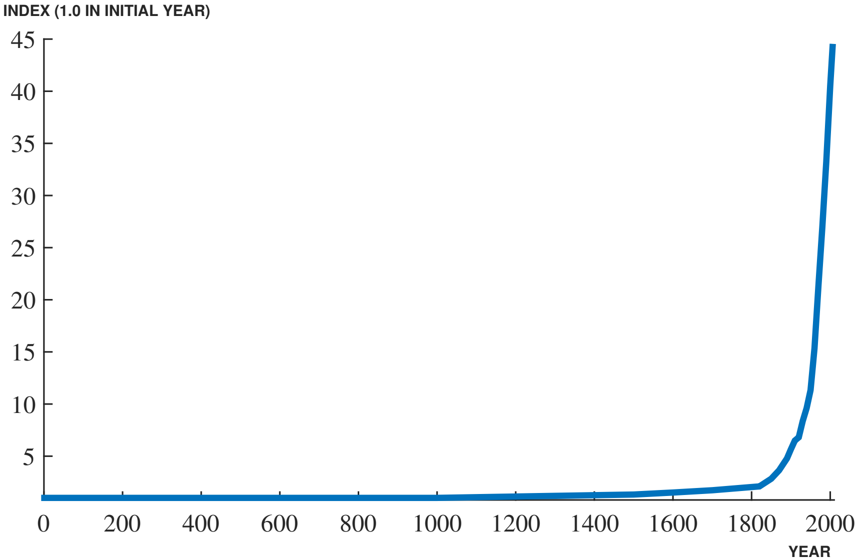
- Why are we richer today than in the past?

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

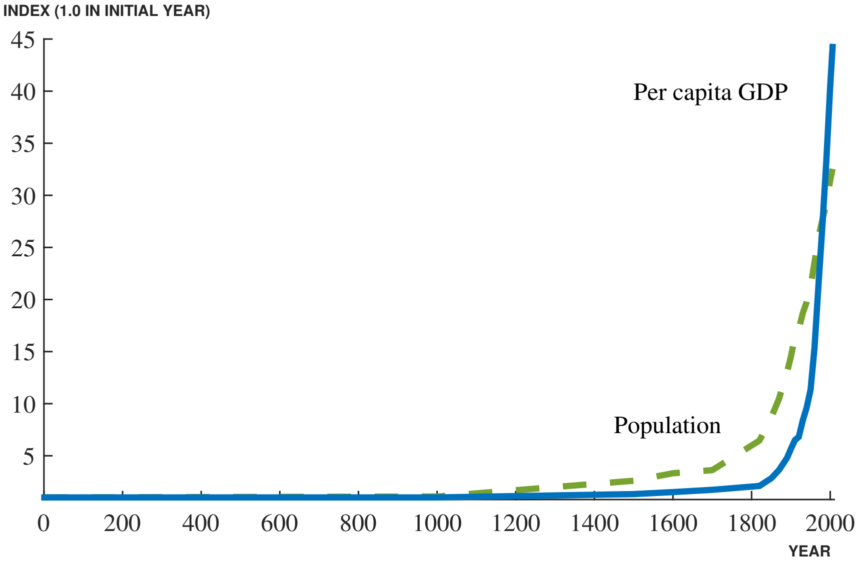
- Population growth is a historical fact.
  - If we take it as given, then growth in per capita income is not surprising
  - No other ad hoc linearity is needed

- Two applications:
  - Growth over the last 100,000 years
  - The future of U.S. economic growth

What is graphed here?



Population and Per Capita GDP: the Very Long Run



Growth over the Very Long Run

- Malthus: $c = y = AL^{\alpha}, \quad \alpha < 1$
  - Fixed supply of land: $\uparrow L \;\Rightarrow\; \downarrow c$ holding A fixed
- Story:
  - 100,000 BC: small population $\Rightarrow$ ideas come very slowly
  - New ideas $\Rightarrow$ temporary blip in consumption, but permanently higher population
  - This means ideas come more frequently
  - Eventually, ideas arrive faster than Malthus can reduce consumption!
- People produce ideas and Ideas produce people

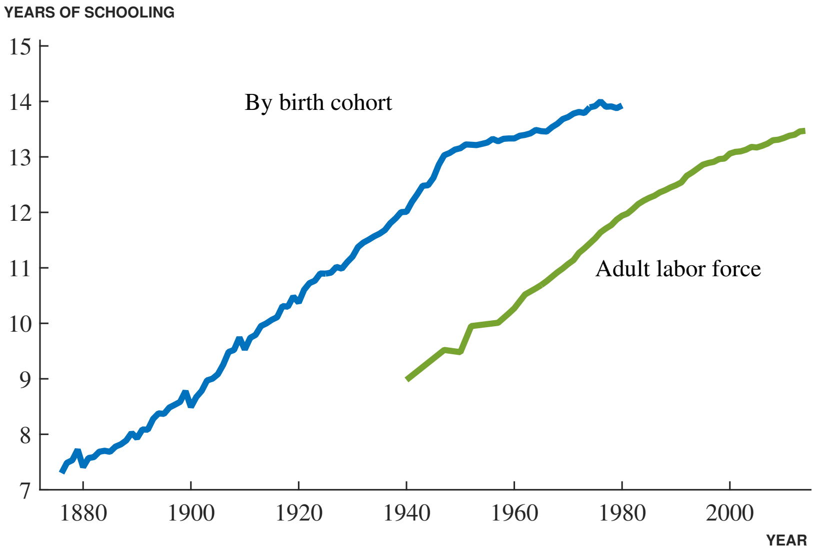
Accounting for U.S. Growth, 1950–2007

$$y^* \approx \left(\frac{K}{Y}\right)^{\beta} \cdot h \cdot (\text{R\&D intensity})^{\gamma} \cdot L^{\gamma}$$

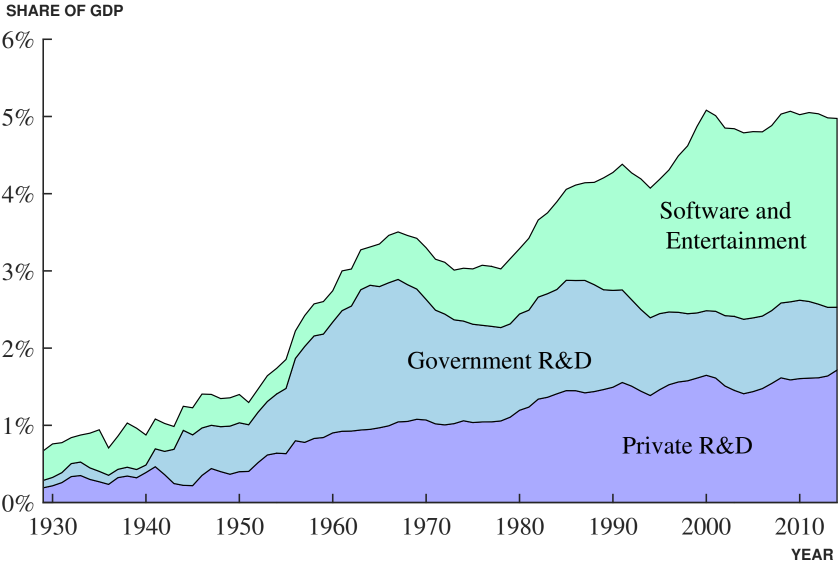
	Solow	Lucas	Romer/AH/GH	J/K/S
2.0	0.0	0.4	1.2	0.4
(100%)	(0%)	(20%)	(58%)	(21%)

- Educational attainment rises $\approx$ 1 year per decade. With $\psi = .06$ $\Rightarrow$ about 0.6 percentage points of growth per year.
- Transition dynamics are 80 percent of growth.
- "Steady state" growth is only 20 percent of recent growth!
  - Possibly slower as population growth declines...

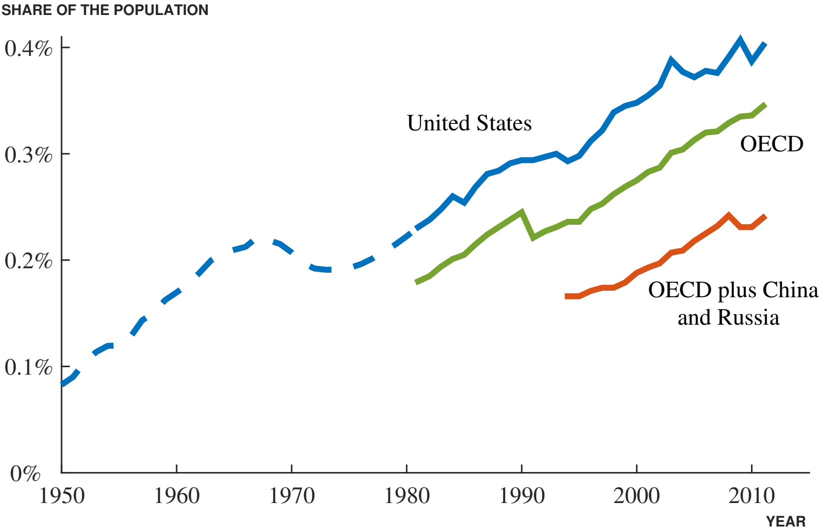
U.S. Educational Attainment



U.S. R&D Spending Share



Research Share of Total Employment



Are ideas getting harder to find?

Bloom, Jones, Van Reenen, Webb (2018)

Overview

- New stylized fact:

  Exponential growth is getting harder to achieve.

Economic growth	=	Research productivity	$\times$	Number of researchers
e.g. 2% or 5%		$\downarrow$ (falling)		$\uparrow$ (rising)

- Aggregate evidence: well-known (Jones 1995)
- This paper: micro evidence
  - Moore's law, Agricultural productivity, Medical innovations
  - Firm-level data from Compustat

Exponential growth results from the rising research effort that offsets declining research productivity.

The Importance of Micro Data

- In response to the "scale effects" critique:
  - Howitt (1999), Peretto (1998), Young (1998) and others
  - Composition bias: perhaps research productivity *within* every quality ladder is constant, e.g. if number of products N_t grows at the right rate:

$$\frac{\dot{A}_{it}}{A_{it}} = \alpha S_{it} \qquad (*)$$

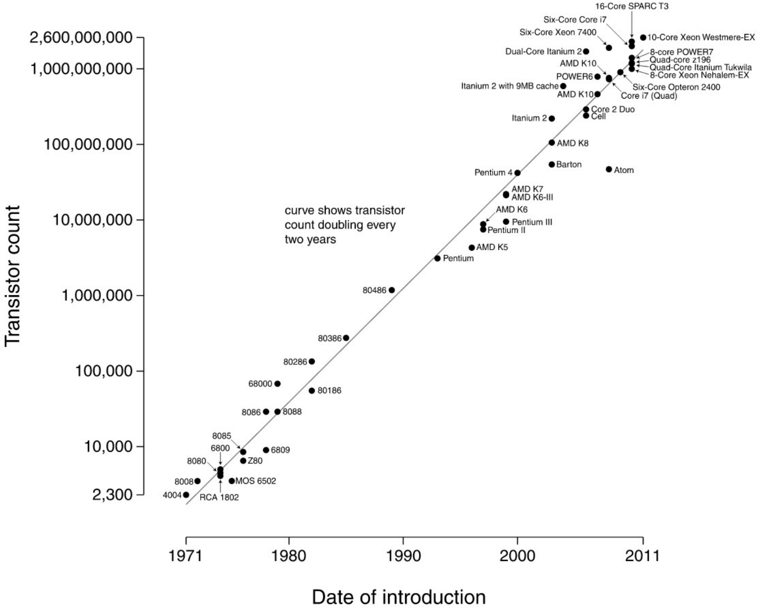
$\Rightarrow S_{it} = \frac{S_t}{N_t}$ invariant to scale, but responds to subsidies

  - Aggregate evidence would then be misleading
  - Permanent subsidies would still have growth effects.

- Key to addressing this concern:

Study (*) directly $\Rightarrow$ research productivity within a variety!

The Steady Exponential Growth of Moore's Law



Moore's Law and Measurement

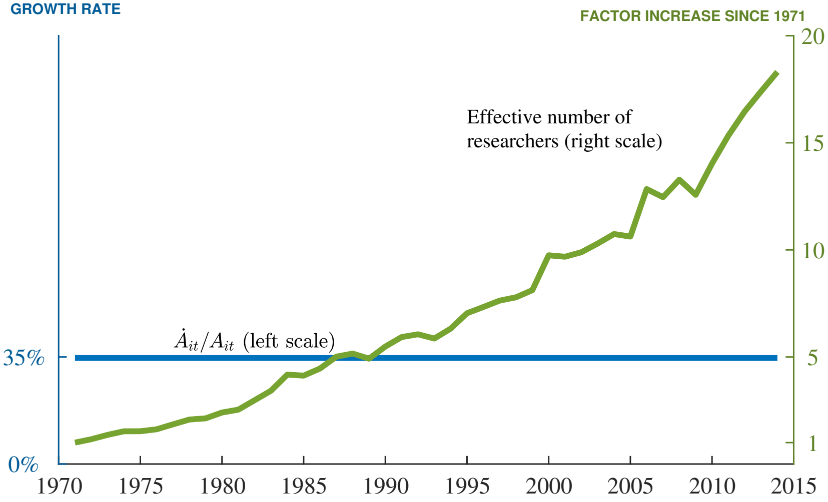
- Idea output: Constant exponential growth at 35% per year

$$\frac{\dot{A}_{it}}{A_{it}} = 35\%$$

- Idea input: R&D spending by Intel, Fairchild, National Semiconductor, TI, Motorola (and 25+ others) from Compustat
  - Pay close attention to measurement in the 1970s, where omissions would be a problem...
  - Use fraction of patents in IPC group H01L ("semiconductors") to allocate to Moore's Law

Evidence on Moore's Law

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



Summary of Evidence

- Moore's Law
    - 18x harder today to generate the doubling of chip density
    - Have to double research input every decade!
- Qualitatively similar findings in rest of the economy
    - Agricultural innovation (yield per acre of corn and soybeans)
    - Medical innovations (new drugs or mortality from cancer/heart disease)
    - Publicly-traded firms
    - Aggregate economy

New ideas are getting harder to find!

Summary: Evidence on Research Productivity

Scope	Average annual growth rate	Half-life (years)	Extent of Diminishing Returns, β
Aggregate economy	-5.1%	14	3.1
Moore's law	-6.8%	10	0.2
Agriculture (seeds)	-5.5%	13	4.8
New molecular entities	-3.5%	20	...
Disease mortality	-5.6%	12	...
Compustat firms	-11.1%	6	1.1

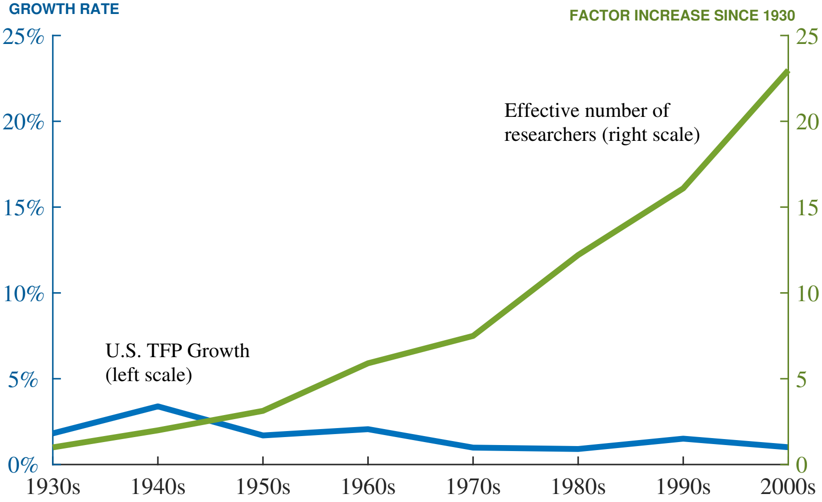
Note: β is from $\frac{\dot{A}_t}{A_t} = (\alpha A^{-\beta})S$ (hence $\beta = 1 - \phi$)

Aggregate Evidence

- What if research productivity declines sharply *within* every product line, but growth proceeds by developing new products?
  - Steam, electricity, internal combustion, semiconductors, gene editing, etc.
  - Maybe research productivity is constant via the discovery of new products?
- But the extreme of this $\Rightarrow$ Romer (1990)!
- Standard problem:
  - Growth is steady or declining (here BLS TFP growth)
  - Aggregate R&D rises sharply (here NIPA IPP deflated by the nominal wage for 4+ years of college/postgrad education)

Aggregate Evidence

Research effort: 23x (+4.3% per year)
Research productivity: 41x (-5.1% per year)



How this supports Romer, not detracts...

- Highlights Romer's key insight: nonrivalry
- Why? Consider Akcigit, Celik, and Greenwood (2014) "Buy, Keep, or Sell..."

$$Y = A^{\alpha} K^{\beta} L^{1-\alpha-\beta} \quad \text{constant returns}$$

$$\frac{\dot{A}_t}{A_t} = \theta S$$

  - Ideas are fully rivalrous here, just like capital!
  - Growth and innovation in a perfectly competitive model

Implications for Growth Theory

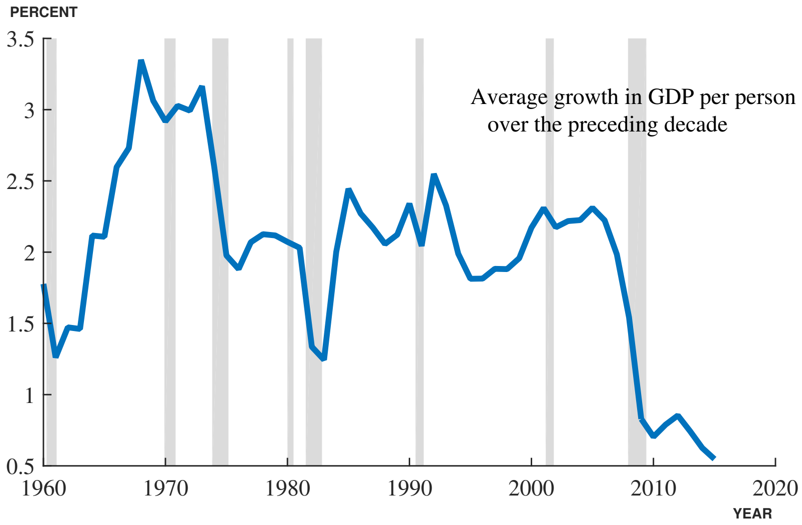
- Where does long-run growth come from?

Economic growth	=	Research productivity	×	Research effort
2%		↓ **(falling)**		↑ **(rising)**

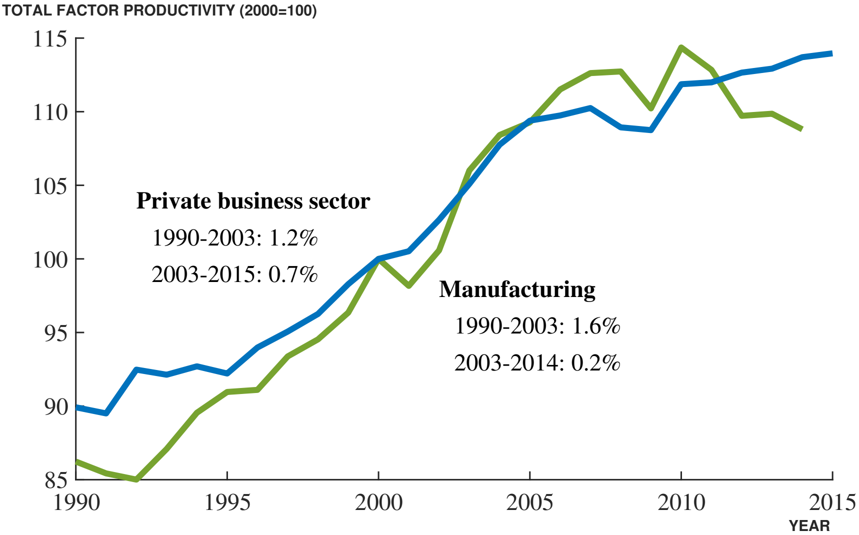
- Ideas are getting harder and harder to find
- A "Red Queen" model of economic growth:

We have to run faster and faster just to generate constant exponential growth (e.g. at 2%)

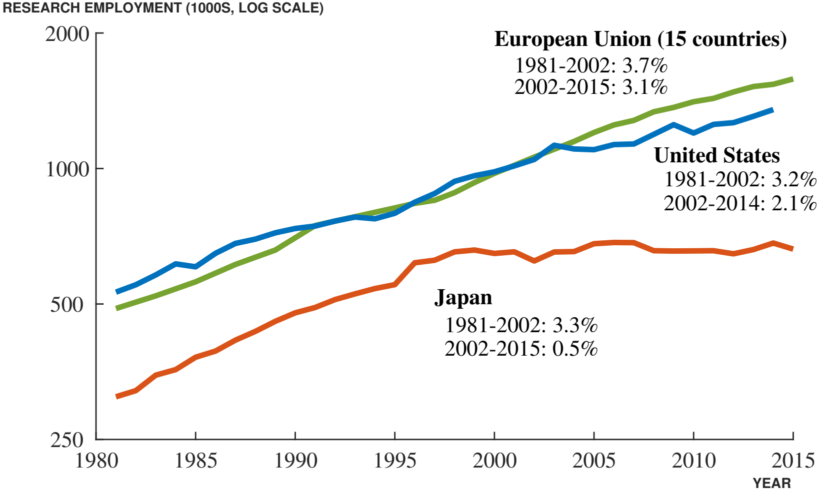
Recently, growth has slowed!



U.S. Total Factor Productivity



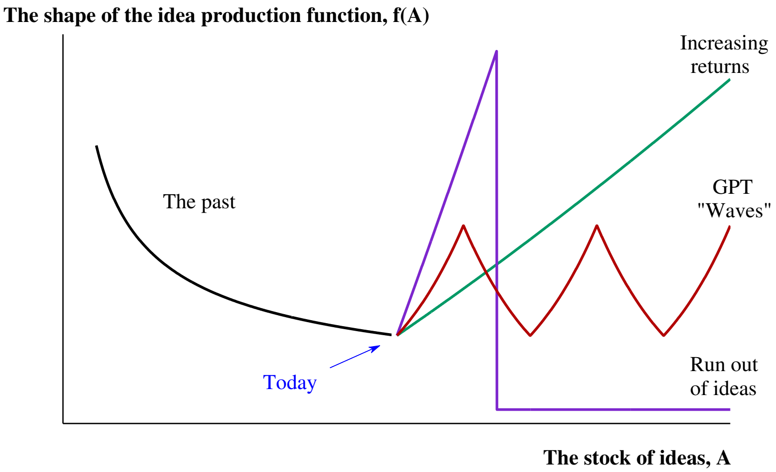
Research Employment in Select Economies



The Future of U.S. 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 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?

Alternative Futures?



Questions I wish I knew the answer to

- What is the social rate of return to R&D?

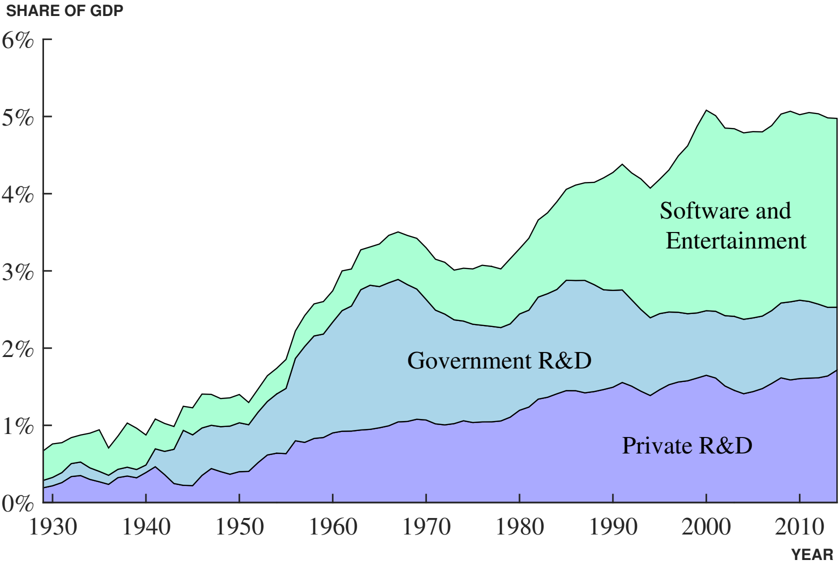
- Does the decline in government funding of research / GDP matter?

    - Are we doing too little basic research?

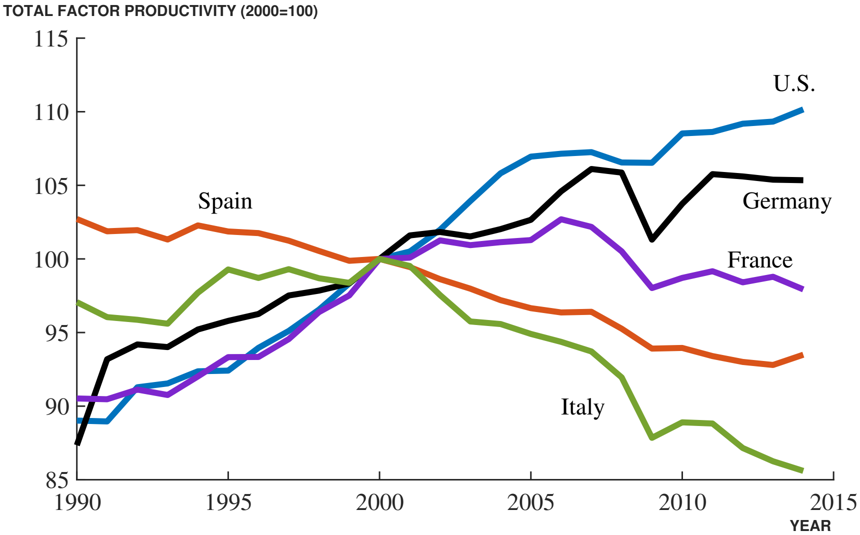
- Why has growth slowed down around the world since 2000?

    - Even the level of TFP has fallen sharply in Italy/Spain

U.S. R&D Spending Share



TFP in Select Advanced Economies



Growth Theory: Two Determinants of TFP

- Ideas
  - Are ideas getting harder to find?
  - Are we searching less intensely?
- Misallocation (Restuccia-Rogerson, Hsieh-Klenow, etc.)
  - Italy/Spain: Has misallocation gotten worse?
  - US/Germany: Has misallocation changed over time?

Conclusion

Many good questions $\Rightarrow$ growing field of economic growth!

These slides draw from the following papers:

- Jones (2005) "Growth and Ideas" *Handbook of Economic Growth*
- Fernald and Jones (2014) "The Future of U.S. Economic Growth" *AEAP&P*
- Jones (2016) "The Facts of Economic Growth" *Handbook of Macroeconomics*
- Bloom, Jones, Van Reenen, Webb (2018) "Are Ideas Getting Harder to Find?" NBER working paper.
- Jones (2017) "The Productivity Slowdown in Advanced Economies" *ECB Forum on Central Banking*