Are Ideas Getting Harder to Find?
A Semi-Endogenous Perspective

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Outline:

- A simple semi-endogenous growth model
- Are ideas getting harder to find?
- Why future growth could slowdown
- Why future growth might not slow and could speed up

(draws on “The Past and Future of Economic Growth” essay)
A Simple Model of Semi-Endogenous Growth
U.S. GDP per Person

PER CAPITA GDP (RATIO SCALE, 2020 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 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
\[ \frac{\dot{A}_t}{A_t} = R_t A_t^{-\beta} \]

Resource constraint
\[ R_t + L_yt = L_t = L_0e^{nt} \]

Allocation
\[ R_t = \bar{s}L_t, \quad 0 < \bar{s} < 1 \]
A Simple Model

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

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

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

\[ A_t^* = \text{Constant} \cdot R_t^{\frac{1}{\beta}} \]
**A Simple Model**

**Final good**

\[ Y_t = A_t^\sigma L y_t \]

**Ideas**

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

**Resource constraint**

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**Allocation**

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

\[ A_t^* = \text{Constant} \cdot R_t^{1/\beta} \]

Combine these two equations...
Steady State of the Simple Model

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

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

⇒ BGP growth rate:

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

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

• Objects: Add 1 computer ⇒ make 1 worker more productive; for a million workers, need 1 million computers

  Output per worker \sim \# \text{ of computers per worker}

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

  Income per person \sim \text{the aggregate stock of knowledge, not on the number of ideas per person.}

  \textit{But it is easy to make aggregates grow: population growth!}

  IRS ⇒ 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*
Are ideas getting harder to find?

Bloom, Jones, Van Reenen, Webb (2020)
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 Steady Exponential Growth of Moore’s Law

curve shows transistor count doubling every two years
Moore’s Law and Measurement

• **Idea output:** Constant exponential growth at 35% per year

\[
\frac{\dot{A}_t}{A_t} = 35\%
\]

• **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

GROWTH RATE

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

Effective number of researchers (right scale)

<table>
<thead>
<tr>
<th>Year</th>
<th>Effective number of researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>1.0</td>
</tr>
<tr>
<td>1980</td>
<td>3.5</td>
</tr>
<tr>
<td>1990</td>
<td>10.0</td>
</tr>
<tr>
<td>2000</td>
<td>20.0</td>
</tr>
<tr>
<td>2010</td>
<td>35.0</td>
</tr>
</tbody>
</table>

FACTOR INCREASE SINCE 1971

$\frac{\dot{A}_{it}}{A_{it}}$ (left scale)
Summary of Evidence

• Moore’s Law
  o 18x harder today to generate the doubling of chip density
  o Have to double research input every decade!

• Qualitatively similar findings in rest of the economy
  o Agricultural innovation (yield per acre of corn and soybeans)
  o Medical innovations (new drugs or mortality from cancer/heart disease)
  o Publicly-traded firms
  o 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>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate economy</td>
<td>-5.1%</td>
<td>14</td>
</tr>
<tr>
<td>Moore’s law</td>
<td>-6.8%</td>
<td>10</td>
</tr>
<tr>
<td>Agriculture (seeds)</td>
<td>-5.5%</td>
<td>13</td>
</tr>
<tr>
<td>New molecular entities</td>
<td>-3.5%</td>
<td>20</td>
</tr>
<tr>
<td>Disease mortality</td>
<td>-5.6%</td>
<td>12</td>
</tr>
<tr>
<td>Compustat firms</td>
<td>-11.1%</td>
<td>6</td>
</tr>
</tbody>
</table>
Implications for Growth Theory

- Where does long-run growth come from?

\[
\frac{\dot{A}_t}{A_t} = A_t^{-\beta} \times R_t \quad \text{with} \quad \beta \approx 3
\]

\[
\beta > 0 \Rightarrow \text{ideas are getting harder to find}
\]

\[(\text{more accurately: TFP growth gets harder to achieve})\]

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
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 $M$

$$Y_t = K_t^\alpha (Z_t h_t L_Y t)^{1-\alpha}$$

$$Z_t \equiv A_t M_t$$

$$A_t^* = R_t^\gamma = (s_t L_t)^\gamma$$

- Write in terms of output per person and rearrange:

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

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

\[ d \log y_t = \frac{\alpha}{1 - \alpha} d \log \frac{K_t}{Y_t} + d \log h_t + d \log \ell_t + d \log (1 - s_t) + d \log M_t + d \log A_t \]

GDP per person

Capital-Output ratio

Educational att.

Emp-Pop ratio

Goods intensity

TFP growth

where

\[ \text{TFP growth} \equiv d \log M_t + d \log A_t = d \log M_t + \gamma d \log s_t + \gamma d \log L_t \]

Misallocation

Ideas

Misallocation

Research intensity

LF growth

All terms are zero in the long run, other than \( \gamma n \). Assume \( \gamma = 1/3 \)
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
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

Components of 1.3% TFP Growth

- Population growth: 0.3pp
- Research intensity: 0.7pp
- Misallocation: 0.3pp
Summary of Growth Accounting

- Even in a semi-endogenous growth framework where all LR growth is $\gamma n$,
  - 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%
The Future of Economic Growth?
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 and Jennifer Doudnas 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?
Important Questions for Future Research

• How large is the degree of IRS associated with ideas, $\gamma$?

• 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, idea diffusion

• Automation ongoing for 150 years, but growth slowing not rising: why?