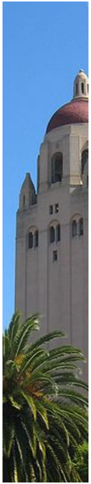


The Past and Future of Economic Growth: A Semi-Endogenous Perspective

Chad Jones

NBER Innovation Bootcamp

July 18, 2022

Outline: The Past and Future of Economic Growth

- A simple semi-endogenous growth model

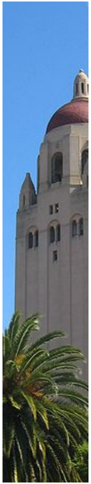
- Historical growth accounting

- Why future growth could slowdown

- Why future growth might not slow and could speed up

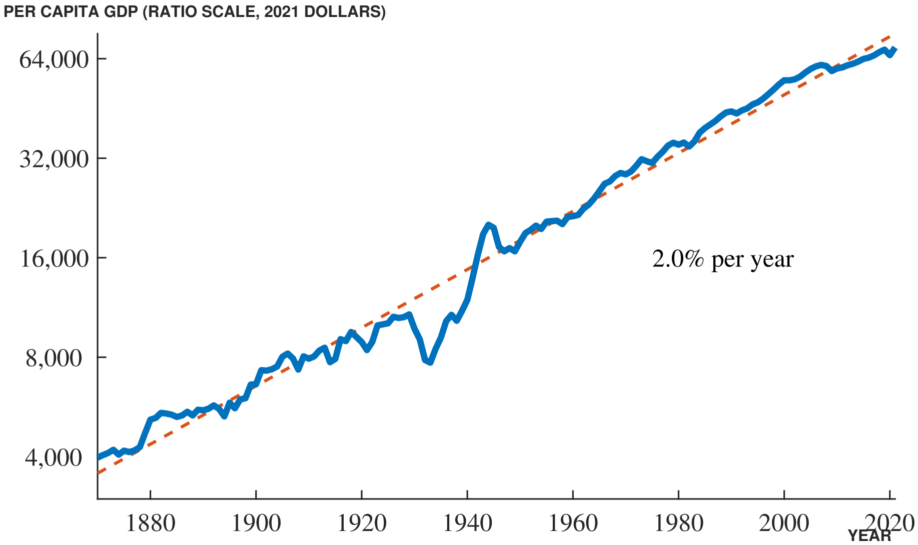
Literature Review

- Early Semi-Endogenous Growth Models
  - Arrow (1962), Phelps (1966), Nordhaus (1969), Judd (1985)
  - Jones (1995), Kortum (1997), Segerstrom (1998)
- Broader Literature: Models with IRS are SEG models!
  - Trade models: Krugman (1979), Eaton-Kortum (2002), Ramondo et al (2016)
  - Firm dynamics: Melitz (2003), Atkeson-Burstein (2019), Peters-Walsh (2021)
  - Sectoral heterogeneity: Ngai-Samaniego ('11), Bloom etc ('20), Sampson ('20)
  - Technology diffusion: Klenow-Rodriguez (2005), Buera-Oberfield (2020)
  - Economic geography: Redding-RossiHansberg (2017)



A Simple Model of Semi-Endogenous Growth

U.S. GDP per Person



The "Infinite Usability" of Ideas (Paul Romer, 1990)

- Objects: Almost everything in the world
  - Examples: iphones, airplane seats, and surgeons
  - Rival: 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 = infinitely useable
  - Can be used by any number of people simultaneously
  - Examples: calculus, HTML, chemical formula of new drug

The Essence of Romer's Insight

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

$$Y = AK^{\alpha}L^{1-\alpha} \tag{*}$$

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!

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

  - Replication argument + Nonrivalry ⇒ CRS to objects
  - Therefore there must be IRS to objects and ideas

A Simple Model

Final good $$Y_t = A_t^{\sigma} L_{yt}$$

Ideas $$\dot{A}_t = R_t A_t^{\phi} \quad \Rightarrow \quad \frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta}$$

Resource constraint $$R_t + L_{yt} = L_t = L_0 e^{nt}$$

Allocation $$R_t = \bar{s} L_t, \quad 0 < \bar{s} < 1$$

ϕ captures knowledge spillovers.

$$\beta \equiv 1 - \phi > 0$$

A Simple Model

Final good $Y_t = A_t^\sigma L_{yt}$

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

Ideas $\dot{A}_t = R_t A_t^\phi \quad \Rightarrow \quad \frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta}$

Resource constraint $R_t + L_{yt} = L_t = L_0 e^{nt}$

Allocation $R_t = \bar{s} L_t, \quad 0 < \bar{s} < 1$

ϕ captures knowledge spillovers.

$$\beta \equiv 1 - \phi > 0$$

A Simple Model

Final good $$Y_t = A_t^\sigma L_{yt}$$

Ideas $$\dot{A}_t = R_t A_t^\phi \quad \Rightarrow \quad \frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta}$$

Resource constraint $$R_t + L_{yt} = L_t = L_0 e^{nt}$$

Allocation $$R_t = \bar{s} L_t, \quad 0 < \bar{s} < 1$$

ϕ captures knowledge spillovers.

$$\beta \equiv 1 - \phi > 0$$

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

On BGP, $\dot{A}/A = \text{Constant} \Rightarrow$

$$A_t^* = \text{Constant} \cdot R_t^{\frac{1}{\beta}}$$

A Simple Model

Final good $Y_t = A_t^{\sigma} L_{yt}$

Ideas $\dot{A}_t = R_t A_t^{\phi} \;\Rightarrow\; \frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta}$

Resource constraint $R_t + L_{yt} = L_t = L_0 e^{nt}$

Allocation $R_t = \bar{s} L_t, \quad 0 < \bar{s} < 1$

ϕ captures knowledge spillovers.

$\beta \equiv 1 - \phi > 0$

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

On BGP, $\dot{A}/A = \text{Constant} \;\Rightarrow$

$$A_t^* = \text{Constant} \cdot R_t^{\frac{1}{\beta}}$$

Combine these two equations...

Steady State of the Simple Model

- Level of income on the BGP (where $\gamma \equiv \frac{\sigma}{\beta}$)

$$y_t^* = \text{Constant} \cdot R_t^{\gamma}$$

$\Rightarrow$ BGP growth rate:

$$g_y = \frac{\sigma n}{\beta} = \gamma n$$

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

What's the difference between these two equations?

Romer $$y_t = A_t^{\sigma}$$

Solow $$y_t = k_t^{\alpha}$$

Hint: It's not the exponent: $\sigma = \alpha = 1/3$ is possible

What's the difference between these two equations?

Romer	$y_t = A_t^{\sigma}$
Solow	$y_t = k_t^{\alpha}$

Hint: It's not the exponent: $\sigma = \alpha = 1/3$ is possible

A_t is an aggregate, while k_t is per capita

But easy to make aggregates grow: population growth!

Or put in words...

- Objects: Add 1 computer $\Rightarrow$ make 1 worker more productive; for a million workers, need 1 million computers

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

- Ideas: Add 1 new idea $\Rightarrow$ make unlimited # more productive or better off.
  - E.g. cure for lung cancer, drought-resistant seeds, spreadsheet

  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.

Where does growth ultimately come from?

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

That's IRS associated with the nonrivalry of ideas

Evidence for Semi-Endogenous Growth (Bloom et al 2020)

Where do ideas come from?

$$\frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta}$$

$\beta > 0 \Rightarrow$ *ideas are getting harder to find*

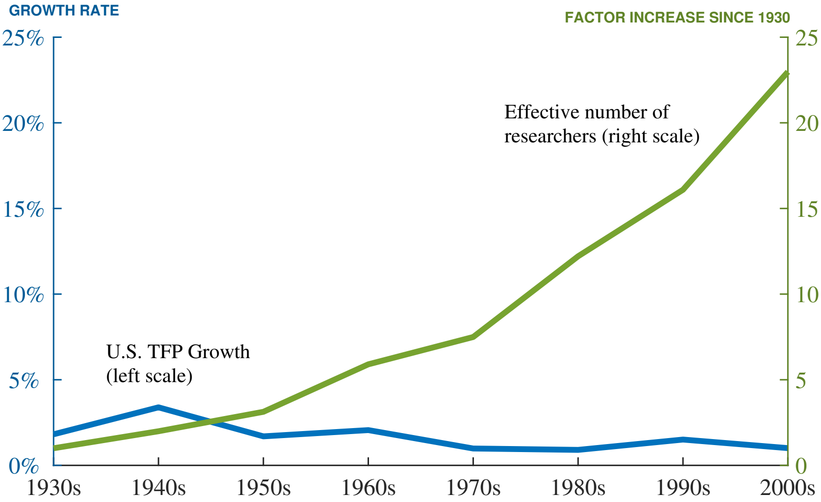
(more accurately: TFP growth gets harder to achieve)

Red Queen Interpretation of SEG:

Maintaining constant TFP growth requires exponential growth in research effort

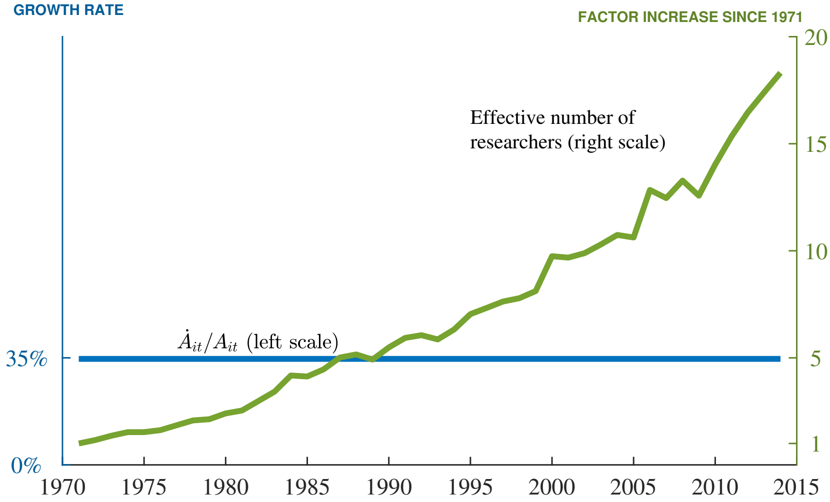
– You run faster and faster just to maintain 2% growth

Evidence: Aggregate U.S. Economy



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

Evidence: Moore's Law



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

Transition Dynamics in the Simple Model

- How many years does it take for growth to move half-way to steady state?

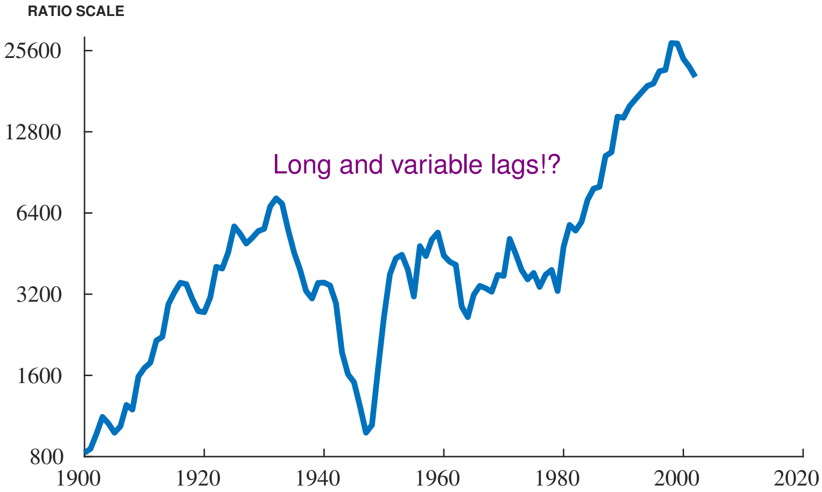
$$t^*_{1/2} = \frac{1}{\beta g_A^*} \ln\left(\frac{g_{A0} + g_A^*}{g_{A0}}\right)$$

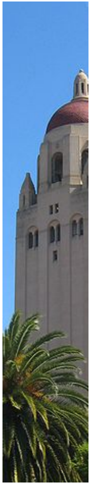
β	$g_{A0} = 2\%$	$g_{A0} = 4\%$
0.2	203	112
1	41	22
3	14	7
5	8	4

Assumes $g_A^* = 1\%$

- Potentially long transitions...

Breakthrough Patents from Kelly, Papanikolaou, Seru, Taddy (2021)





Historical Growth Accounting

In LR, all growth from population growth. But historically...?

Extended Model

- Include physical capital K, human capital per person h, and misallocation M

$$Y_t = K_t^{\alpha}(Z_t h_t L_{Yt})^{1-\alpha}$$
$$Z_t \equiv A_t M_t$$
$$A_t^* = R_t^{\gamma} = (s_t L_t)^{\gamma}$$

- Write in terms of output per person and rearrange:

$$y_t = \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}} A_t M_t h_t \ell_t (1 - s_t)$$

- In LR, all growth from population growth. But historically...?

Growth Accounting Equations

$$\underbrace{d\log y_t}_{\text{GDP per person}} = \underbrace{\frac{\alpha}{1-\alpha} d\log \frac{K_t}{Y_t}}_{\text{Capital-Output ratio}} + \underbrace{d\log h_t}_{\text{Educational att.}} + \underbrace{d\log \ell_t}_{\text{Emp-Pop ratio}} + \underbrace{d\log(1-s_t)}_{\text{Goods intensity}}$$

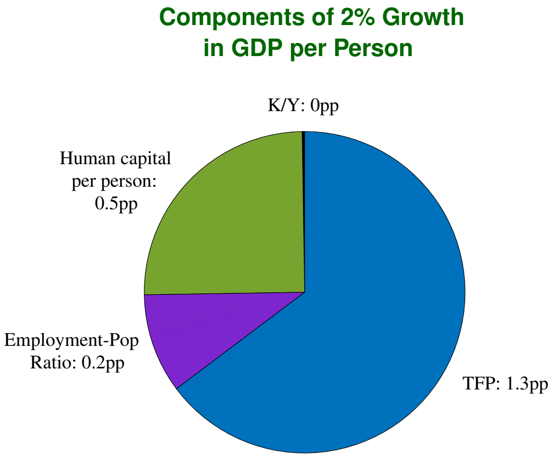
$$+ \underbrace{d\log M_t + d\log A_t}_{\text{TFP growth}}$$

where

$$\text{TFP growth} \equiv \underbrace{d\log M_t}_{\text{Misallocation}} + \underbrace{d\log A_t}_{\text{Ideas}} = \underbrace{d\log M_t}_{\text{Misallocation}} + \underbrace{\gamma\, d\log s_t}_{\text{Research intensity}} + \underbrace{\gamma\, d\log L_t}_{\text{LF growth}}$$

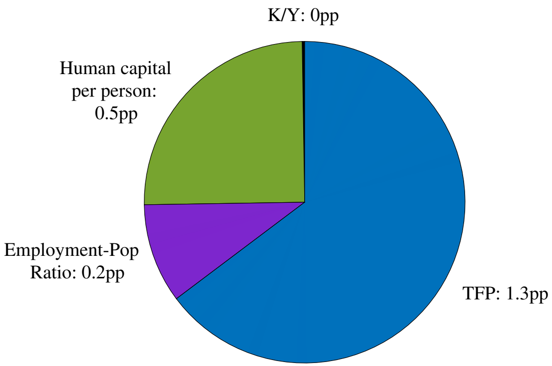
All terms are zero in the long run, other than γn. Assume $\gamma = 1/3$

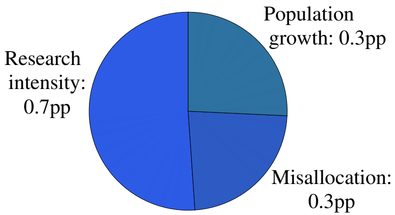
Historical Growth Accounting in the U.S., 1950s to Today



Historical Growth Accounting in the U.S., 1950s to Today

Components of 2% Growth in GDP per Person

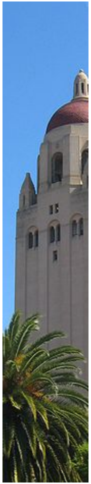




Components of 1.3% TFP Growth

Summary of Growth Accounting

- Even in a semi-endogenous growth framework where all LR growth is γn,
  - Other factors explain more than 80% of historical growth
- Transitory factors have been very important, but all must end:
  - rising educational attainment
  - rising LF participation
  - declining misallocation
  - increasing research intensity
- Implication: Unless something changes, growth must slow down!
  - The long-run growth rate is $\approx$ 0.3%, not 2%

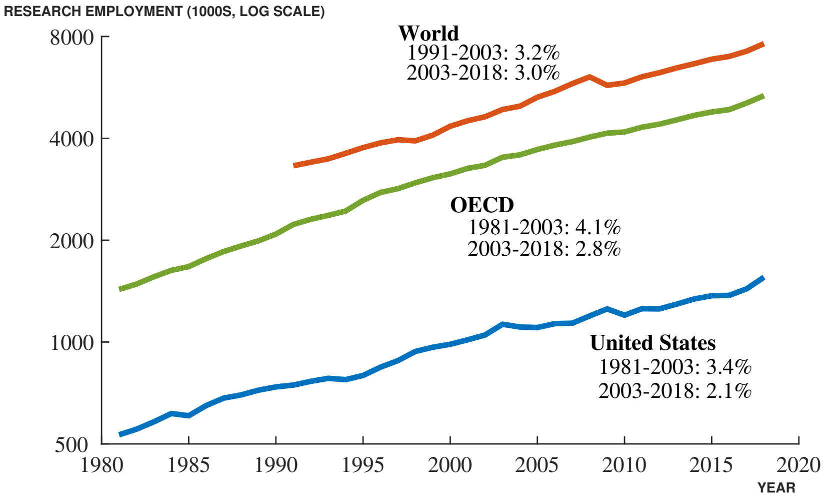


Why Future Growth might be Slower

Why Future Growth might be Slower

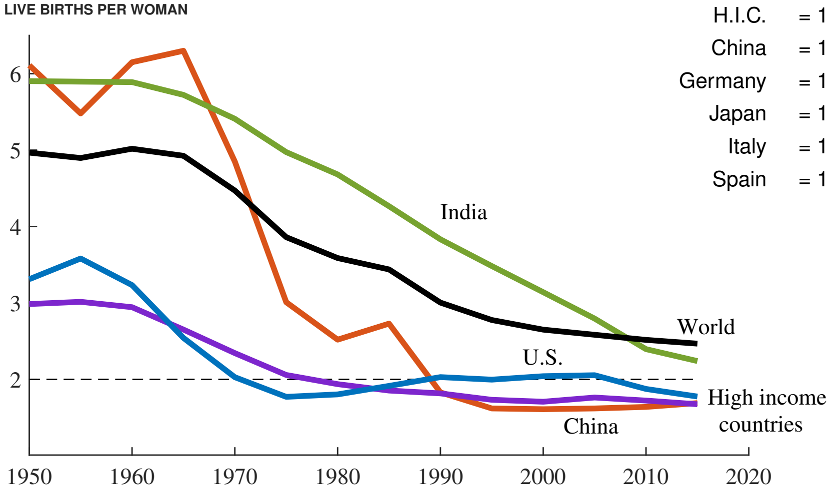
- Growth accounting exercise just presented: $\gamma n \approx 0.3\%$
- Slowdown in the growth rate of research
- Slowing population growth

Research Employment in the U.S., OECD, and World



The Total Fertility Rate (Live Births per Woman)

U.S.	= 1.8
H.I.C.	= 1.7
China	= 1.7
Germany	= 1.6
Japan	= 1.4
Italy	= 1.3
Spain	= 1.3



What happens if future population growth is negative?

- Suppose population *declines* exponentially at rate η: $R_t = R_0 e^{-\eta t}$
- Production of ideas

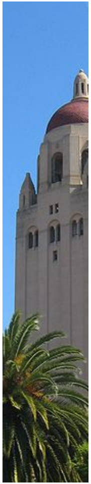
$$\frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta} = R_0 A_t^{-\beta} e^{-\eta t}$$

- Integrating reveals that A_t asymptotes to a constant!

$$A^* = \begin{cases} A_0 \left(1 + \frac{\beta g_{A0}}{\eta}\right)^{1/\beta} & \text{if } \beta > 0 \\ A_0 \exp\left(\frac{g_{A0}}{\eta}\right) & \text{if } \beta = 0 \end{cases}$$

The Empty Planet Result

- Fertility has trended down: 5, 4, 3, 2, and less in rich countries
  - For a family, nothing special about “above 2” vs “below 2”
  - But macroeconomics makes this distinction critical!
- Standard result shown earlier: $n > 0 \Rightarrow$ **Expanding Cosmos**
  - Exponential growth in income and population
- Negative population growth $\Rightarrow$ much more pessimistic **Empty Planet**
  - Stagnating living standards for a population that vanishes
  - Could this be our future?



Why Future Growth might be Faster?

(Or at least not as slow as the preceding section implies!)

1. Finding Lost Einsteins
2. Automation and artificial intelligence

Finding Lost Einsteins

- How many Edisons and Doudnas have we missed out on historically?
  - The rise of China, India, and other emerging countries
    - China and India each have as many people as U.S.+Europe+Japan
  - Brouillette (2021): Only 3% of inventors were women in 1976; only 12% in 2016
  - Bell et al (2019): Poor people missing opportunities

- Increase global research by a factor of 3 or 7?
  - For $\gamma = 1/3$: Increase incomes by $3^\gamma - 1 = 40\%$ and $7^\gamma - 1 = 90\%$
  - Could easily raise growth by 0.2pp to 0.4pp for a century

Automation and A.I.

- Suppose research involves many tasks X_i that can be done by people or by machines

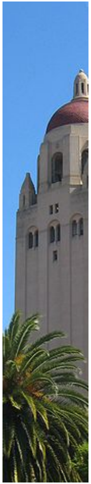
$$\dot{A}_t = A_t^{1-\beta} X_1^{\alpha_1} X_2^{\alpha_2} \cdot \ldots \cdot X_n^{\alpha_n}, \quad \sum \alpha_i = 1$$
$$= A_t^{1-\beta} K_t^{\alpha} R_t^{1-\alpha}$$

α is the fraction of research tasks that have been automated

- Long-run growth rate:

$$g_A = \frac{n}{\beta - \alpha}$$

- Rising automation could raise economic growth
  - Singularity if $\alpha = \beta$ (or at least all possible ideas get discovered quickly)
  - Labs, computers, WWW: recent automation has not offset slowing growth



Conclusion: Key Outstanding Questions

Important Questions for Future Research

- How large is the degree of IRS associated with ideas, γ?
- What is the social rate of return to research?
  - Are we underinvesting in basic research?
- Better growth accounting: contributions from DARPA, NIH, migration of European scientists during WWII, migration more generally
- Automation ongoing for 150 years, but growth slowing not rising: why?