# NBER Innovation Research Boot Camp:
# 1. Introduction
# 2. Human Capital and Innovation

Ben Jones
July 11, 2025

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## Boot Camp Outline

| Session Title | Time | Faculty |
|---|---|---|
| **Introduction /<br>Human Capital & Innovation** | Friday 9am-12pm | Ben Jones |
| **Contracting and Control Rights for Innovation** | Friday 1:30-4:30pm | Pierre Azoulay |
| **Supply of Innovators** | Saturday 9am-12pm | Ina Ganguli |
| **Economics of Science** | Saturday 1:30-4:30pm | Kyle Myers |
| **Idea-Based Models of Economic Growth** | Monday 9am-12pm | Chad Jones |
| **Budget Analysis of Productivity Policies** | Monday 1:30-4:30pm | Jeff Kling, Heidi Williams |
| **Dinner Keynote** | Monday 6:30pm | Glenn Hubbard |
| **NBER Innovation Meeting (Tuesday-Wednesday)** | | |
| **Diffusion** | Thursday 9am-12pm | Kevin Bryan |
| **Advice on Research and Careers** | Thursday 1:30-4:30pm | Matt Clancy, Dylan Matthews, Caleb Watney, and Heidi Williams |
| **Dinner Keynote, Joint with ERBC** | Thursday 6:30pm | Ed Glaeser |

## Introduction

- Boot Camp Outline
- **Why Study Innovation?**
- The Nature of Ideas
- Market Failures & Social Returns

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## For most of human history, the average person has not been much more prosperous than their ancestors….all this changed beginning in the late $18^{th}$ century

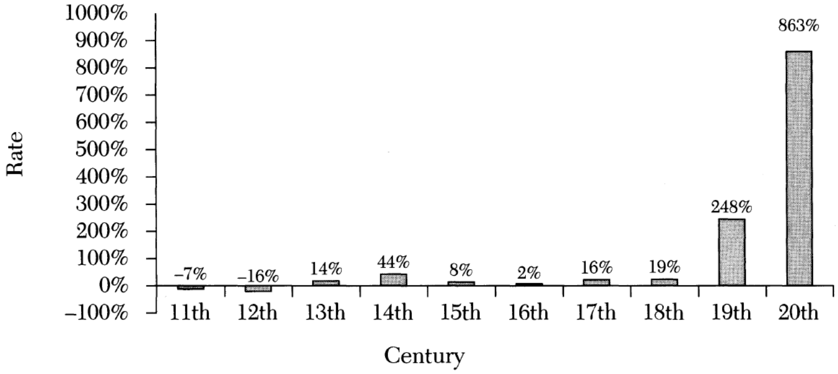
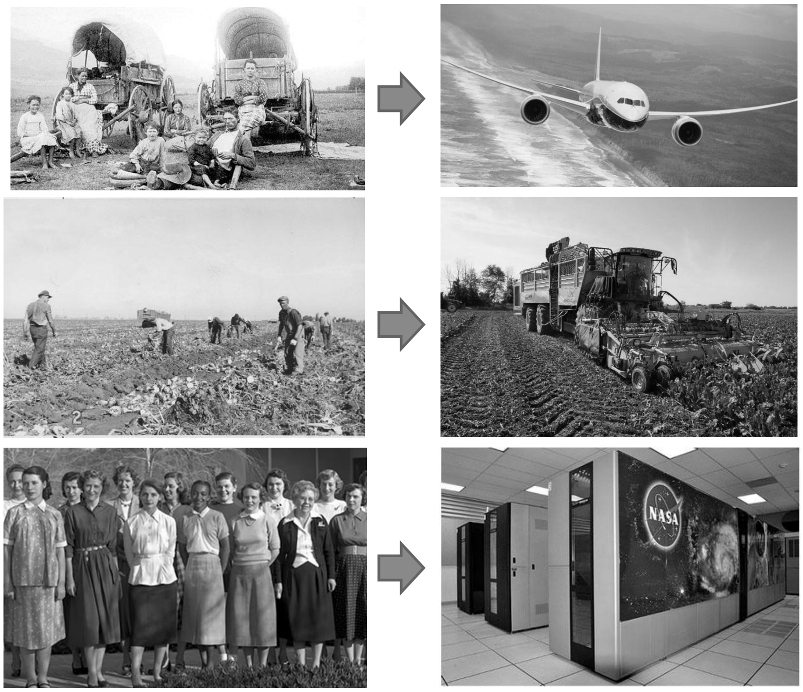
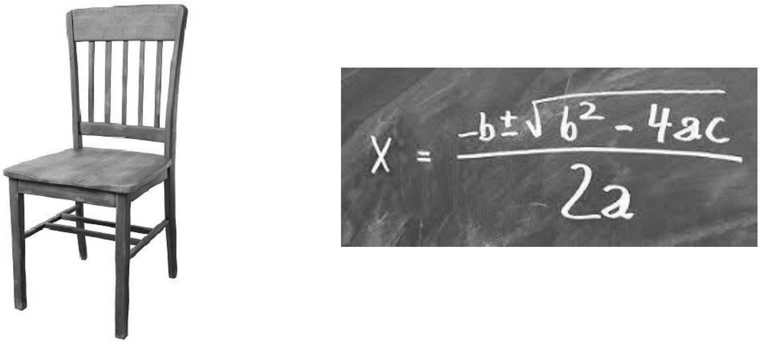


*Figure* 1. Growth in Real World Per-Capita GDP by Century.
*Source:* J. Bradford DeLong 2000.

- It seems almost self evident that the advance of "ideas" is key. See, e.g., Mokyr (1990) "Lever of Riches" for a history of ideas and their impact.



NASA



$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

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# Why Study Innovation?

- The advance of ideas informs central phenomena
  - The path of economic prosperity
    (income, health; inequality)
  - The dynamics of markets, industries, trade
  - The role of institutions and policy

- Ideas are a special form of good. Idea production can be understood through distinctive economic, institutional, and sociological features.

- Idea production interfaces with many forms of market failure, pointing to key roles for public policy

## Why Study Innovation?

- Ordinary production

$$Y_t = F(B_t K_t, A_t L_t)$$

  - Technology forms the key state variables, determining path of standard of living, inequality, industry dynamics, comparative advantage, etc.

- The "ideas production function"

$$\frac{d(Ideas_t)}{dt} = q(H_t, K_t, Z_t, Ideas_t)$$

  - The "Economics of Innovation" largely focuses here, with macro and micro perspectives

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## Introduction

- Course Outline
- Why Study Innovation?
- **The Nature of Ideas**
- Market Failures & Social Returns

## Ideas are Special Goods: An Introduction

Non-rivalry

Excludability

Cumulativeness

Uncertainty

All underpinning market failures.

- ❖ The boot camp will emphasize these features to understand major phenomena and several special institutions (e.g., intellectual property, universities, R&D tax credits…)

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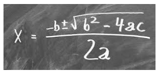
## Ideas are Special Goods: Non-Rivalry

- ❖ Ideas are *non-rival* goods
  - ▪ Unlike most goods, the use of an idea by one party does not preclude its use by another party

Rival good



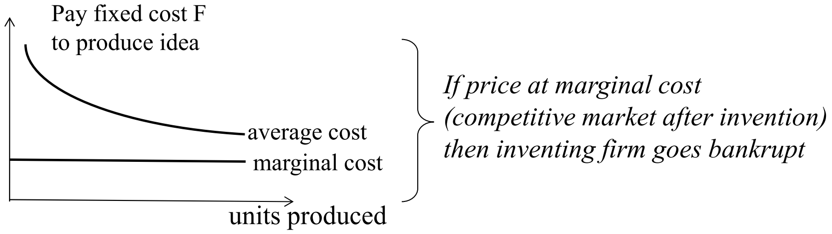
Non-rival good

| | |
|---|---|
| Non-rivalry: | Algebra<br>Germ theory of disease<br>Assembly line<br>Chemical process<br>Regression<br>CRISPR |

- ❖ This property quickly leads to *market failures*

## Ideas are Special Goods: Non-Rivalry

- *Non-rivalry* suggests that markets underinvest in new ideas
  - *Spillovers:* Hard for innovator to capture full benefit of ideas
  - *Competition:* hard to produce idea (fixed cost, possibly very large) but easier to make copies (non-rival)



## Ideas are Special Goods: Excludability

- Ideas may (or may not) be *excludable*
  - Excludability: can you stop others from using something?
  - Excludability is a source of *market power* (and thus private return on investment)

- Excludability depends on institutions and technology
  - *Institutions.* The patent system provides patent holder the right to exclude others from using an idea for a fixed period of time in exchange for disclosure of that idea to the public domain. Other intellectual property forms include copyright, trademarks, non-competes.
  - *Technology*. Ideas may be excludable without IP (secrets, cryptography, control of complementary inputs)

## Ideas vs Other Goods: Examples

| | Non-Excludable | Excludable |
|---|---|---|
| Non-Rivalrous | Basic Research, Calculus | Satellite Radio, Patented Ideas |
| Rivalrous | Fish in Ocean | Lawyer services, Airplane seat |

- ❖ Need special institutions to support idea creation. Consider:
  - Intellectual property provides ex-post excludability
  - Public agencies (e.g., NIH) provide ex-ante funding

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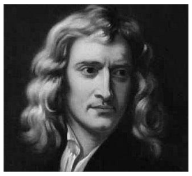
## Ideas are Special Goods: Cumulativeness

- ❖ The production of ideas is associated with spillovers
  -- across time, location, industries, etc



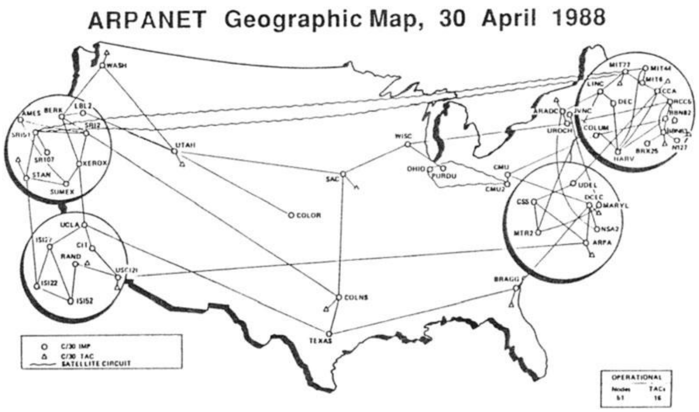
- ❖ Ideas are *cumulative* -- spillovers across time
  - *"If I have seen further, it is by standing on ye shoulders of giants" (Newton)*

- ❖ This cumulative process seems largely unpriced
  - We don't pay Newton for using calculus. Should we?

- ❖ Implications for
  - Social welfare / policy
  - Strategic interaction
  - The nature of creativity itself

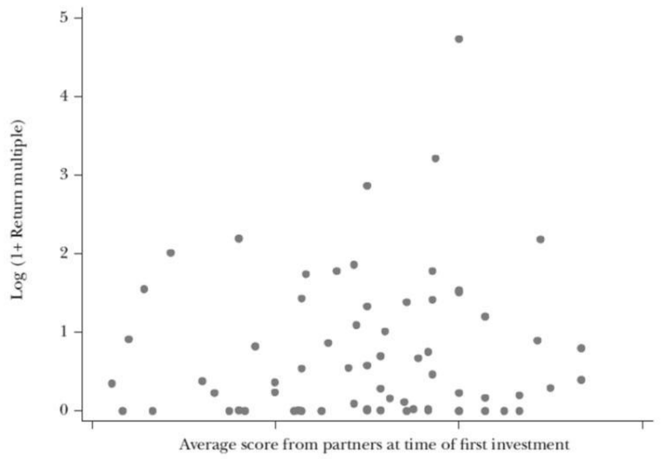
## Ideas are Special Goods: Uncertainty

Could you have foreseen the value of ARPANET when it was first developed?



## Even close, incentivized observers (i.e., the VCs) don't know what will happen…

B: Correlation between Scores and Outcomes



*Note:* The labels on the horizontal axis have been suppressed to maintain the confidentiality of the investor's rating scale, but lower predictions were on the left and higher predictions were on the right.

Kerr et al., JEP 2014

## The inability to forecast innovation seems to be fundamental (Rosenberg)

| | |
|---|---|
|  | Bell Labs Development of the Maser & Laser:<br>"Bell's patent department at first refused to patent our amplifier…for optical frequencies because…optical waves had never been of any importance to communications and hence the invention had little bearing on Bell System interests" (Charles Townes, Nobel Laureate) |
|  | Bell - Western Union Patent Agreement of 1878:<br>Western Union will agree to stay out of the telephone business if Bell agrees to stay out of the telegraph business |

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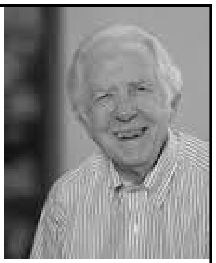
## Nate Rosenberg's Dimensions of Uncertainty



Can think of as a lack of foresight (not just risk)

- Initial technology is developed for a narrow application
- Little understanding of potential applications or uses
- Dependence on the emergence of complementary innovations and/or the emergence of entirely new technological systems
- Inability to anticipate satisfying human needs in a novel way

## Related Note on Research Methods: Sampling

- ➢ In innovation, there is substantial interest in upper tail "outliers"
  - Highest-value patents
  - Home-run papers, "star" scientists, prizes (e.g., Nobel)
  - High-growth entrepreneurship

- ➢ Conversely, studying median inventors, entrepreneurs, or researchers may not be representative for outcomes of interest  
  ~ distributions of citations, firm size, etc. are power laws

- ➢ In empirical research on ideas/innovation, it can be good to examine the census (or a random sample thereof), but also good to emphasize the upper tail

## Uncertainty and the Market for Ideas

- ➢ What should the "price" of a given idea be?
  - Main determinant of "willingness to pay" for a traditional economic commodity is buyer's *ex-ante* information about the characteristics of that good. The correct willingness-to-pay for an idea therefore depends on *knowing* the idea
  - At which point one does not need to pay for it!

- ➢ Figuring out the "price" for an idea requires information that intrinsically reduces its value  
  ~ the Arrow information paradox  
  ~ not simply "information asymmetry" of the traditional kind, but a more fundamental consequence of value being hard to verify until after possession, limiting transactions in the market for ideas

## Uncertainty meets Organizational Design

## Example: Organizations for Basic Research

- Important link between *cumulativeness* and *uncertainty* about downstream applications for understanding org design.

- What is the appropriate organizational form to encourage basic research? An introductory view:

- The Industrial Lab (e.g., Bell Labs, Google X)
    - “Finger in many pies” (Nelson 1959). Integration downstream essential to monetize uncertain outcomes from basic research. Scope is key.
    - Absorptive capacity view (Cohen and Levinthal 1990). Do research so organization is a better consumer of key, new ideas ‘out there’.

- The University (e.g., outputs like ML, CRISPR)
    - Public funding, embracing public goods model. Different set of organizational rules, norms, personal motivations.

## The Nature of Ideas:
## Private vs. Social Returns

- The nature of ideas suggests many market failures
  - The social returns to innovation may then differ substantially from the private (market) return.
  - If so, room for institutions and policy interventions

- But how big are the social returns to innovation? Are markets a little off or way off? Do we really underinvest?

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## What Are the Social Returns to Innovation?

- To answer this question we must (a) measure the social benefits from innovation investment, and (b) compare these benefits to the investment costs.

- But assessing the social benefits of specific advances is super difficult.

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

## Social Returns and the Spillover Challenge

- The root measurement challenge is that society-wide gains seem to differ considerably from the private returns to the innovator and are fundamentally hard to trace.

- Numerous “spillover” margins; e.g.,
  - Imitative spillovers (+)
  - Intertemporal spillovers (+/-)
  - Business stealing (-)
  - Duplication (-)

- How can we estimate the social returns in light of these complex spillovers?
- And how can we avoid “picking winners” for these assessments, since innovation investments often fail?

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## Literature

- Classic:  Case studies
  - But successes only?  What about failures?
  - What about advances with diffuse applications?

- Regression methods
  - Spillover boundaries?  Intertemporal spillovers?  Lags?
  - Causative interpretation?
  - Key: Bloom et al. (2013); Fieldhouse & Mertens (2024)

- Enduring measurement challenges
  - Social returns to science (basic research)
  - General purpose technologies

## Jones and Summers (2022):  Overview

1) Consider the *average* social returns to innovation

- Examine path of GDP per capita to net out spillovers
- Examine total innovation investment to capture success and failure
- Produce baseline calculation, based on transparent and easily editable assumptions

2) Generalize the baseline

- Reasons baseline may be too low
- Reasons baseline may be too high

3) Consider distinction between marginal and average returns

- Micro-founded arguments
- Macro growth models

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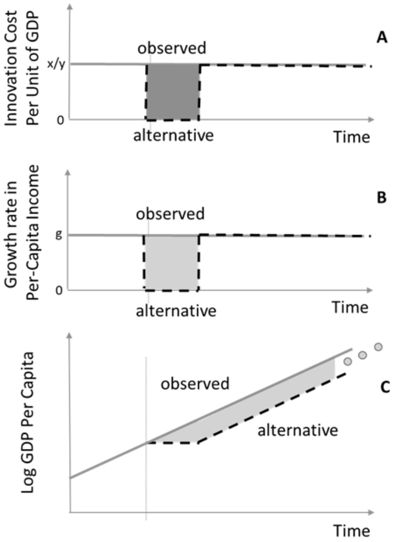
## Baseline Calculation:  Conceptual Model



Investment cost is x/y for one year

Benefit is g% higher income forever

Present value of benefit is g/r

## Baseline Calculation: Conceptual Model

The *average* social returns are then

Present value of the benefits

$$\rho = \frac{g/r}{x/y}$$

Investment cost

Implications:
If $x$ is R&D costs only, then average social returns appear enormous.
If $x$ incorporates all sorts of other investment costs, then the average social returns are still very large.

## The "R&D Only" Baseline: Candidate Social Returns

Take $g = 1.8\%$ and $x/y = 2.7\%$ (U.S.)
Then the average social returns are:

**Table 1: The Average Social Returns, by Social Discount Rate**

| Social discount rate ($r$) | Average Social Benefit-Cost Ratio ($\rho$) |
|---|---|
| 1% | 66.7 |
| 2% | 33.3 |
| 3.5% | 19.0 |
| 5% | 13.3 |
| 7% | 9.5 |
| 10% | 6.7 |
| 67% | 1 |

## Extending the Baseline

The baseline calculation may be too high or too low.
Introduce the corrective factor, $\beta$.

$$\rho = \beta \frac{g/r}{x/y}$$

Baseline too high? ($\beta < 1$)

- Lags
- Capital investment
- Other sources of innovation

Baseline too low? ($\beta > 1$)

- Inflation bias
- Health gains
- International spillovers

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## Conclusions: Jones and Summers (2022)

- An approach complementary to prior literature
  - Focus on the *average* return to innovation investments
  - Allows extensions to many potentially first-order issues
- Findings
  - Even under conservative assumptions, it is difficult to find an average return below $4 per $1 spent.
  - Middle-of-the-road estimate suggests at least $10 per $1 spent, and perhaps multiples higher
  - Marginal returns look somewhat lower, but not much lower

## The Bigger Picture: Policy

- ❖ If the social returns are, on average, large, what are the main market failures? What institutional structures and policies can overcome specific market failures? For example, how important is science and how can we can support science effectively?

United States Patent and Trademark Office
uspto

NSF

hhmi
Howard Hughes Medical Institute

NIH
National Institutes of Health

Argonne National Laboratory

Alfred P. Sloan Foundation

Open Philanthropy

CERN

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# NBER Innovation Research Boot Camp:
1. Introduction
2. **Human Capital and Innovation**
(short version!)

Ben Jones
July 11, 2025

## The “Ideas Production Function”

- Question: How do inputs to innovative activity map into innovations and new firms?

$$\frac{dA}{dt} = q(H, K, Z, A)$$

- Inputs
  - Human capital (H), physical capital (K)
  - Institutions (Z)
  - Current state of ideas (A)

- How do we understand the role of human capital, especially in light of views/models of the creative process?

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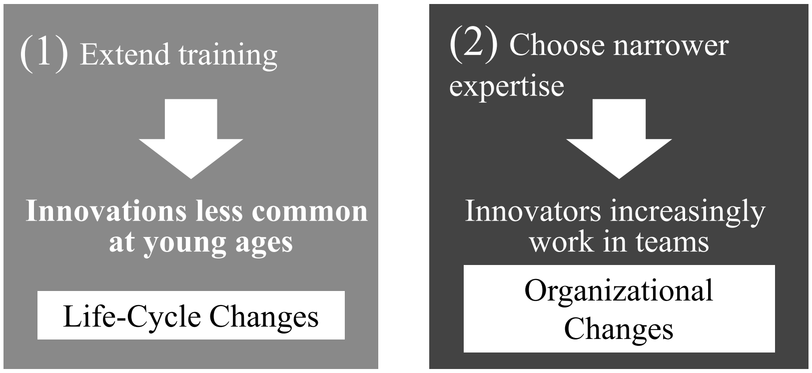
## Cumulativeness & The Burden of Knowledge

- What happens if new ideas, by creating new knowledge, impose an increasing educational burden on future innovators?



(1) Extend training

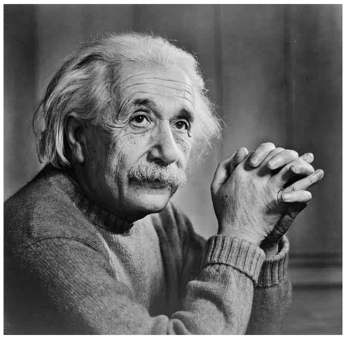
**Innovations less common at young ages**

Life-Cycle Changes

(2) Choose narrower expertise

Innovators increasingly work in teams

Organizational Changes



> "…knowledge has become vastly more profound in every department of science. But the assimilative power of the human intellect is and remains strictly limited. Hence it was inevitable that the activity of the individual investigator should be confined to a smaller and smaller section…"
>
> -- Albert Einstein (1932)

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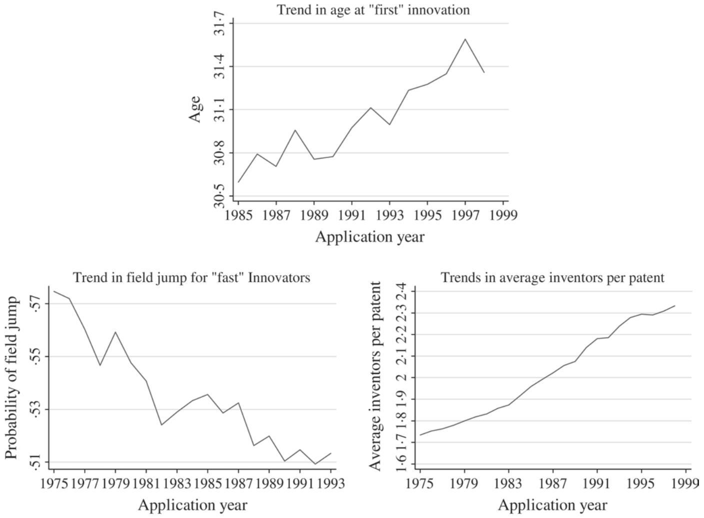
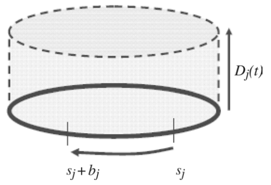
## The Burden of Knowledge: Some Evidence

- ❖ Micro-evidence from patent data (B. Jones 2009)



## The Burden of Knowledge and Growth

❖ Focus on creativity effect of narrowing expertise. Consider a “circle of knowledge” with a continuum of knowledge types (indexed around circle) where depth of knowledge is *D(t)*



❖ Let educational attainment for innovator born at time *t* be their breadth (*b*) times the prevailing depth (*D*)

$$E(t) = b(t)D(t)$$

❖ Let creativity (for an individual) be

$$\dot{A} = A^{\chi} L_A^{-\sigma} b^{\beta}$$

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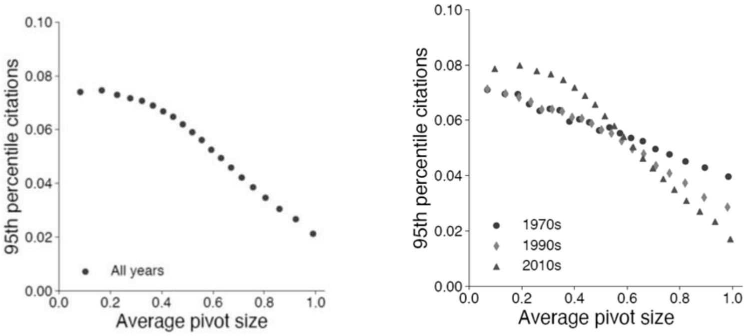
## Collaboration

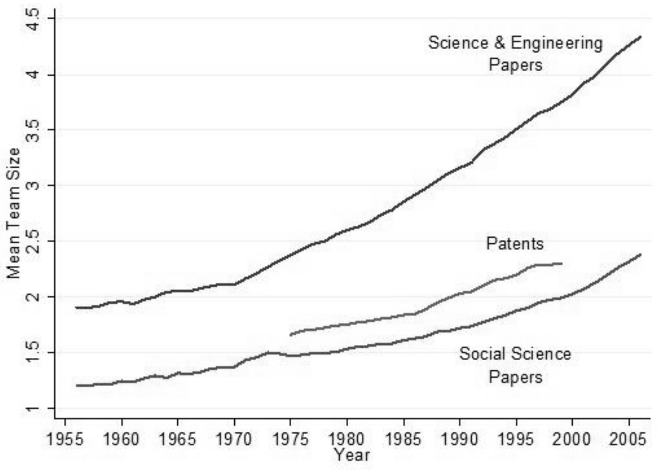
## Specialization & the Pivot Penalty

❖ Measure “pivot size” as how far you move in a given paper or patent from your recent work (Hill et al. 2025)



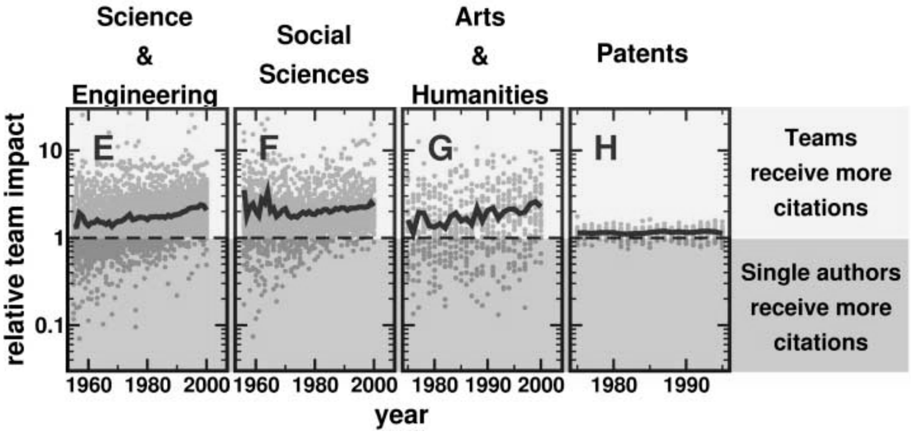
- Find that work has lower impact the further you pivot.
- And this pivot penalty is getting steeper with time.

## The Ubiquitous Rise in Teamwork



Data: Web of Science, USPTO (Wuchty et al. 2007)

## The Rising Team Impact Advantage



Data: Web of Science, USPTO (Wuchty et al. 2007)

## Question: Team Organization

- ❖ How should you organize individuals into teams?

↑ How do you allocate pilots across planes?

↑ How do you allocate musicians across quartets?

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## Question: Individual Assessment

How should you credit the individual member?

↑

e.g., if team output is good, is it due to the best person (pilot-copilot) or must all the team members be good (string quartet)?

## Method: Key Idea

$$y = \beta_n \left[ \frac{1}{n} \sum_{i=1}^{n} a_i^{\rho} \right]^{\frac{1}{\rho}}$$

- Ahmadpoor and Jones (2019) consider the “Hölder Mean” (a.k.a. “Generalized Mean”, CES)
  - $y$ is a measure of impact, $a_i$ is productivity of individual $i$, and $n$ is team size
- Special cases
  - max ($\rho \to \infty$)
  - min ($\rho \to -\infty$)
  - arithmetic mean ($\rho = 1$)
  - geometric mean ($\rho = 0$)
  - harmonic mean ($\rho = -1$)

## Potential Team Advantage

$$y = \beta_n \left[ \frac{1}{n} \sum_{i=1}^{n} a_i^{\rho} \right]^{\frac{1}{\rho}}$$

- $\beta_n$ captures impact benefit associated with team of size $n$, incl. advantages of aggregating effort, skill, marketing, or disadvantages via coordination costs (Wuchty et al. 2007; NAS 2015).
- Normalize by setting $\beta_1 = 1$ for solo-authored work.
  - Thus $y = a_i$ for solo-authored work => individual productivity measured on the scale of outcome metric.
  - $\hat{\beta}_n$ interpreted as the impact advantage of teamwork over solo-work for individuals that share a common individual productivity level.

## Results: Team Production Function Parameters

- $\hat{\rho} < 1$
  - Universal across fields
  - Centers between geometric and harmonic averages
  - Implication: Greater influence of lower-productivity team members

- $\hat{\beta}_n > 1$
  - For all WOS fields and 94% of patenting fields
  - $\hat{\beta}_2 = 1.85$ (papers) and $\hat{\beta}_2 = 1.44$ (patents)
  - Implication: team advantage exists conditional on quality of individual team members.

## Summary: Collaboration

- Big dynamics
  - People increasingly work in teams in all fields
  - Highest impact ideas increasingly come from teams
  - Researchers experience increasing impact penalties when moving into new areas

    (Burden of knowledge reasoning may explain patterns)

- Team production: Innovation teams appear like “string quartets.” Consistent with “specialist” teams.
  - Positive assortative matching

- Individual assessment: How we credit individuals is essential to career progression, incentives, etc.
  - “Decoding teams” method to confront teamwork challenge

When in life is one most innovative?

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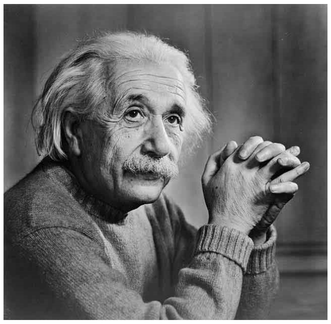
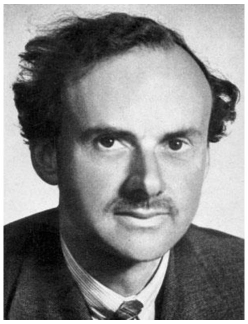
# Common Views



“A person who has not made his great contribution to science before the age of thirty will never do so.”

(Einstein)



“Age is, of course, a fever chill
that every physicist must fear.
He’s better dead than living still
when once he’s past his 30th year.”

(Dirac)

## Why These Views?

- Young people sometimes thought to have advantages in:

1) Deductive reasoning (e.g., Galenson and Weinberg 2005)
2) Transformative thinking (e.g., Planck 1949, Weinberg 2007)
3) Energy / Time (e.g. Jones et al. 2014)

…Yet key resources may accumulate with age

- Human capital, financial capital, social capital (e.g., Lazear 2004, Chatterji 2009, Jones 2009, Evans and Jovanovich 1989, etc.)

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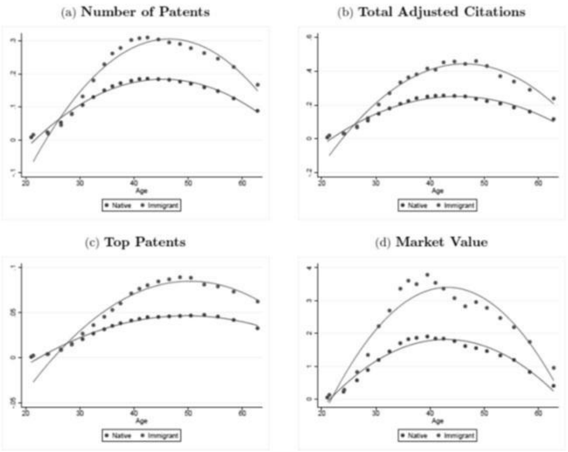
## Science, Invention, and the Life-Cycle Peak

- Bernstein et al. (2022): U.S. patent data, virtually all U.S. <u>inventors</u>



(a) Number of Patents

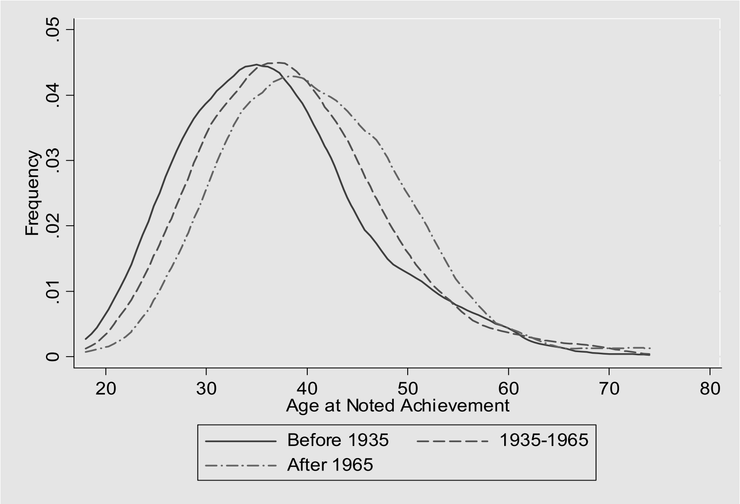
(b) Total Adjusted Citations

(c) Top Patents

(d) Market Value

- Jones, Reedy, Weinberg (2015): Review literature on <u>scientists</u>. *Middle age peak is a universal finding*.

# The Shifting Life Cycle Peak



Data: (1) Nobel Prize winners in Physics, Chemistry, Medicine, and Economics; (2) Great technological achievements over 20th Century. (Jones "Age and Great Invention" 2010)

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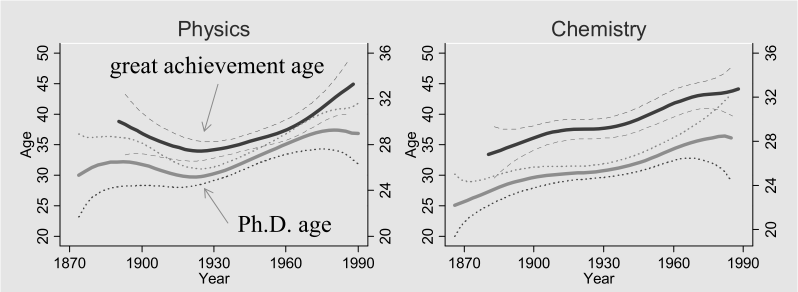
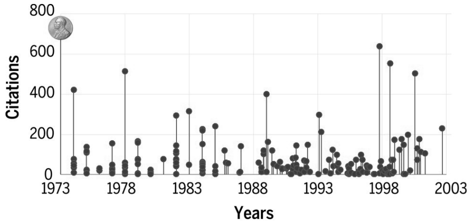
# The Physics Experiment



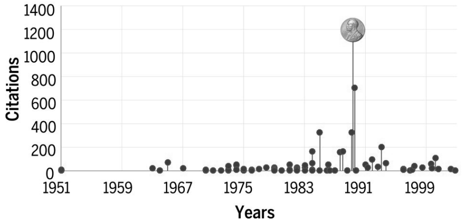
- ❖ Early 20th century physics experienced the quantum mechanics revolution, a broad shift in foundational knowledge
- ❖ The age at Ph.D. and Nobel Prize winning work in physics, and only in physics, fell during that time

## Random Impact Rule & Hot Streaks

- ❖ Despite strong tendency toward middle age peak, it appears that your single very best work may appear anywhere in the *sequence* of your work with uniform probability (Sinatra et al. 2016)



Wilczek
(Physics Nobel)



Fenn
(Chemistry Nobel)

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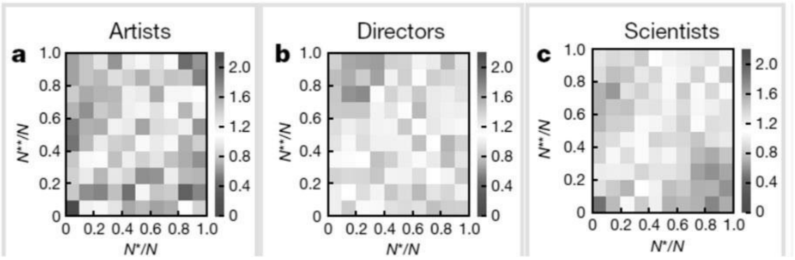
## Random Impact Rule & Hot Streaks

- ❖ Moreover, there are "hot streaks" where second or third best work come near your best work (Liu et al. 2018)



- ❖ Putting literature together:
  - ▪ The quantity of work bunches in middle age (middle age peak)
  - ▪ But quality/impact peaks randomly in sequence of your work (random impact rule) and tends to bunch up (hot streaks)
  - ▪ Good years ahead of you…!

## A.I. in the "Ideas Production Function"

❖ Question: How do inputs to innovative activity map into innovations and new firms?

$$\frac{dA}{dt} = q(H, K, Z, A)$$

❖ Inputs

- Human capital (H), physical capital (K)
- Institutions (Z)
- Current state of ideas (A)

❖ How do we understand the role of physical capital, including A.I. and its potential to accelerate progress?

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## The Task Framework

Some tasks are done by machines ("automated") while others are performed by labor

**Overall output** $Y = \left[\int_0^1 y(i)^\rho \, di\right]^{\frac{1}{\rho}}$

**Task outputs** $y(i) = \begin{cases} Hl(i) & \text{if performed by labor} \\ Zk(i) & \text{if performed by a machine} \end{cases}$

**The parameter $\rho$ defines the strength of bottlenecks.**

## The Task Framework

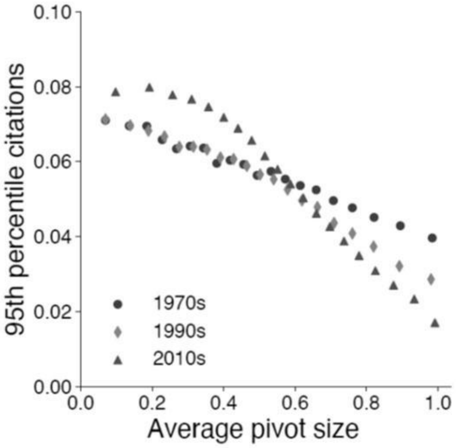
Can apply framework to ordinary production function (GDP), and ideas production function (R&D). To assess growth prospects, you must take a stand on the following key questions:

| | **Good and Services Production** | **Idea Production** |
|---|---|---|
| What share of tasks can AI take over? | $\beta_{GDP}$ | $\beta_{ideas}$ |
| How good is AI at these tasks? | $Z_{GDP}$ | $Z_{ideas}$ |
| How strong are bottlenecks? | $\rho_{GDP}$ | $\rho_{ideas}$ |

## Creative Search View

Opportunities near and far. Which doors to open?
Creative search literature emphasizes "exploit vs. explore" tradeoff (March 1990, etc.)

## Human Limits



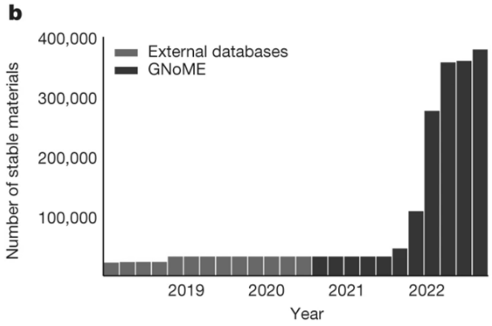
Recall Hill et al. (2025) “The Pivot Penalty in Research”
Pivoting further from prior expertise means lower impact.
And more so with time.

## AI & Creativity

While human experts search locally around own expertise…

AI can draw on all knowledge. It can expand search and suggest more fruitful doorways

In these frameworks, AI can appear more creative than humans



END