The Future of Economic Growth

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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

PER CAPITA GDP (RATIO SCALE, 2009 DOLLARS)

YEAR

2.0% per year
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:
  \[ \frac{\dot{y}_t}{y_t} = g \] 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

Solow

$\dot{k}_t = sk_t^\alpha$

$\dot{A}_t = \bar{g}A_t$

AK model

$\dot{K}_t = sAK_t$

Lucas

$\dot{h}_t = uh_t$

Romer/AH/GH

$\dot{A}_t = SA_t$

Variation on Romer (J/K/S)

$\dot{L}_t = nL_t$
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 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 $\nless 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

\[ Y = AK^{\alpha}L^{1-\alpha} \] (*)

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

\[ Y_t = A_t^\sigma L_Y t \]

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

\[ L_{At} = \bar{s} L_t, \quad 0 < \bar{s} < 1 \]
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\[ y_t \equiv \frac{Y_t}{L_t} = A_t^\sigma (1 - \bar{s}) \]
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\[ g_y = \sigma g_A \]

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

\[ g_A = \frac{g_{LA}}{1 - \phi} \]

}\]
$$g_y = \gamma n$$

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 ⇒ more new ideas ⇒ 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

INDEX (1.0 IN INITIAL YEAR)

Per capita GDP

Population
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

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

<table>
<thead>
<tr>
<th></th>
<th>Solow</th>
<th>Lucas</th>
<th>Romer/AH/ GH</th>
<th>J/K/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>2.0</td>
<td>0.0</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>(100%)</td>
<td>(0%)</td>
<td>(20%)</td>
<td>(58%)</td>
<td>(21%)</td>
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- Educational attainment rises \( \approx 1 \) year per decade. With \( \psi = .06 \) ⇒ 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

YEARS OF SCHOOLING

YEAR

By birth cohort

Adult labor force

1880 1900 1920 1940 1960 1980 2000
Research Share of Total Employment

SHARE OF THE POPULATION

0% 0.1% 0.2% 0.3% 0.4%


YEAR

United States

OECD

OECD plus China and Russia
Are ideas getting harder to find?

Bloom, Jones, Van Reenen, Webb (2018)
Overview

- New stylized fact:

  Exponential growth is getting harder to achieve.

  \[
  \text{Economic growth} = \text{Research productivity} \times \text{Number of researchers}
  \]
  
  e.g. 2% or 5% ↓ (falling) ↑ (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:
    \[
    \frac{\dot{A}_{it}}{A_{it}} = \alpha S_{it} \tag{*}
    \]
    \[
    \Rightarrow S_{it} = \frac{S_t}{N_t} \text{ invariant to scale, but responds to subsidies}
    \]
    - 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

curve shows transistor count doubling every two years

Transistor count

Date of introduction
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)

Effective number of researchers (right scale)
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

<table>
<thead>
<tr>
<th>Scope</th>
<th>Average annual growth rate</th>
<th>Half-life (years)</th>
<th>Extent of Diminishing Returns, $\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate economy</td>
<td>-5.1%</td>
<td>14</td>
<td>3.1</td>
</tr>
<tr>
<td>Moore’s law</td>
<td>-6.8%</td>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td>Agriculture (seeds)</td>
<td>-5.5%</td>
<td>13</td>
<td>4.8</td>
</tr>
<tr>
<td>New molecular entities</td>
<td>-3.5%</td>
<td>20</td>
<td>...</td>
</tr>
<tr>
<td>Disease mortality</td>
<td>-5.6%</td>
<td>12</td>
<td>...</td>
</tr>
<tr>
<td>Compustat firms</td>
<td>-11.1%</td>
<td>6</td>
<td>1.1</td>
</tr>
</tbody>
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Note: $\beta$ 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)

U.S. TFP Growth (left scale)

Effective number of researchers (right scale)
How this supports Romer, not detracts...

- Highlights Romer’s key insight: **nonrivalry**


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

\[
\frac{\dot{A}_t}{A_t} = \theta S
\]

- 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?

\[
\text{Economic growth} = \text{Research productivity} \times \text{Research effort}
\]

\[
2\% \quad \downarrow \quad (\text{falling}) \quad \uparrow \quad (\text{rising})
\]

• Ideas are getting harder and harder to find

• A “Red Queen” model of economic growth:

\[
\text{We have to run faster and faster just to generate constant exponential growth (e.g. at 2%)}
\]
Recently, growth has slowed!

Average growth in GDP per person over the preceding decade.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PERCENT</th>
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<tbody>
<tr>
<td>1960</td>
<td>0.5</td>
</tr>
<tr>
<td>1970</td>
<td>1.0</td>
</tr>
<tr>
<td>1980</td>
<td>1.5</td>
</tr>
<tr>
<td>1990</td>
<td>2.0</td>
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<tr>
<td>2000</td>
<td>2.5</td>
</tr>
<tr>
<td>2010</td>
<td>3.0</td>
</tr>
<tr>
<td>2020</td>
<td>3.5</td>
</tr>
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U.S. Total Factor Productivity

**Private business sector**
- 1990-2003: 1.2%
- 2003-2015: 0.7%

**Manufacturing**
- 1990-2003: 1.6%
- 2003-2014: 0.2%
Research Employment in Select Economies

United States
1981-2002: 3.2%
2002-2014: 2.1%

European Union (15 countries)
1981-2002: 3.7%
2002-2015: 3.1%

Japan
1981-2002: 3.3%
2002-2015: 0.5%
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?

The shape of the idea production function, $f(A)$

The past

Today

Increasing returns

GPT "Waves"

Run out of ideas

The stock of ideas, $A$
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
TFP in Select Advanced Economies

TOTAL FACTOR PRODUCTIVITY (2000=100)

YEAR


TOTAL FACTOR PRODUCTIVITY (2000=100)

85 90 95 100 105 110 115

Spain

Germany

France

Italy

U.S.
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 ⇒ growing field of economic growth!
These slides draw from the following papers:

- Jones (2005) “Growth and Ideas” *Handbook of Economic Growth*