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

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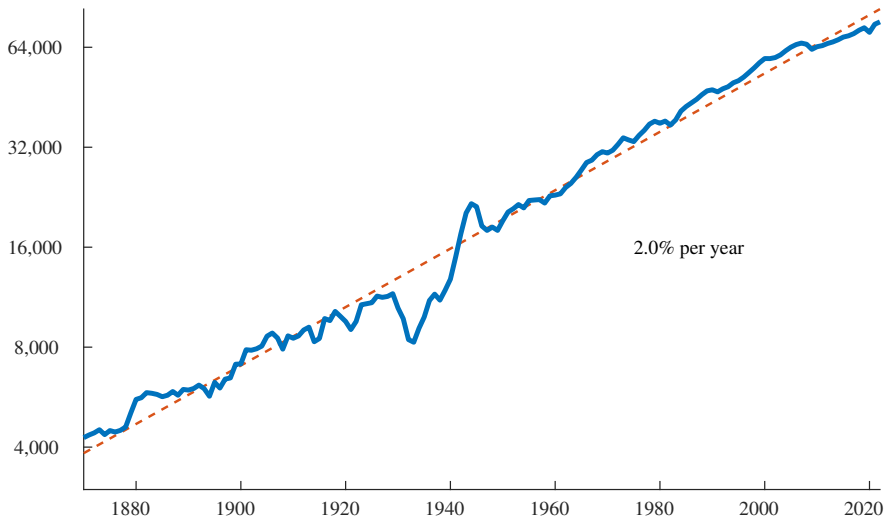**Outline: The Past and Future of Economic Growth**

- A simple semi-endogenous growth model

- Historical growth accounting

- Why future growth could slowdown

- Why future growth might not slow and could speed up

A Simple Model of
Semi-Endogenous Growth

U.S. GDP per Person

PER CAPITA GDP (RATIO SCALE, 2022 DOLLARS)

2.0% per year

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

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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!

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

  ○ Replication argument $+$ Nonrivalry $\Rightarrow$ CRS to objects

  ○ Therefore there must be IRS to objects and ideas

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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.

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

A Simple Model

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

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

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

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

Ideas $\qquad \dot{A}_t = R_t A_t^\phi \;\; \Rightarrow \;\; \dfrac{\dot{A}_t}{A_t} = R_t A_t^{-\beta}$ $\qquad$ On BGP, $\dot{A}/A = \text{Constant} \;\Rightarrow$

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

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

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

Allocation

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

Combine these two equations...

ϕ captures knowledge spillovers.

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

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.

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)

- Document a new stylized fact:

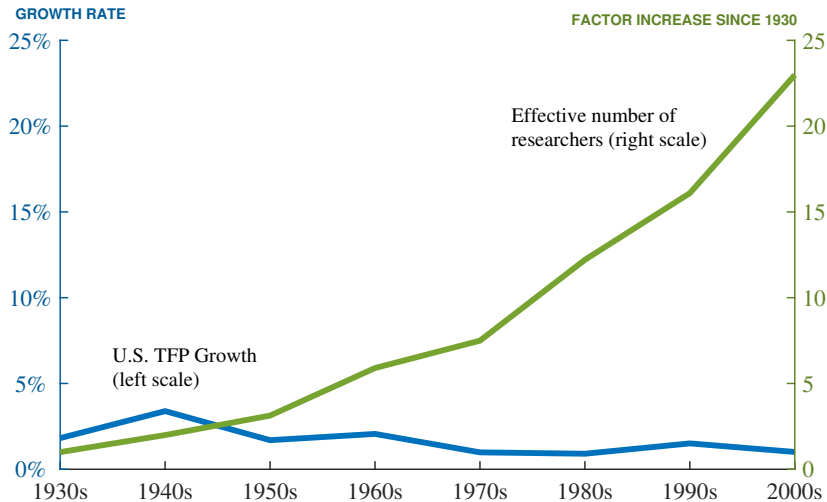 Exponential growth is getting harder to achieve.

Economic growth	=	Research productivity	×	Number of researchers
e.g. 2% or 5%		↓ (falling)		↑ (rising)

- Consistent with the SEG model:

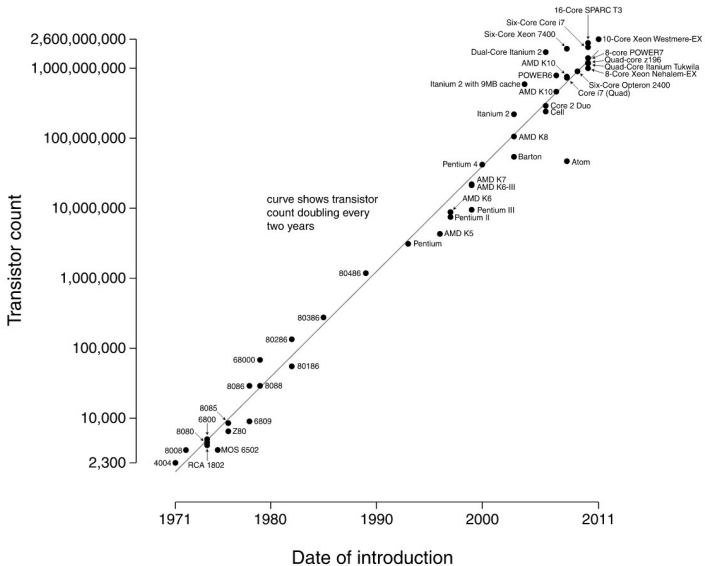$$\frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta}$$

$$\beta > 0 \Rightarrow \textit{ideas are getting harder to find}$$

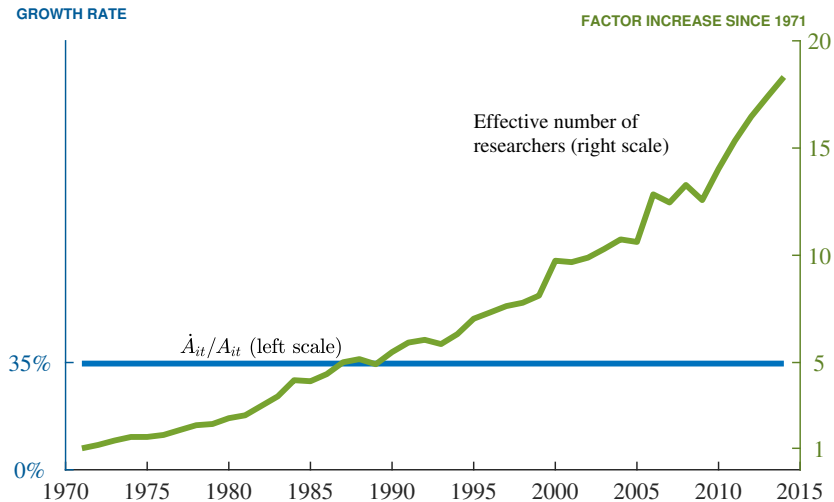# Evidence: Aggregate U.S. Economy

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

# The Steady Exponential Growth of Moore's Law

Evidence: Moore's Law

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

- 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!

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

Long and variable lags!?
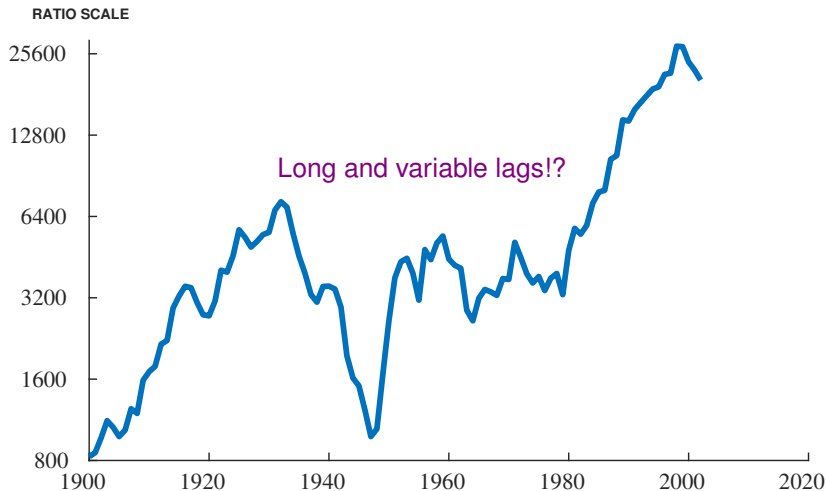
Literature Review

- 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)

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

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

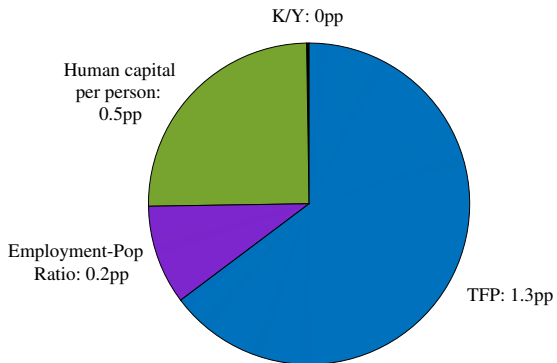$$+ \underbrace{d\log M_t + d\log A_t}_{\text{TFP growth}}$$

where

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

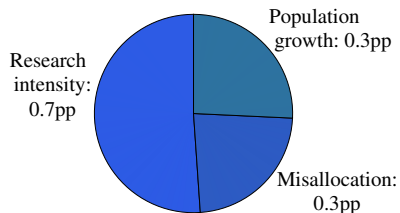All terms are zero in the long run, other than γn. Assume $\gamma = 1/3$

**Components of 2% Growth
in GDP per Person**

K/Y: 0pp

Human capital
per person:
0.5pp

Employment-Pop
Ratio: 0.2pp

TFP: 1.3pp

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

**Components of 2% Growth
in GDP per Person**

K/Y: 0pp

Human capital
per person:
0.5pp

Employment-Pop
Ratio: 0.2pp

TFP: 1.3pp

Population
growth: 0.3pp

Research
intensity:
0.7pp

Misallocation:
0.3pp
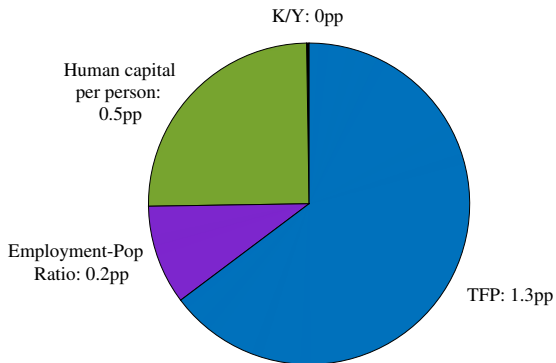
Components of 1.3% TFP Growth

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%
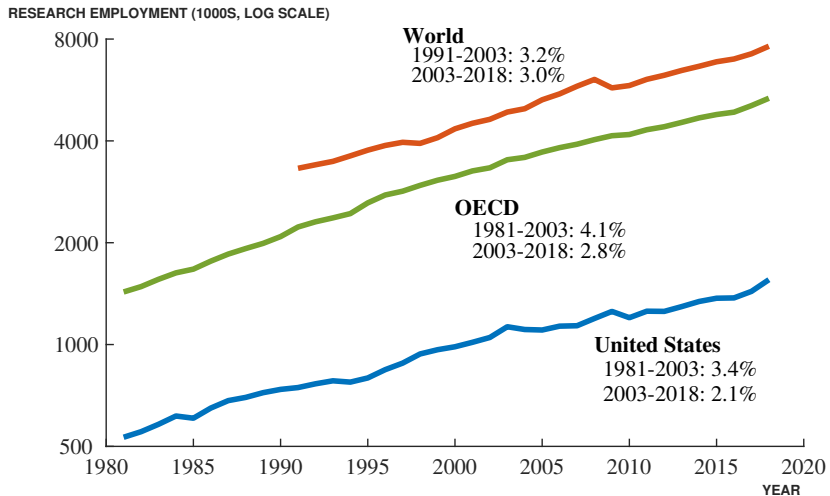
Why Future Growth might be Slower

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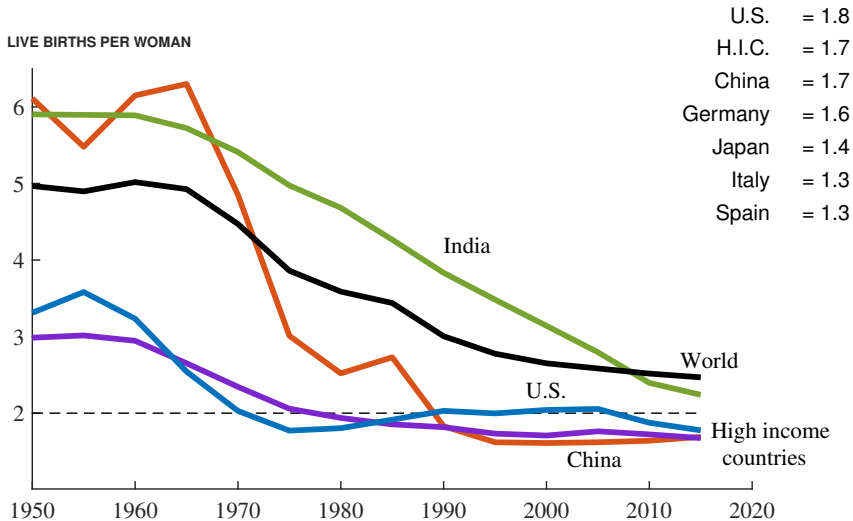
- Growth accounting exercise just presented: $\gamma n \approx 0.3\%$

- Slowdown in the growth rate of research

- Slowing population growth

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

RESEARCH EMPLOYMENT (1000S, LOG SCALE)

World
1991-2003: 3.2%
2003-2018: 3.0%

OECD
1981-2003: 4.1%
2003-2018: 2.8%

United States
1981-2003: 3.4%
2003-2018: 2.1%

YEAR

The Total Fertility Rate (Live Births per Woman)

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

India

World

U.S.

High income
countries

China

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!

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

Source: Jones (2022) "The End of Economic Growth..."

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 (2022): 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

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

  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?