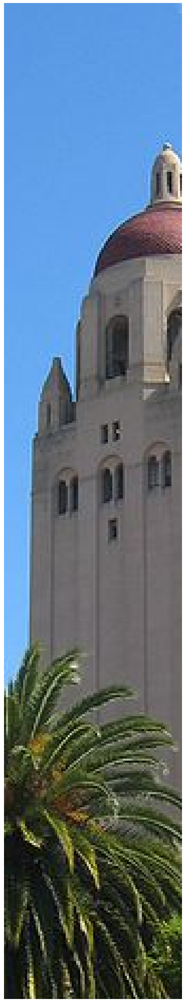


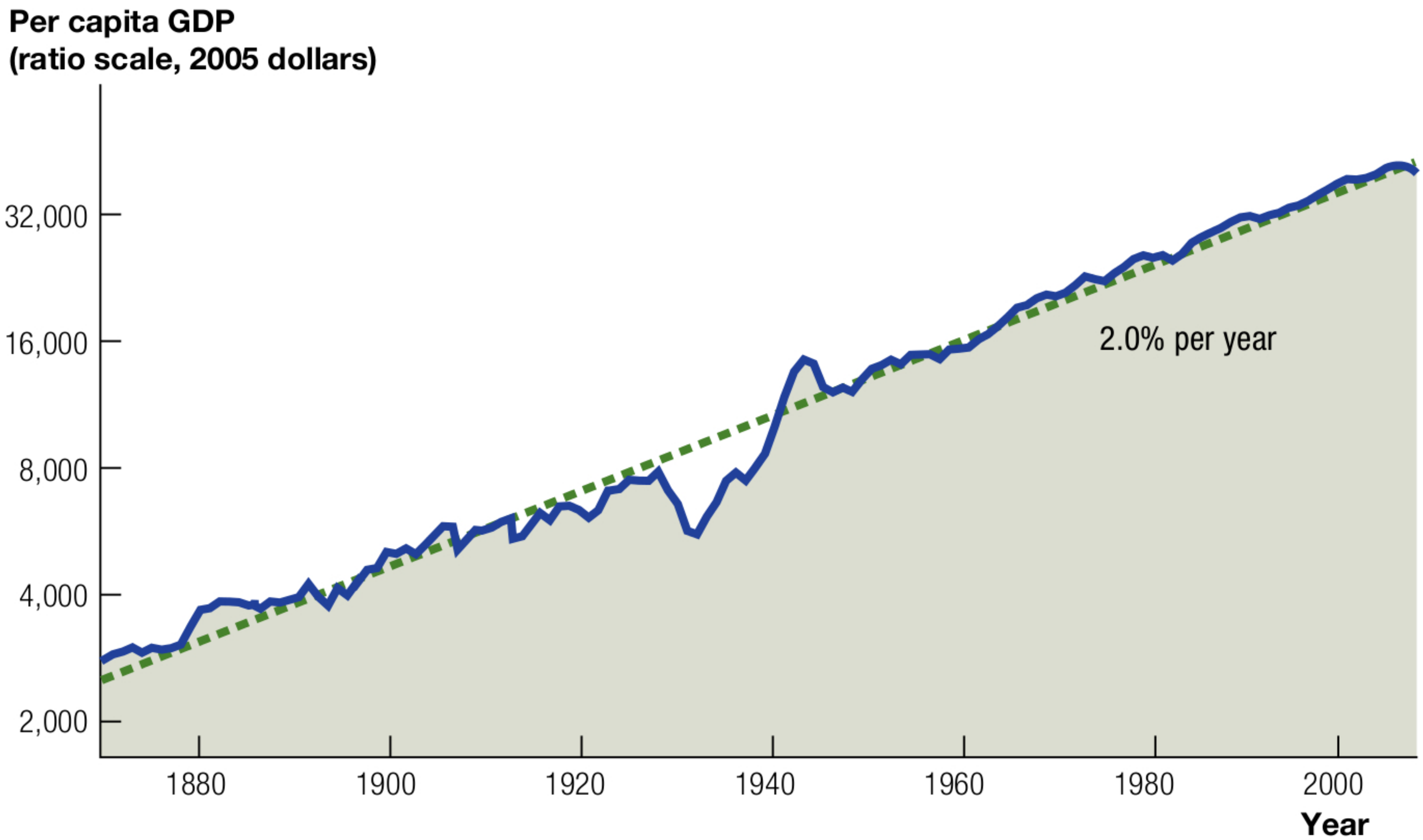
Growth and Ideas

Chad Jones

Stanford GSB

October 14, 2015

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 the X_t variable 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	$\dot{A}_t = RA_t$
Extension of Romer	$\dot{L}_t = nL_t$

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 accountants
  - 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
  - The Pythagorean Theorem or oral rehydration therapy
  - My use $\not\Rightarrow$ less of the idea is available to you

The Nonrivalry of Ideas $\Rightarrow$ 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

Nonrivarly $\Rightarrow$ IRS $\Rightarrow$ Growth follows easily!

Production of final good	$Y_t = A_t^{\sigma} L_t$
Production of ideas	$\dot{A}_t = \bar{\beta}_t R_t = \beta R_t A_t^{\phi}$
Resource constraint	$L_t + R_t = N_t = N_0 e^{nt}$
Allocation of people	$R_t = \bar{s} N_t, \quad 0 < \bar{s} < 1$

$\phi = 0$: Useful benchmark!

$\phi > 0$: Standing on shoulders

$\phi < 0$: “Fishing out”

$$g_y = \frac{\sigma n}{1 - \phi}$$

From IRS to Growth

- Objects: Add one computer $\Rightarrow$ make one worker more productive.

  Output per worker $\sim$ # of computers per worker

- Ideas: Add one new idea $\Rightarrow$ make everyone better off.
  - E.g. the first spreadsheet or email software

  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.

The Ultimate Resource

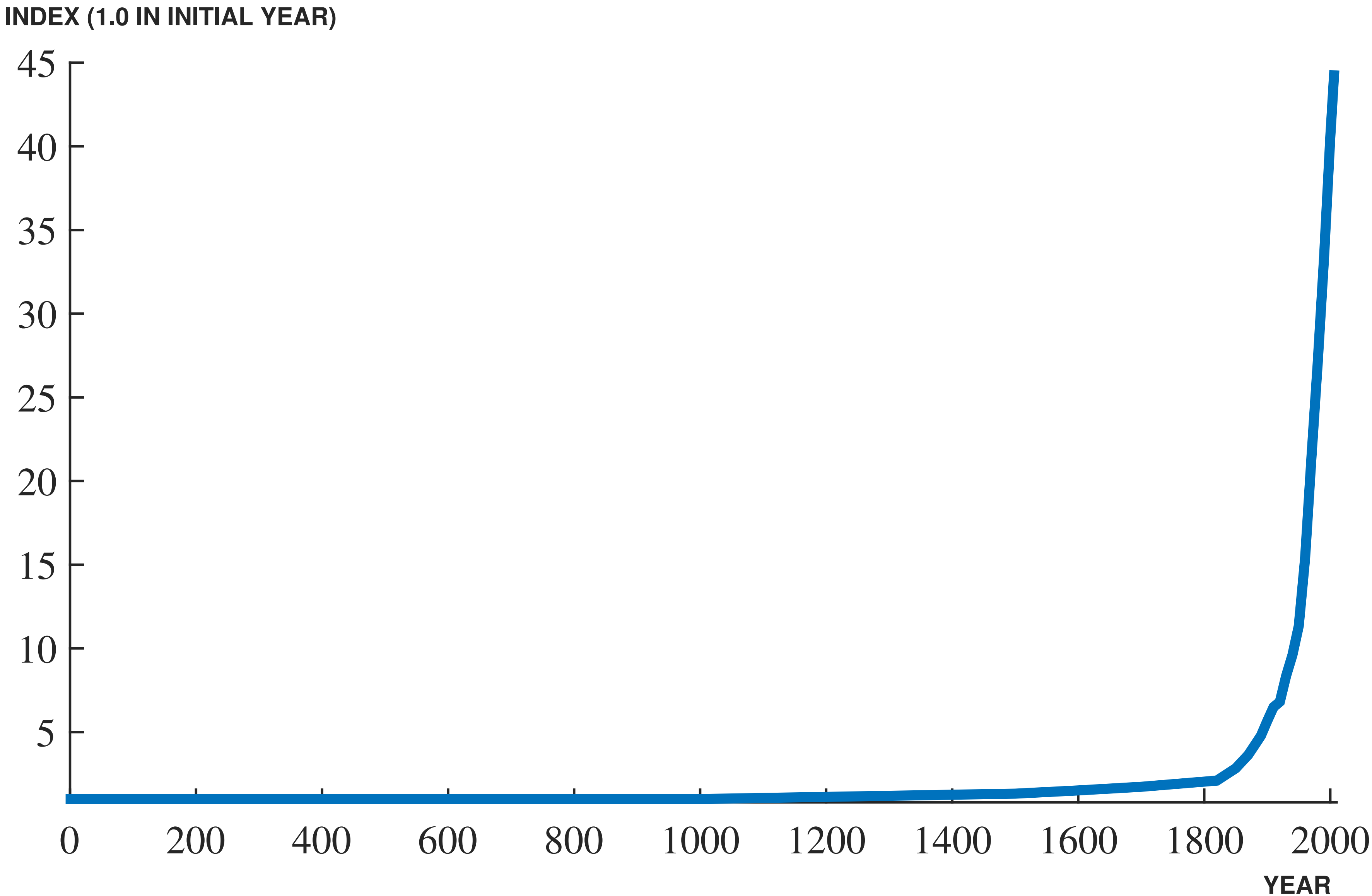
- Why are we richer today than in the past?

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

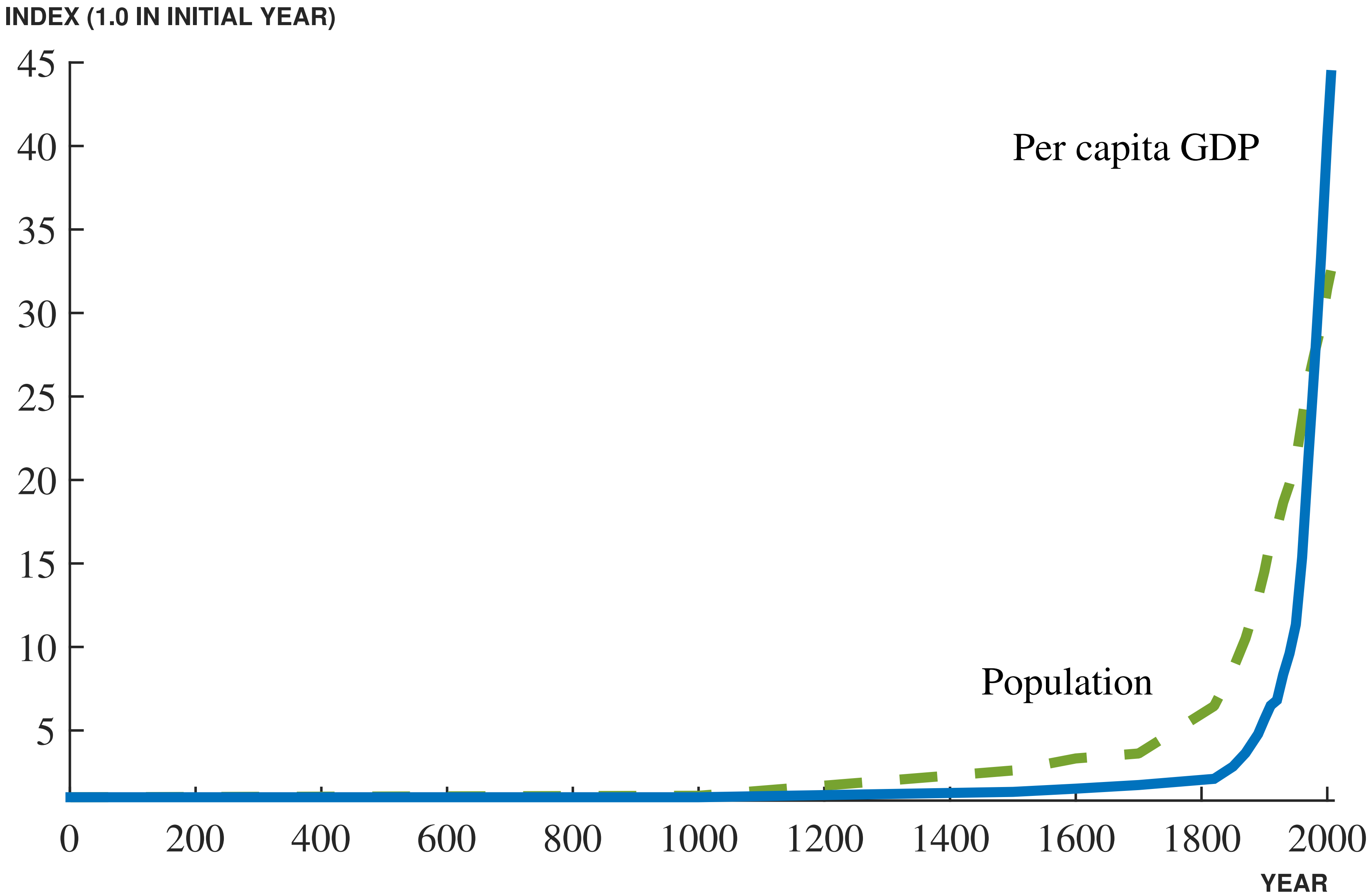
- Population growth is a historical fact.
  - If we take it as given, then growth in per capita income is not surprising
  - No other ad hoc linearity is needed

- 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
  - If nonrivarly $>$ Malthus, this leads to the hockey stick

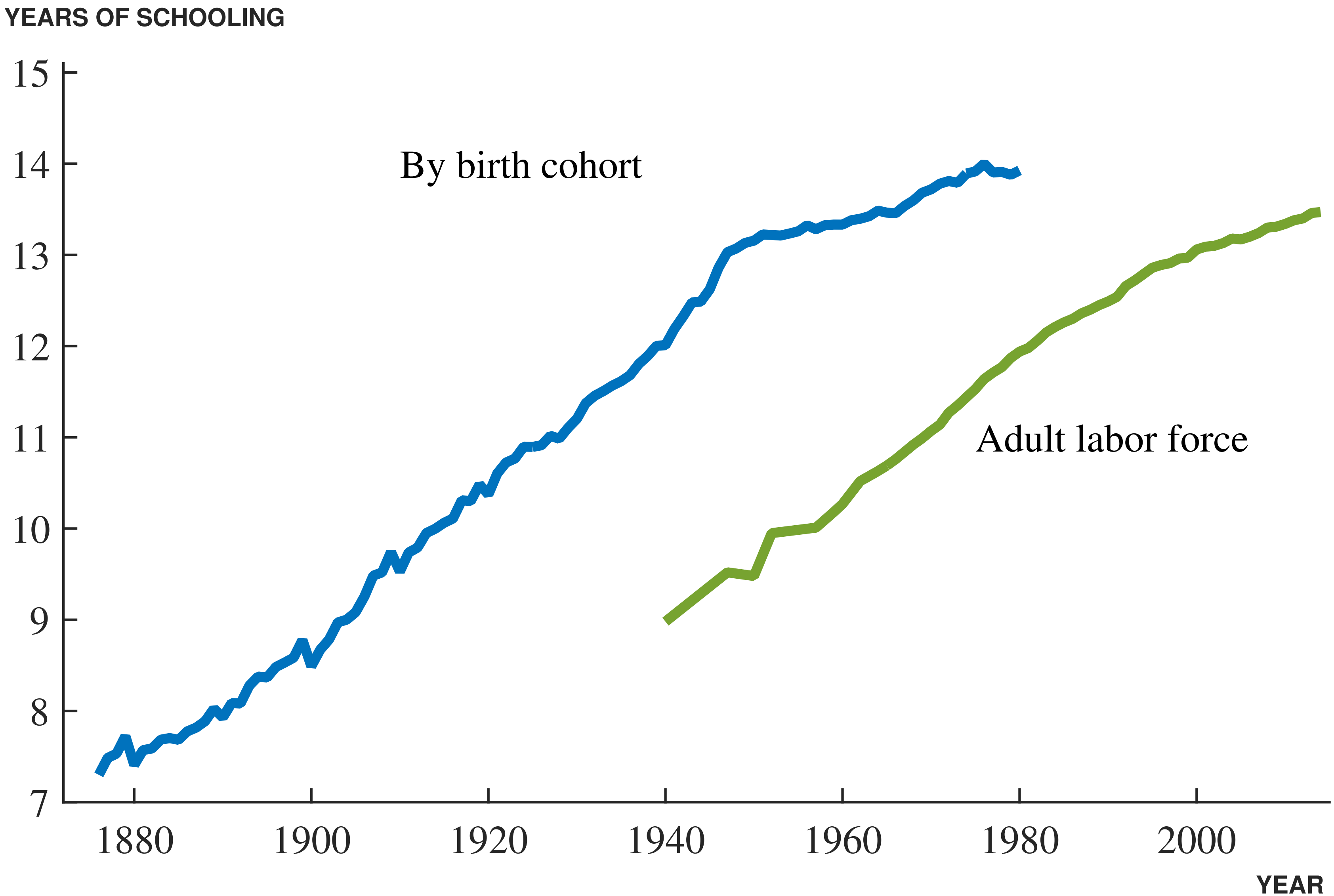
Accounting for U.S. Growth, 1950–2007

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

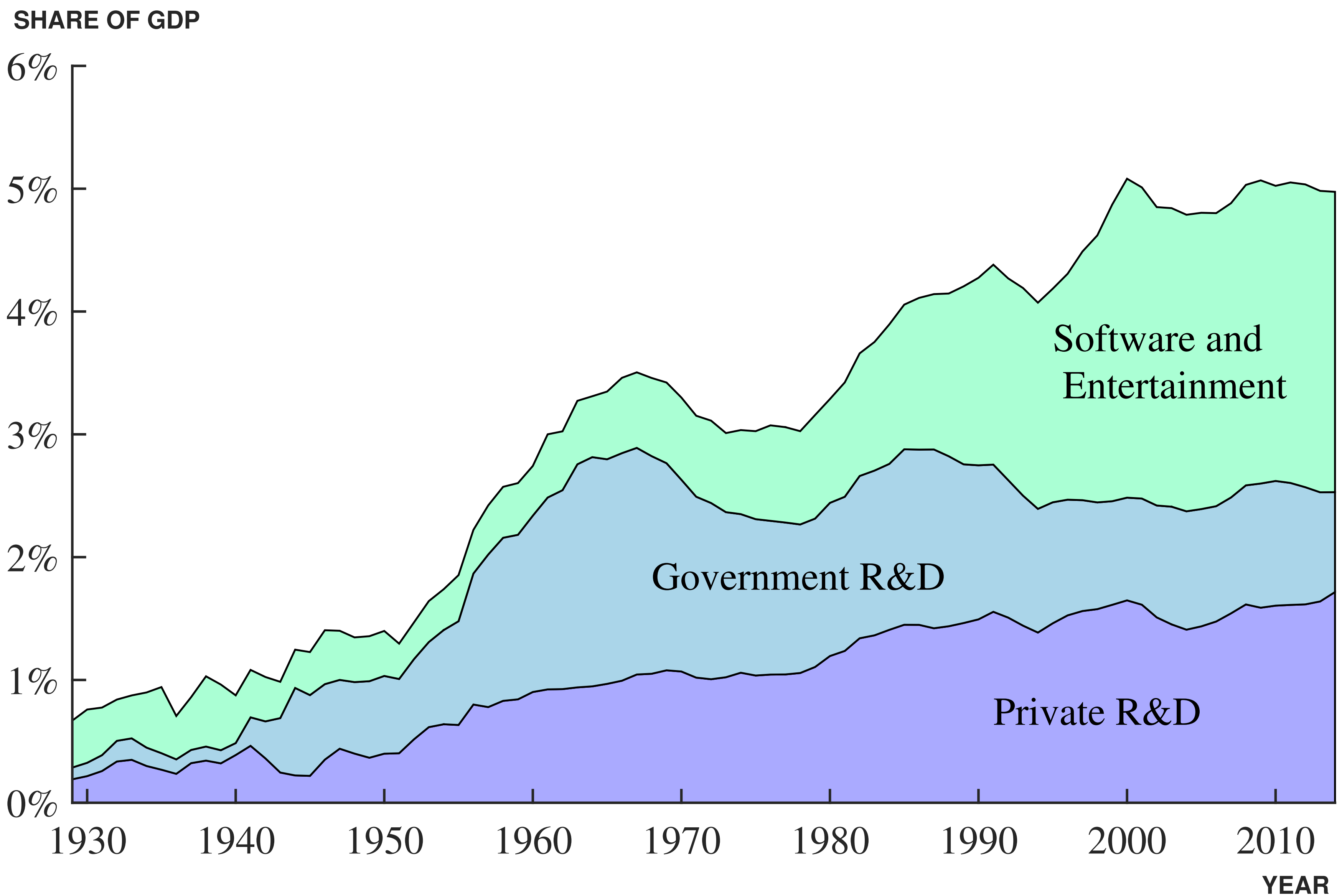
	Solow	Lucas	Romer/AH/GH	J/K/S
2.0	0.0	0.4	1.2	0.4
(100%)	(0%)	(20%)	(58%)	(21%)

- 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...

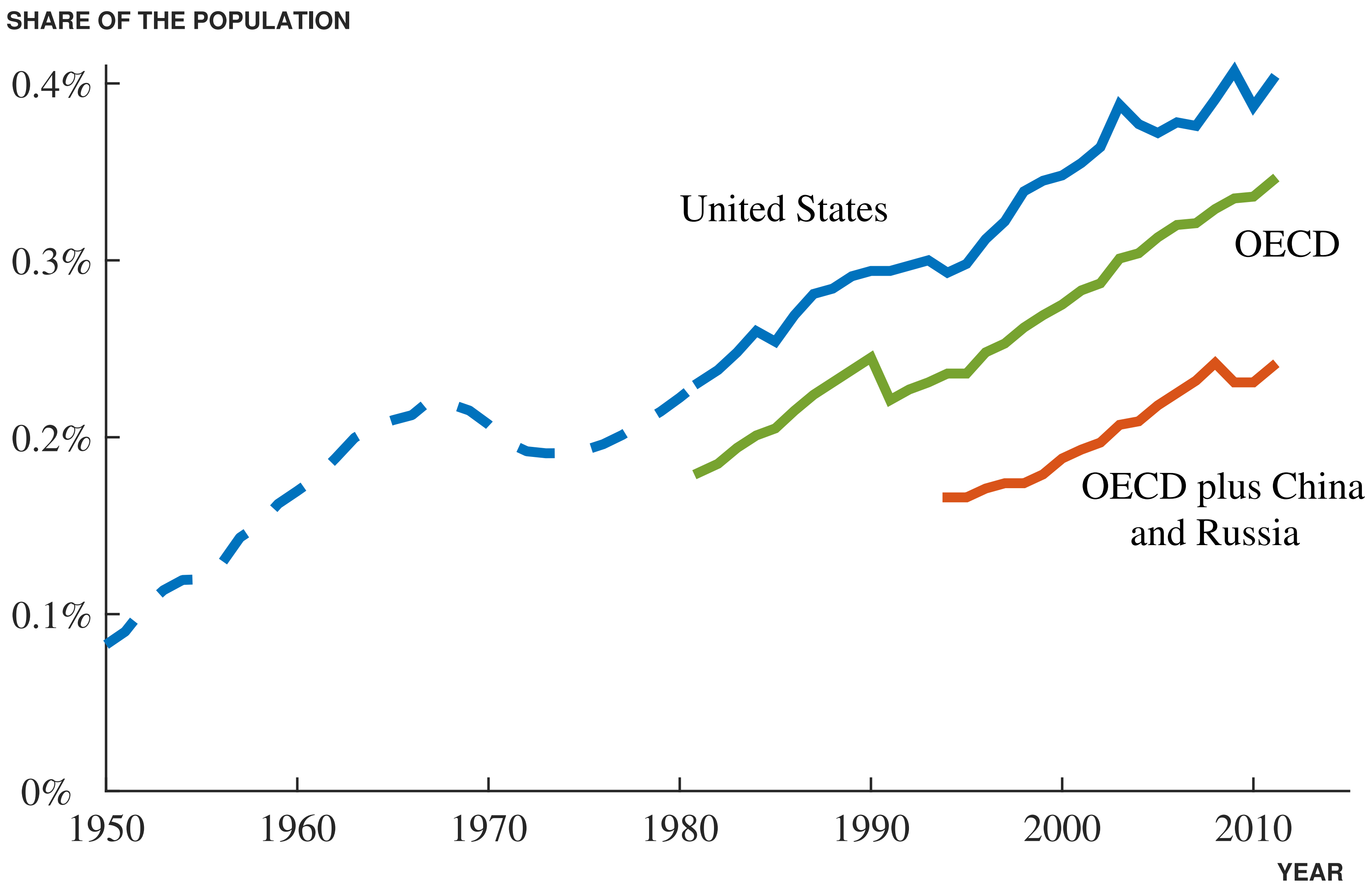
U.S. Educational Attainment



U.S. R&D Spending Share



Research Share of Total Employment



Other considerations?

- The development of China and India
  - 2.5 billion people starting to create ideas!
  - Ratio of Chinese PhDs in Sci/Eng to U.S.:
    $1978 < 5\%, \quad 2010 = 130\%!$
  - How many future “Thomas Edisons” are there?
- Can robots create new ideas?
- Is the “idea production function” stable?

Why growth?

- Proportional ideas are getting harder and harder to find
- The idea production function essentially looks like:

$$\frac{\dot{A}_t}{A_t} = \underbrace{\text{TFP}_t}_{\text{falling}} \cdot \underbrace{S_t}_{\text{rising}}$$

  - Falling TFP $\Rightarrow$ constant growth requires exponential growth in scientists/entreprenuers

Growing human resources devoted to R&D offsets rising difficulty of discovering new ideas

Alternative Futures?