Ideas and Economic Growth

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Big Picture Questions about Growth

- What sustains growth at the frontier?
  (Will it continue in the future?)

- Why are some countries so far behind the frontier?
  (What might help them close the gap?)

This lecture focuses on the first of these questions

Knowledge versus Capital

- Solow model: Capital accumulation not a source of long-run growth
  - Reason: Diminishing returns
- What about knowledge?
- If knowledge succeeds where capital fails, there must be something fundamentally different about knowledge than capital

The AK Model

- To drive home the importance of diminishing returns, let's consider a model without diminishing returns
- Suppose

$$Y(t) = AK(t)$$

and

$$\dot{K}(t) = sY(t) - \delta K(t)$$

where

  - s is the exogenous savings rate (as in Solow model)
  - Labor is assumed constant and normalized to one (which implies that $Y(t)$ is output per person)

The AK Model

- Combining these two equations yields

$$\dot{Y}(t) = sAY(t) - \delta Y(t)$$

$$g_Y = \frac{\dot{Y}_t}{Y_t} = sA - \delta$$

- We get long-run growth from capital accumulation
- The long-run growth rate of output (per person) is governed by s, A, and δ
- Long-run growth is endogenous to the extent that s, A, and δ can be influenced by policy / behavior

Growth from Externalities

- But why might we think $Y = AK$ makes sense?
- One "micro-foundation" is learning-by-doing externalities
  - Productivity gains coming from investment and production
  - Empirical evidence from airframe manufacturing, shipbuilding, etc. (Wright 36, Searle 46, Asher 56, Rapping 65)
- Several early endogenous growth models followed this path (e.g., Frankel 62, Griliches 79, Romer 86, Lucas 88)
- We consider Romer (1986) version here (see Romer 19, p. 119-121; Barro and Sala-i-Martin 04, sec. 4.3; Acemoglu 09, sec. 11.4)

Romer (1986): Knowledge Spillovers

- Suppose there is a continuum of firms with production function

$$Y_i(t) = F(K_i(t), A_i(t)L_i(t))$$

- Two assumptions:
  - Strong learning-by-doing (investing):
    Knowledge grows proportionally with firm's capital stock
  - Knowledge spillovers are perfect across firms
    (all firms benefit from each firm's learning)
- These assumptions imply:

$$A_i(t) = BK(t)$$

Romer (1986): Knowledge Spillovers

- Combining prior two equations:

$$Y_i(t) = F(K_i(t), BK(t)L_i(t))$$

- Suppose further that all firms are identical:

$$Y(t) = F(K(t), BK(t)L(t))$$

- If F is homogeneous of degree one, we have

$$Y(t) = F(1, BL(t))K(t)$$

- This model therefore yields a production function of the $Y = AK$ form

Growth and Knowledge Spillovers

- Romer (1986) model yields endogenous growth
- But arguably makes unrealistic assumptions:
  - Assumes very large amounts of learning-by-doing
  - Doesn't work if knowledge grows less than proportionally with K
- Lucas (1988) builds similar model with human capital externalities.
  - Arguably also makes unrealistic assumptions
    (see Jones 22, section 2.2)
- Doesn't seem to capture what is "special" about knowledge

Why Is Knowledge Special?

- Knowledge is non-rival
- This is the fundamental difference versus capital
- Implies that knowledge can be a source of long-run growth

Ideas vs. Objects

- Ideas: a design, a blueprint, or a set of instructions
  - How to make fire using sticks, calculus, the design of the incandescent light bulb, oral rehydration therapy, Beethoven's 3th symphony, etc.
- Objects: Goods, capital, labor, land, highways, barrels of oil, etc.
  - A particular incandescent light bulb, a particular oral rehydration pill, etc.

IDEAS VS. OBJECTS

- Objects are rival:
  - If I use a particular lawn mower, you can't use that same lawn mower at the same time
- Ideas are non-rival:
  - My use of calculus, does not negatively affect your ability to use calculus at the same time
  - Once invented, calculus can be used by any number of people simultaneously (ideas are "infinitely usable")

Non-Rivalry and Returns to Scale

- Consider production function

$$Y = F(A, X)$$

  - A is index of the stock of knowledge
  - X is all rival inputs (vector)

- Replication implies constant returns to objects:

$$\lambda Y = F(A, \lambda X)$$

  - This argument implicitly uses non-rivalry of ideas
  - We can use same A to build second factory as first factory.

- Implies that if we increase A as well we get increasing returns:

$$F(\lambda A, \lambda X) > F(A, \lambda X) = \lambda Y$$

Non-Rivalry and Growth

- Since ideas are non-rival, per capita output depends on the overall stock of knowledge, NOT knowledge **per capita**

$$Y(t) = A(t)^{\sigma} K(t)^{\alpha} L(t)^{1-\alpha}$$

$$y(t) = A(t)^{\sigma} k(t)^{\alpha}$$

- Output per person depends on:
    - Total stock of knowledge ($A(t)^{\sigma}$)
    - Capital **per capita** ($k(t)^{\alpha}$)
- Solow model: Capital **per capita** can't grow forever (if A is constant)
- If stock of knowledge can grow forever, $y(t)$ can growth forever

Romer (1990)

- Romer (1990) is the paper that crystallized these ideas
- See Jones (2019) for role of this paper in relation to earlier and subsequent literature
- But Romer (1990) made some extreme assumptions that we will want to move away from

Knowledge Production

- Key new feature: Knowledge is produced
- Workers do one of two things:
  - Produce goods and services
  - Produce knowledge (R&D)
- Key choice: How are workers allocated between these activities?
- Simplifying assumption: A fraction s of workers work on R&D
  - Similar to Solow assumption about savings rate
  - Workers choose optimally in Romer (1990)
  - We will consider a model where workers choose optimally later on
  - For now:

$$L_A(t) = sL(t) \qquad\qquad L_Y(t) = (1-s)L(t)$$

Knowledge Production in Romer (1990)

- Knowledge production function in Romer (1990):

$$\dot{A}(t) = \theta L_A(t) A(t)$$

- Knowledge production depends on two inputs:
  - Research effort: $L_A(t)$ denotes labor devoted to research
  - Existing knowledge: $A(t)$

- Importantly, exponent on $A(t)$ is one

- Implies that

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} = \theta L_A(t)$$

Knowledge Production in Romer (1990)

- Suppose for simplicity that $L_A(t) = L_A$ (i.e., a constant)

- Then growth rate of knowledge is constant

$$g_A = \frac{\dot{A}(t)}{A(t)} = \theta L_A$$

- Suppose for simplicity that goods production function is

$$Y(t) = A(t)^\sigma L_Y \qquad => \qquad y(t) = A(t)^\sigma (1 - s)$$

  where $1 - s$ is (constant) share of pop. working on goods production, σ is importance of ideas for production (degree of increasing returns)

- This implies

$$g_y = \sigma g_A = \sigma \theta L_A$$

Knowledge Production

- But why would knowledge production be linear in A(t) and L(t)?
- More generally:

$$\dot{A}(t) = \theta L_A(t)^{\lambda} A(t)^{\phi}$$

- Not necessarily constant returns to objects ($\lambda = 1$):
  - Twice as much research effort may not generate twice as much knowledge
  - There may be congestion / duplication / diminishing returns
  - This would yield $\lambda < 1$
  - We assume however that $\lambda > 0$

Knowledge Production

$$\dot{A}(t) = \theta L_A(t)^\lambda A(t)^\phi$$

- Not necessarily constant returns to existing knowledge ($\phi = 1$)
- $\phi > 0$: Standing on the shoulders of giants
  - Having more knowledge lets a researcher create knowledge faster
  - E.g., printed books, internet, computers, microscopes, etc.
- $\phi < 0$: No more low hanging fruit
  - Suppose you are fishing in a pond with 100 fish
  - As you catch more, harder to catch the rest
- Nothing particularly natural about $\phi = 1$

Simple Endogenous Growth Model

1. Goods production: $Y(t) = A(t)^{\sigma} L_Y(t)$
2. Ideas production: $\dot{A}(t) = \theta L_A(t)^{\lambda} A(t)^{\phi}$
3. Allocation: $L_A(t) = sL(t)$
4. Resource constraint: $L(t) = L_A(t) + L_Y(t)$
5. Population growth: $L(t) = L(0)e^{nt}$

Simple Endogenous Growth Model

Notable features:

- Constant fraction of labor force s conducts research
  - Simple short cut
  - Similar to constant savings rate in Solow model
  - We will endogenize later
- Constant population growth at rate n
- σ captures degree to which increase in knowledge increases productivity in production of goods and services
  - How much does 1% increase in knowledge increase productivity?
  - But what is a 1% increase in knowledge? How is this measured?

Balanced Growth in Simple Model

- Combining (1), (3) and (4) and dividing by L(t) we get:

$$y(t) = A(t)^{\sigma}(1 - s)$$

- Taking logs and time derivatives yields

$$g_y(t) = \sigma g_A(t)$$

- Suppose there is a balanced growth path with constant growth:

$$g_y(t) = g_y \qquad \text{and} \qquad g_A(t) = g_A$$

- Then we have

$$g_y = \sigma g_A$$

Balanced Growth in Simple Model

- Combining (2) and (3) and dividing by $A(t)$:

$$g_A(t) = \theta s^{\lambda} L(t)^{\lambda} A(t)^{\phi-1}$$

- Taking logs and time derivatives yields

$$0 = \lambda g_L + (\phi - 1) g_A$$

  where we use $g_A(t) = g_A$ on BGP

- Rearranging and using $g_L = n$ we get

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

Output Growth and Population Growth

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

- Long-run growth proportional to population growth rate
- If $L_A(t)$ were constant at L_A (which implies $n = 0$):

$$\frac{\dot{A}(t)}{A(t)} = \theta L_A^{\lambda} A(t)^{\phi-1} = \frac{\theta L_A^{\lambda}}{A(t)^{1-\phi}}$$

- If $1-\phi > 0$, or equivalently $\phi < 1$:

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} \rightarrow 0$$

- Growth can't keep up with the level and thus goes to zero

Research Effort Must Grow Exponentially

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

- With $\phi < 1$, research effort must grow exponentially for knowledge to grow exponentially
- Exponential population growth and constant share of labor force working on research (s) does the trick

Something Must Have Linear Differential Eq.

Three ways to get sustained growth:

1. AK Model: Capital accumulation linear differential eq.

$$\dot{K}(t) = sAK(t) - \delta K(t) \qquad => \qquad \dot{K}(t) = (sA - \delta)K(t)$$

2. Romer (1990) / $\phi = 1$: Knowledge prod. linear differential eq.

$$\dot{A}(t) = \theta L_A(t)A(t)$$

   - "Fully-endogenous" growth model
   - Also true of Aghion-Howitt 92, Grossman-Helpman 91

3. Jones (1995) / $\phi < 1$: Pop. growth linear differential eq.

$$\dot{A}(t) = \theta L_A(t)A(t)^{\phi} \qquad \dot{L}(t) = nL(t)$$

   - "Semi-endogenous" growth model

Evolution of Growth in Simple Model

- Growth of knowledge is generally (even outside BGP):

$$g_A(t) = \theta s^{\lambda} L(t)^{\lambda} A(t)^{\phi - 1}$$

- Taking logs and differentiating by time yields

$$\frac{\dot{g}_A(t)}{g_A(t)} = \lambda n - (1 - \phi) g_A(t)$$

- Multiplying through by $g_A(t)$ yields

$$\dot{g}_A(t) = \lambda n g_A(t) - (1 - \phi) g_A(t)^2$$

Evolution of Growth in Simple Model

$$g_A(t) = \theta s^{\lambda} L(t)^{\lambda} A(t)^{\phi - 1} \tag{1}$$

$$\dot{g}_A(t) = \lambda n g_A(t) - (1 - \phi) g_A(t)^2 \tag{2}$$

- Equation (1) determines initial level of $g_A(t)$
  - Depends, e.g., on s (and therefore innovation policy)
- Equation (2) determines subsequent evolution of $g_A(t)$
  - Independent of s
- With $\phi < 1$ a change in s only has a “level effect”, not a “growth effect”

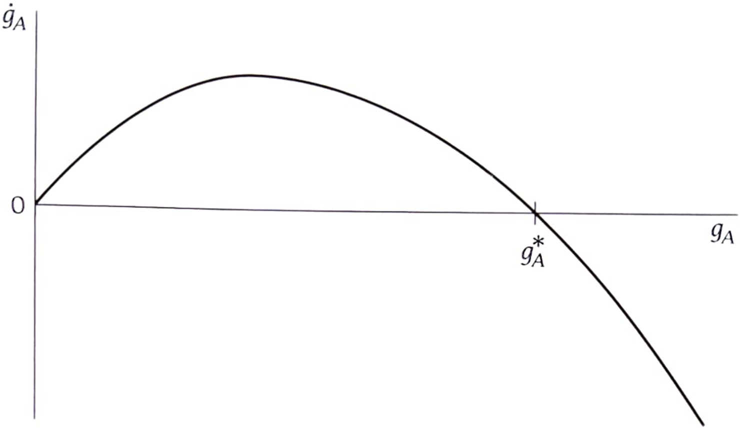


FIGURE 3.1 The dynamics of the growth rate of knowledge when $\theta < 1$

Source: Romer (2019). In Romer's notation $\theta < 1$ is what I have called $\phi < 1$.

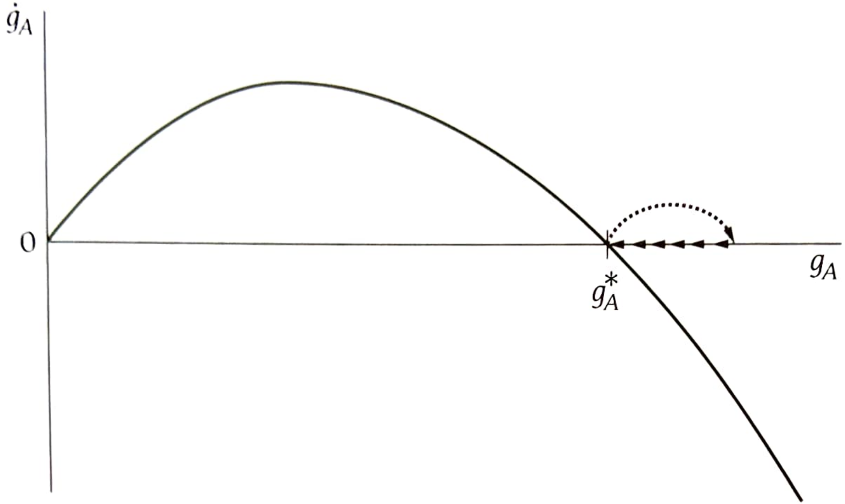


FIGURE 3.2 The effects of an increase in a_L when $\theta < 1$

Source: Romer (2019). In Romer's notation $\theta < 1$ is what I have called $\phi < 1$ and a_L is what I have called s

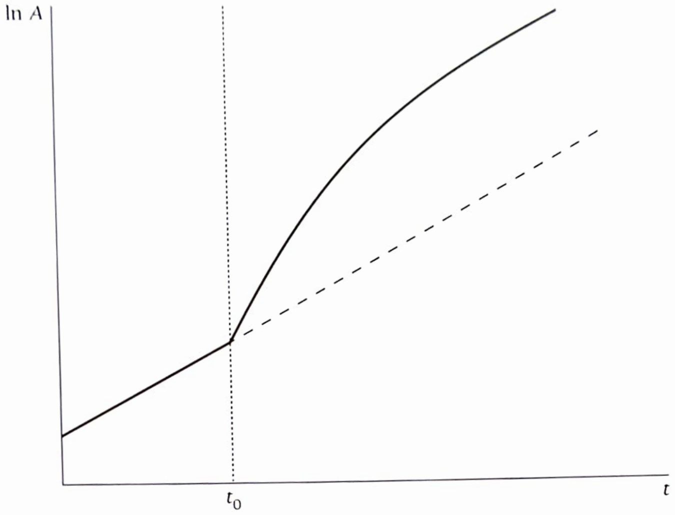


FIGURE 3.3 The impact of an increase in a_L on the path of A when $\theta < 1$

Source: Romer (2019). In Romer's notation $\theta < 1$ is what I have called $\phi < 1$ and a_L is what I have called s

Effect of s on Growth

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} = \theta L_A^{\lambda} A(t)^{\phi-1} = \frac{\theta s^{\lambda} L(t)^{\lambda}}{A(t)^{1-\phi}}$$

- Models with $\phi = 1$: s affects long run growth rate

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} = \theta s^{\lambda} L(t)^{\lambda}$$

- Models with $\phi < 1$: s does not affect long run growth rate

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

Scale Effects

- Models with $\phi = 1$ have "strong" scale effects
  - Growth rate is increasing in **level** of population:

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} = \theta s^{\lambda} L(t)^{\lambda}$$

- Models with $\phi < 1$ have "weak" scale effects
  - Growth rate is increasing in **growth rate** of population:

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

- These are interesting testable implications of these model classes

Do Scale Effects Apply at Country Level?

- One reading of scale effects is that large countries or countries with fast population growth should have high TFP growth
- Obviously counterfactual (Luxembourg, Iceland, Singapore)
- But ideas flow between countries
- Scale effects likely to operate largely at the world level (although flow of ideas is not perfect or instantaneous)

Strong Scale Effects

- There is arguably very strong evidence against strong scale effects:
  - Frontier growth has been quite stable for a long time
  - Research effort has increased very substantially
- With strong scale effects, increased research effort should increase TFP growth at frontier

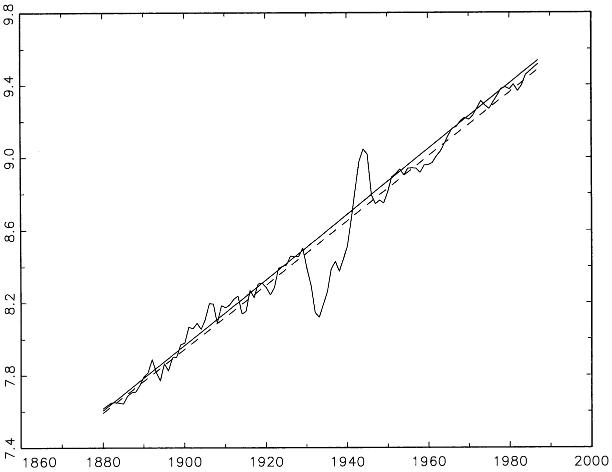


FIGURE I

Per Capita GDP in the United States, 1880–1987 (Natural logarithm)

Source. The data are from Maddison [1982, 1989] as compiled by Bernard [1991]. The solid trend line represents the time trend calculated using data only from 1880 to 1929. The dashed line is the trend for the entire sample.

Source: Jones (1995).

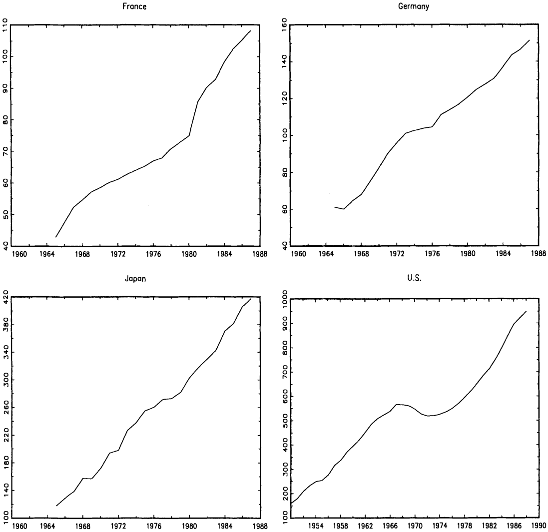


FIGURE IV
Scientists and Engineers Engaged in R&D (1000s)

Source. NSF Science and Engineering Indicators 1989 and Bureau of the Census (various).

Source: Jones (1995).

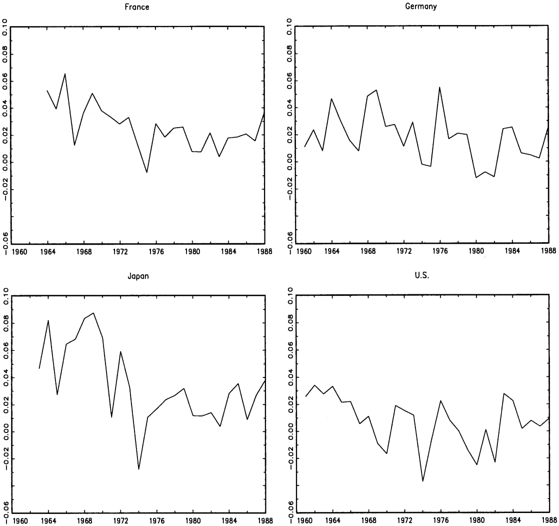


FIGURE V
Aggregate Total Factor Productivity Growth

Source. OECD Department of Economics and Statistics Analytic Database. Data provided by Steven Englander.

Source: Jones (1995).

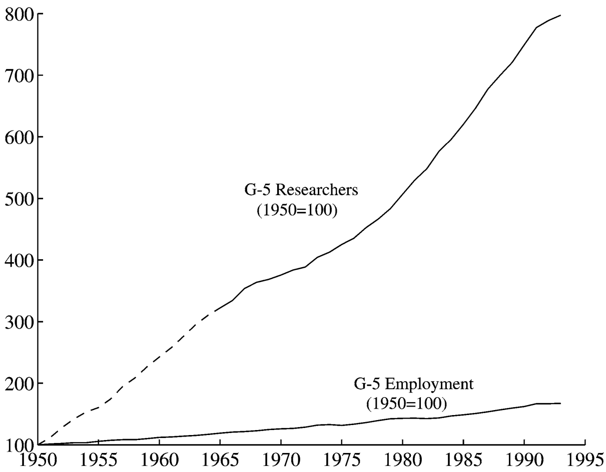


Figure 2. Researchers and employment in the G-5 countries (index). *Note*. From calculations in Jones (2002b). Data on researchers before 1950 in countries other than the United States is backcasted using the 1965 research share of employment. The G-5 countries are France, Germany, Japan, the United Kingdom and the United States.

Source: Jones (2005).

EVIDENCE AGAINST STRONG SCALE EFFECTS

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} = \theta s L(t)$$

- Research effort has risen by a factor of 8
- Models with $\phi = 1$ imply that growth should have increased by a factor of 8
- Clearly way off!

Ideas Harder to Find

- This evidence suggests that ideas are harder to find
- By ideas, we mean "proportional increases in productivity"
- Research productivity is falling. It takes more research effort to produce the same growth rate
- This means $\phi < 1$ ($\beta > 0$ using Jones (2022) notation)
- But by how much?
  - If $\phi = 0.95$ growth effects of change in *s* on transition path would last for a long time

Bloom, Jones, Van Reenen, Webb (2020)

- Estimate extent to which ideas are getting harder to find at both macro and micro level
- Ideas production function

$$\frac{\dot{A}(t)}{A(t)} = \alpha A(t)^{-\beta} S(t)$$

  - $S(t)$ denotes "scientists" (i.e., research effort in units of people)
  - Notice that $\beta = 1 - \phi$
- If g_A is constant:

$$\beta = \frac{g_S}{g_A}$$

- Define:

$$\text{Research Productivity} = \frac{\dot{A}(t)/A(t)}{S(t)}$$

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

- Consider the "lab equipment" model of research

$$\dot{A}_t = \alpha R_t$$

- R_t denotes research expenditures (labor and capital/equipment)
- Divide through by A_t and multiply-divide by w_t (wage):

$$\frac{\dot{A}_t}{A_t} = \underbrace{\frac{\alpha w_t}{A_t}}_{\text{Research Prod.}} \times \underbrace{\frac{R_t}{w_t}}_{\text{Scientists}}$$

- In Romer-type model R_t/w_t and w_t/A_t are constant
- Measure research effort (in units of "scientists") by R_t/w_t

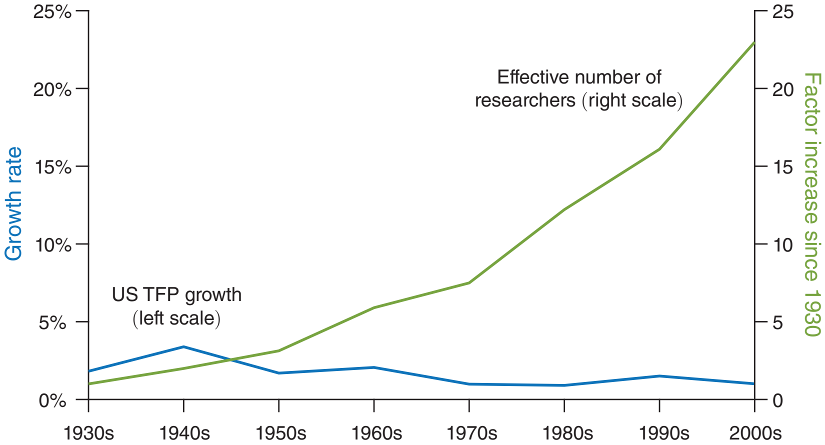


Figure 1. Aggregate Data on Growth and Research Effort

Source: Bloom, Jones, Van Reenen, Webb (2020).

Moore's Law

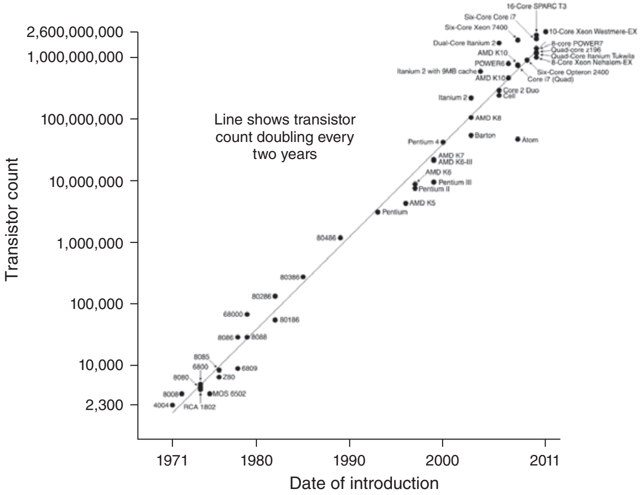


Figure 3. The Steady Exponential Growth of Moore's Law

Source: Bloom, Jones, Van Reenen, Webb (2020).

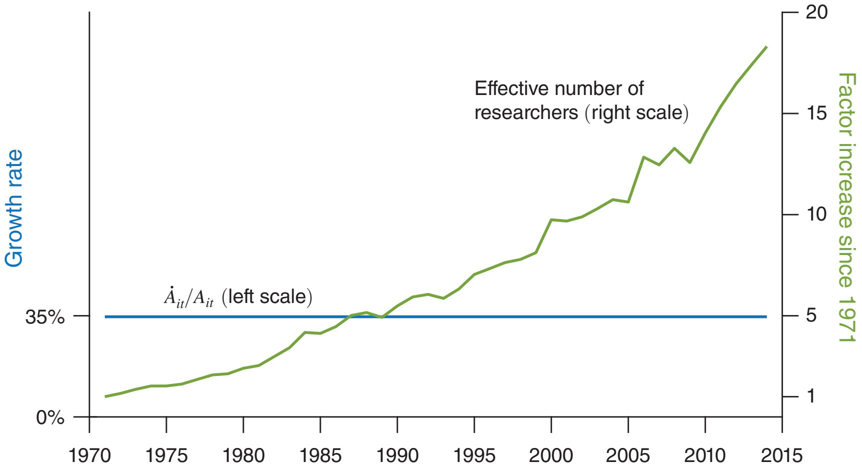


FIGURE 4. DATA ON MOORE'S LAW

Source: Bloom, Jones, Van Reenen, Webb (2020). Research expenditure for several dozen specific firms.

Moore's Law

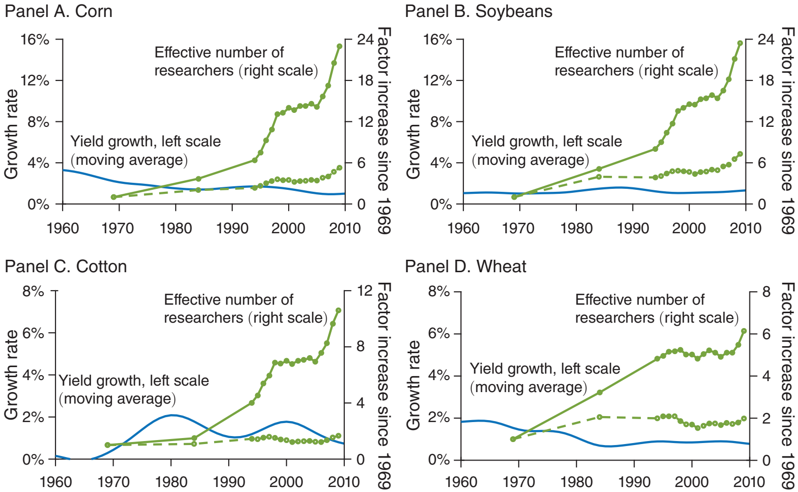


Figure 6. Yield Growth and Research Effort by Crop

Source: Bloom, Jones, Van Reenen, Webb (2020). Productivity is yield per acre.

TABLE 7—SUMMARY OF THE EVIDENCE ON RESEARCH PRODUCTIVITY

Scope	Time period	Average annual growth rate (%)	Half-life (years)	Dynamic diminishing returns, β
Aggregate economy	1930–2015	−5.1	14	3.1
Moore's Law	1971–2014	−6.8	10	0.2
Semiconductor TFP growth	1975–2011	−5.6	12	0.4
Agriculture, US R&D	1970–2007	−3.7	19	2.2
Agriculture, global R&D	1980–2010	−5.5	13	3.3
Corn, version 1	1969–2009	−9.9	7	7.2
Corn, version 2	1969–2009	−6.2	11	4.5
Soybeans, version 1	1969–2009	−7.3	9	6.3
Soybeans, version 2	1969–2009	−4.4	16	3.8
Cotton, version 1	1969–2009	−3.4	21	2.5
Cotton, version 2	1969–2009	+1.3	−55	−0.9
Wheat, version 1	1969–2009	−6.1	11	6.8
Wheat, version 2	1969–2009	−3.3	21	3.7
New molecular entities	1970–2015	−3.5	20	…
Cancer (all), publications	1975–2006	−0.6	116	…
Cancer (all), trials	1975–2006	−5.7	12	…
Breast cancer, publications	1975–2006	−6.1	11	…
Breast cancer, trials	1975–2006	−10.1	7	…
Heart disease, publications	1968–2011	−3.7	19	…
Heart disease, trials	1968–2011	−7.2	10	…
Compustat, sales	3 decades	−11.1	6	1.1
Compustat, market cap	3 decades	−9.2	8	0.9
Compustat, employment	3 decades	−14.5	5	1.8
Compustat, sales/employment	3 decades	−4.5	15	1.1
Census of Manufacturing	1992–2012	−7.8	9	…

Source: Bloom, Jones, Van Reenen, Webb (2020).

Measuring Innovation Using Patents

- Large literature that uses numbers of patents to measure innovation
- But most patents are not very innovative
- Refinements:
  - Patent citations
  - Market value of patents
- Kelly, Papanikolaou, Seru, Taddy (2021):
  - Use text similarity of patents
  - Important patents are different from previous patents (novel) and similar to subsequent patents (impactful)

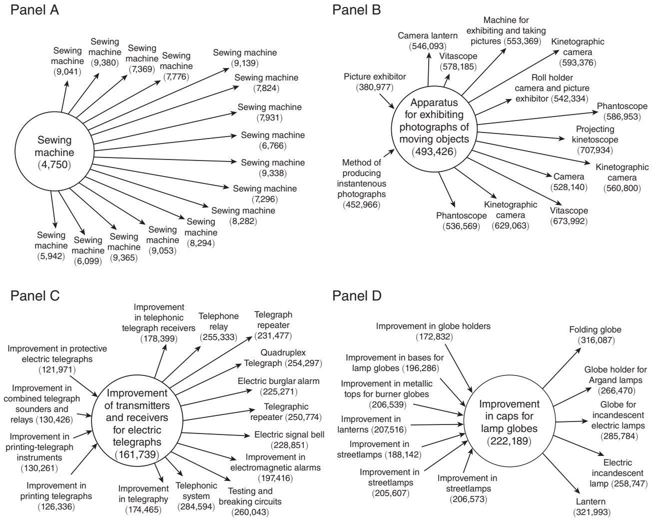
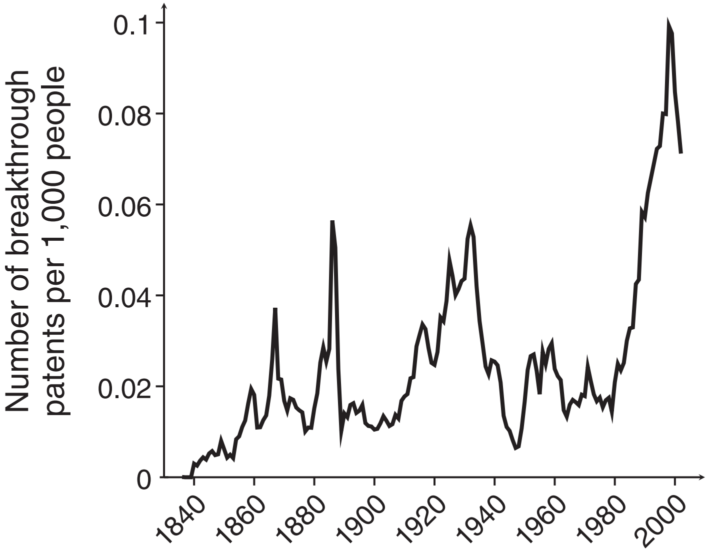


FIGURE 2. EXAMPLES OF SIMILARITY NETWORKS

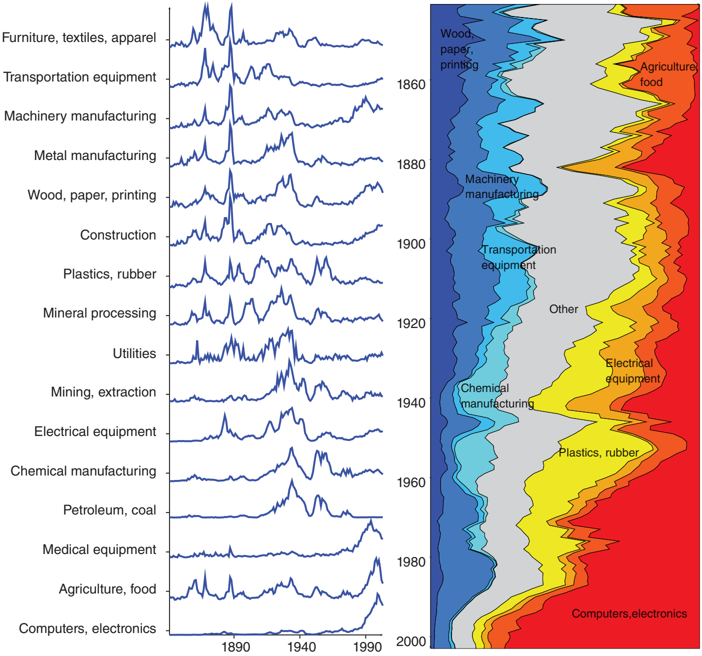
Notes: Figure displays the similarity networks for four patents: the patent for the first sewing machine (panel A), one of the earlier patents for moving pictures (panel B), one of the early patents that led to the telephone (panel C), and a randomly chosen patent from the 1800s (panel D). In plotting the similarity links, we restrict attention to patent pairs led at most five years apart and with a cosine similarity greater than 50 percent.

Source: Kelly, Papanikolaou, Seru, Taddy (2022).

Panel A. Breakthrough patents (top 10 percent in terms of significance) per capita



Source: Kelly, Papanikolaou, Seru, Taddy (2022).



Source: Kelly, Papanikolaou, Seru, Taddy (2022).

Growth in the Past and Future

- Semi-endogenous growth model imply that long-run growth is governed by population growth
- Many other factors have "level effects"
  (e.g., increases in education, R&D share, misallocation)
- But level effects can be large
- How much of recent growth is due to such level effects?
- What does this suggest about the future of growth?

Growth Accounting

- Goods production:

$$Y_t = K_t^{\alpha}(Z_t h_t L_{Yt})^{1-\alpha}$$

  - h_t is human capital per person

- Productivity:

$$Z_t = A_t M_t$$

  - A_t is knowledge
  - M_t is misallocation

- Some manipulation:

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

- Ideas Production function:

$$\dot{A}(t) = \theta L_A(t)^{\lambda} A(t)^{\phi}$$

$$\frac{\dot{A}(t)}{A(t)} = \theta s(t)^{\lambda} L(t)^{\lambda} A(t)^{\phi - 1}$$

- With constant growth of $A(t)$:

$$0 = \lambda g_s + \lambda g_L - (1 - \phi) g_A$$

$$g_A = \frac{\lambda}{1 - \phi}(g_s + g_L)$$

- Jones (2022) assumes $\lambda/(1 - \phi) = \lambda/\beta = \gamma = 1/3$

  (Results that follow are sensitive to this!)

Growth Accounting

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

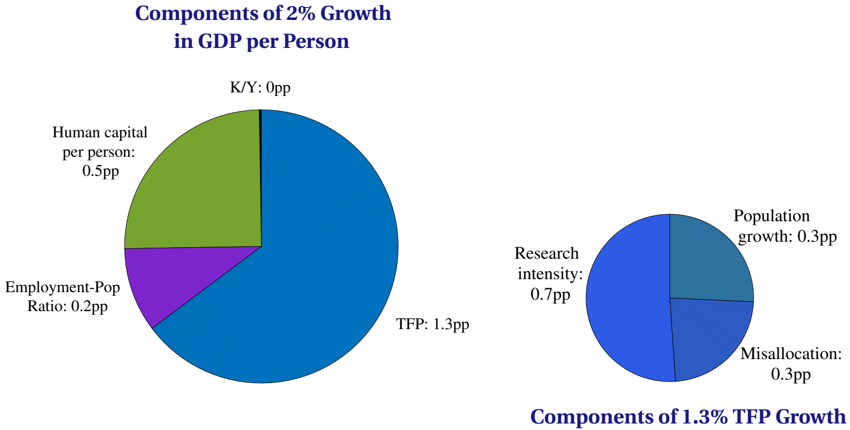
$$+ \underbrace{d\log M_t + d\log A_t}_{\text{TFP growth}} \tag{15}$$

where

$$\text{TFP growth} \equiv \underbrace{d\log M_t}_{\text{Misallocation}} + \underbrace{d\log A_t}_{\text{Ideas}} = \underbrace{d\log M_t}_{\text{Misallocation}} + \underbrace{\gamma\, d\log s_t}_{\text{Research intensity}} + \underbrace{\gamma\, d\log L_t}_{\text{LF growth}} \tag{16}$$

Source: Jones (2022).

Figure 2: Historical Growth Accounting



Note: The figure shows a growth accounting exercise for the United States since the 1950s using equations (15) and (16). See the main text for details.

Source: Jones (2022).

Growth in Past and Future

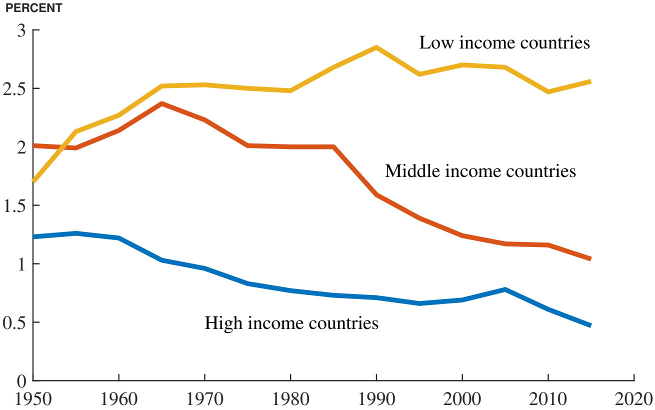
- In the long run:
  - All terms are zero except population growth
  - 100% of growth due to population growth
- Historically:
  - 80% of growth due to other factors
  - Only 20% of growth due to population growth

    (Sensitive to assumption on γ.)

Will Growth Slow?

- Many sources of growth are temporary:
  - Increased education
  - Higher Emp-Pop ratio
  - Falling misallocation
  - Rising research intensity
- But some of these might continue for a very long time (e.g., increased research intensity)
- Population growth is slowing (Population likely to start shrinking soon!)

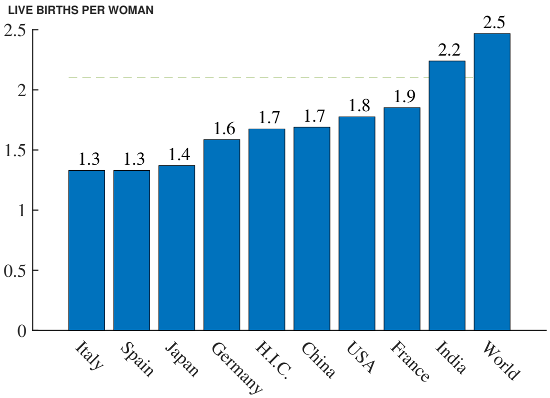
Figure 4: Population Growth around the World



Note: Average annual rates of population growth for countries classified according to their 2018 World Bank income grouping. Each data point corresponds to a five-year period. Source: United Nations (2019).

Source: Jones (2022).

Figure 5: The Total Fertility Rate around the World



Note: The total fertility rate is the average number of live births a hypothetical cohort of women would have over their reproductive life if they were subject during their whole lives to the fertility rates of a given period and if they were not subject to mortality. Each data point corresponds to the five-year period 2015–2020. Source: United Nations (2019).

Source: Jones (2022).

Might Growth Speed Up?

- Finding Einsteins
  - Traditionally most people not able to reach their potential as producers of ideas/knowledge
  - Extreme poverty, cast/class restrictions, discrimination
  - How many Einsteins and Doudnas have we missed
- Automation and Artificial Intelligence
  - Interesting discussion in Jones (2022, sec. 6)
  - Automation of ideas production could even imply a "singularity" (explosive growth driven by AGI)