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

Ben Jones
July 2023

Boot Camp Outline

Session Title	Time	Faculty
Introduction / Human Capital & Innovation	Friday 9am-12pm	Ben Jones
Diffusion	Friday 1:30-4:30pm	Kevin Bryan
Supply of Innovators	Saturday 9am-12pm	Ina Ganguli
Economics of Science I	Saturday 1:30-4:30pm	Pierre Azoulay
Idea-Based Models of Economic Growth	Monday 9am-12pm	Chad Jones
Innovation Policy	Monday 1:30-4:30pm	John Van Reenen
Dinner Keynote: Innovation and the Great Divergence	Monday 6:30pm	Joel Mokyr
NBER Innovation Meeting (Tuesday-Wednesday)		
Economics of Science II	Thursday 9am-12pm	Kyle Myers
Advice on Research and Careers	Thursday 1:30-4:30pm	Heidi Williams, Matt Clancy, Caleb Watney
Dinner Keynote, Joint with ERBC	Thursday 6:30pm	Ajay Agrawal

Introduction

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

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

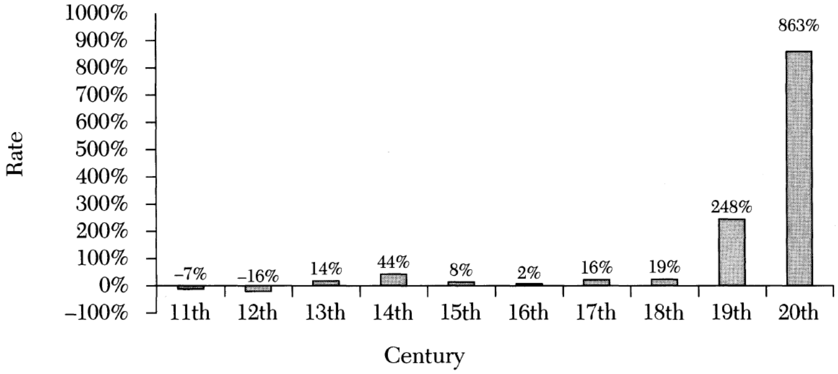
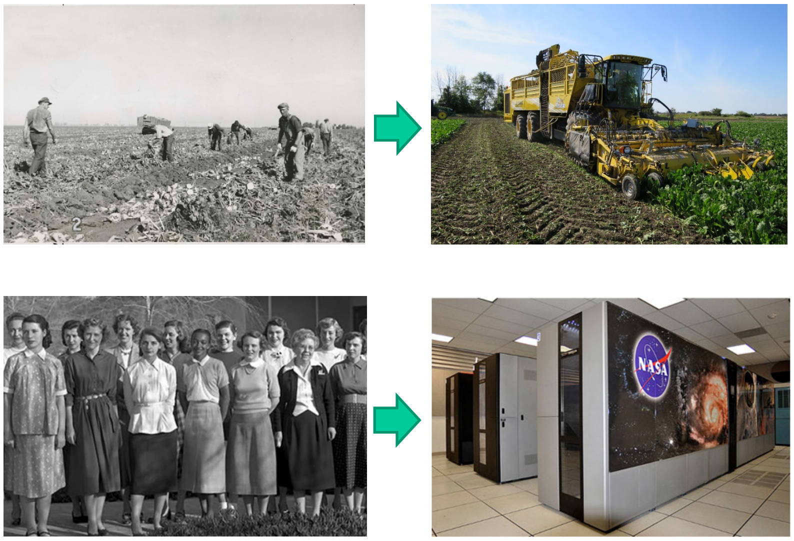
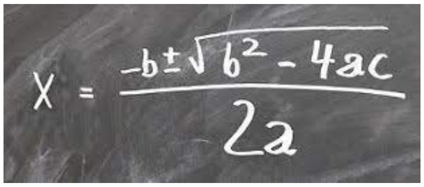


Figure 1. Growth in Real World Per-Capita GDP by Century.
Source: J. Bradford DeLong 2000.

- 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.





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

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

Introduction

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

Ideas are Special Goods: An Introduction

Non-rivalry

Excludability

Cumulativeness

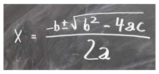
Uncertainty

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…)

Ideas are Special Goods: Non-Rivalry

Rival good



Non-rival good

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

Non-rivalry:
Algebra
Germ theory of disease
Assembly line
Chemical process
Regression
CRISPR

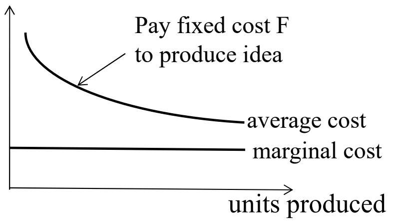
❖ This property quickly leads to *market failures*

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 easy to copy (non-rival)



If price at marginal cost (competitive market after invention) then inventing firm goes bankrupt

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

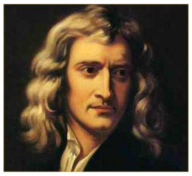
	Non-Excludable	**Excludable**
Non-Rivalrous	Basic Research, Calculus, National Defense	Satellite Radio, Patented Ideas
Rivalrous	Fish in Ocean	Lawyer services, Airplane seat

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

Ideas are Special Goods: Cumulativeness

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

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

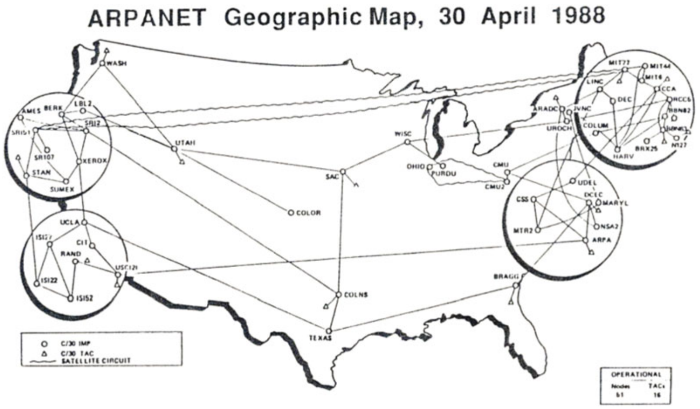


- This cumulative process seems largely unpriced
  - We do not pay Newton for the use of calculus
  - Should we?

- 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?



Uncertainty is fundamental to the production of ideas and innovation…

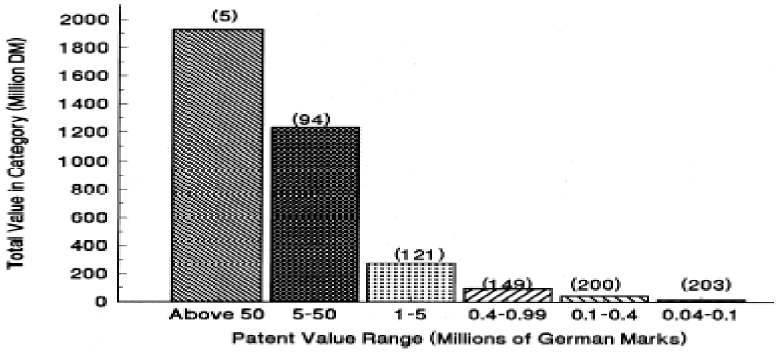
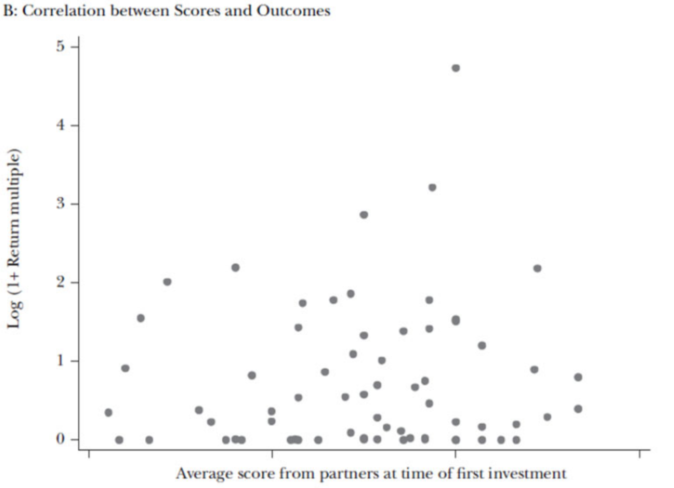


Fig. 1. Distribution of German patent values.

Among more than 750 *patented* inventions, 5 were collectively worth more than 1 billion DM, more than 50% of the total value of the entire sample!

Scherer and Harhoff,
***Research Policy,* 2000**

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



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.

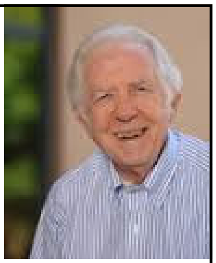
Kerr et al., JEP 2014

Not simply a matter of traditional risk, the inability to forecast innovation seems to be fundamental (Rosenberg)

	Bell Labs Development of the Maser & Laser: "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: Western Union will agree to stay out of the telephone business if Bell agrees to stay out of the telegraph business

---

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 imagine how to satisfy human needs in a novel way

Related Note on Research Methods: Sampling

- Highly convex payoffs suggests somewhat peculiar focus. In studying invention/ innovation/ basic research, there is substantial interest in upper tail "outliers"
  - Highest-value patents
  - Home-run papers, "star" scientists, and prizes (e.g., Nobel)
  - Tech entrepreneurship

- Conversely, studying median inventors, entrepreneurs, or researchers may not be representative for outcomes of interest

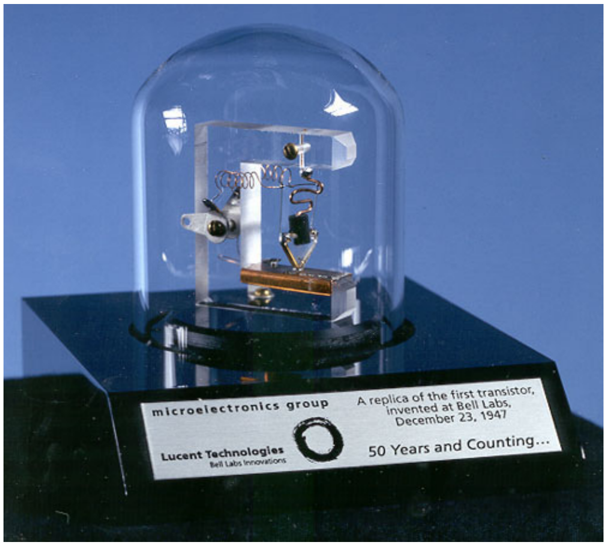
- In empirical research on ideas/innovation, it can be good therefore to either examine the census (or a random sample thereof), but also good to emphasize the upper tail

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
  - N.B.: Not simply "information asymmetry" of the traditional kind, but a more fundamental consequence of inappropriabilty that limits 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)
  - Nelson's "finger in many pies" (Nelson 1959). Integration downstream essential to monetize uncertain outcomes from basic research (industrial lab model). Scope is key.

- 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

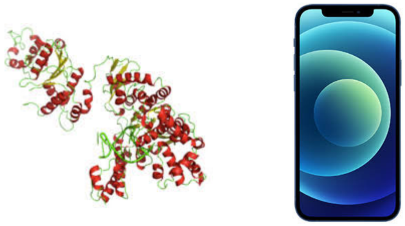
- But how big are the social returns to innovation? Are markets a little off or way off? Do we really underinvest?

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?

Literature: Challenges

- Regression methods
  - Spillover boundaries?
  - Intertemporal spillovers? Lags?
  - Causative interpretation?

- Case studies
  - Successes only? What about failures?
  - What about advances with diffuse applications?

- Innovation investments that may be especially important seem especially hard to assess
  - Basic research
  - General purpose technologies

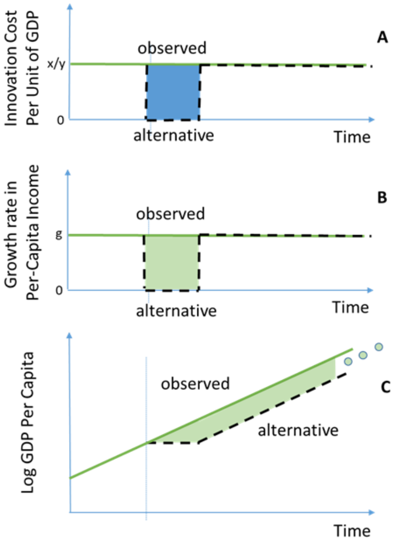
Jones and Summers (2021): Overview

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

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

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

Present value of the benefits

Investment cost

Implications:

If x is R&D costs only, then average social returns appear enormous.

If x is 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 (ρ)
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, β.

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

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

- Lags
- Capital investment
- Other sources of innovation

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

- Inflation bias
- Health gains
- International spillovers

Conclusions: Jones and Summers (2021)

- A new 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, very 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?

NBER Innovation Research Boot Camp:

1. Introduction

2. **Human Capital and Innovation**

(short version!)

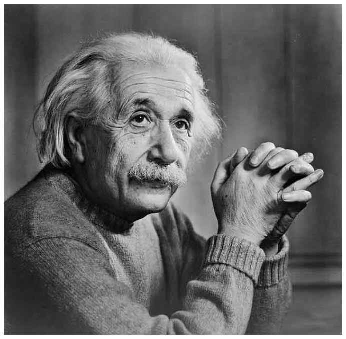
Ben Jones
July 2023

The Burden of Knowledge

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

❖ Two margins of response
- Spend more time in training
- Choose narrower expertise

❖ Implications
- Individual innovators are less capable
  - Less time to innovate if more time in training
  - Harder to have broad impact if narrowing expertise
- Greater need for collaboration in research

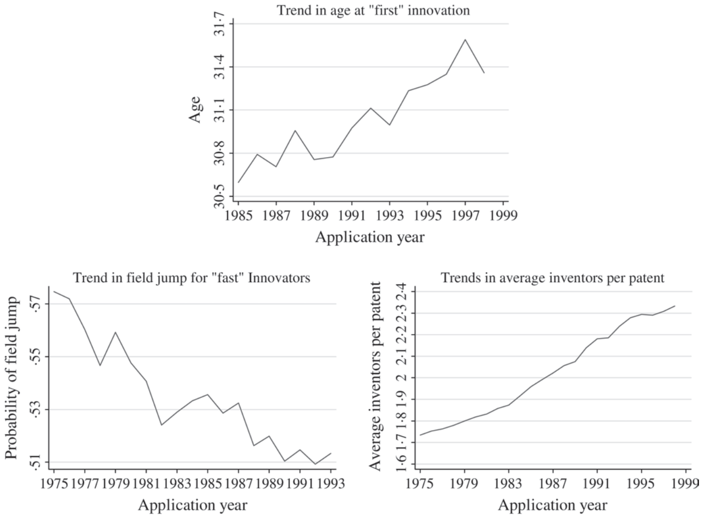


"…knowledge has become vastly more profound in every department of science. But the assimilative power of the human intellect is and remains strictly limited. Hence it was inevitable that the activity of the individual investigator should be confined to a smaller and smaller section…"

-- Albert Einstein (1932)

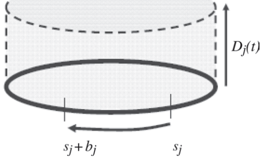
The Burden of Knowledge: Some Evidence

- ❖ 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 by *s* 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

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

Cumulativeness and the Burden of Knowledge: Microeconomic Dimensions

- If knowledge accumulates as science advances, then training decisions naturally shift

(1) Extend training

Innovations less common at young ages

Life-Cycle Changes

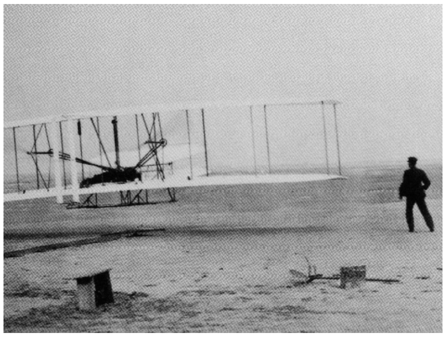
(2) Choose narrower expertise

Innovators increasingly work in teams

Organizational Changes

(Two dimensions of response)

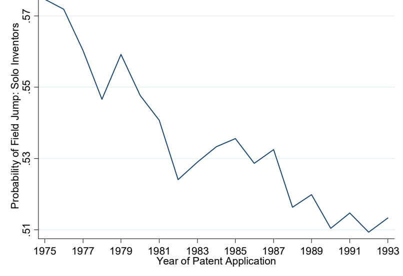
Collaboration



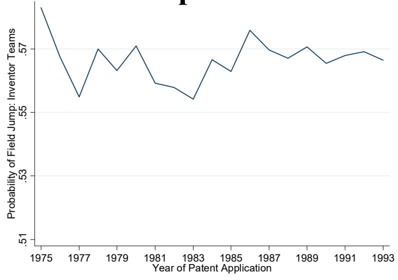
Specialization & Collaboration

❖ Do you switch fields between consecutive patents? (Jones 2011)

Solo inventor



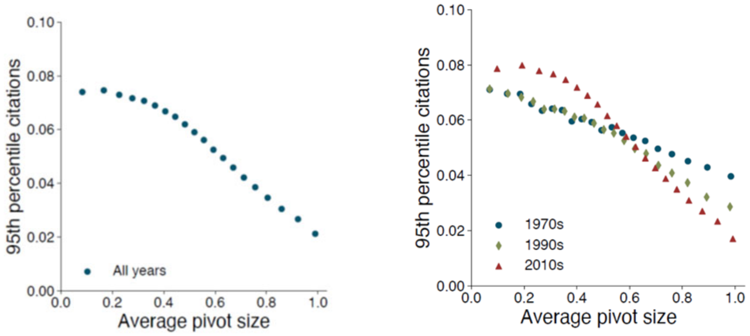
Multiple inventors



- Solo inventors appear increasingly narrow
- Teamwork is associated with sustained breadth

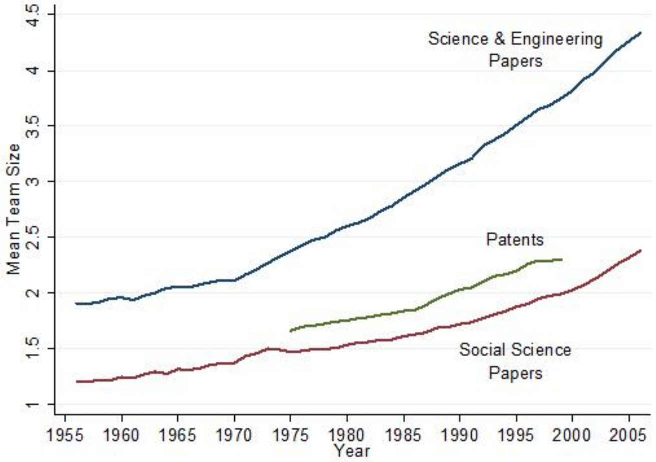
Specialization & the Pivot Penalty

❖ Measure “pivot size” as how far you move in a given paper or patent from your recent work (Hill et al. 2022)



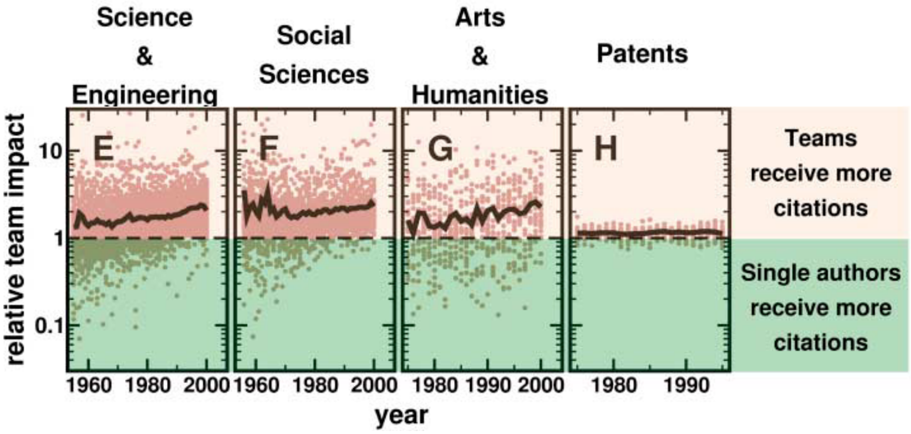
- Find that work has lower impact the further you pivot.
- And this pivot penalty is getting steeper with time.

The Ubiquitous Rise in Teamwork



Data: Web of Science, 19 million articles (Wuchty et al. 2007)

The Rising Team Impact Advantage



Data: Web of Science, 19 million articles (Wuchty et al. 2007)

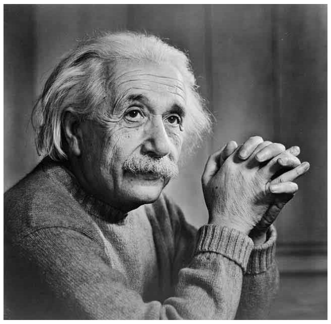
The Team Advantage Today

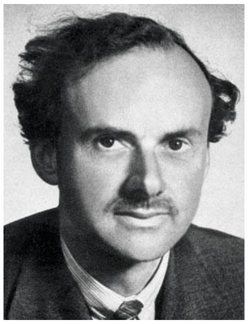
	Mean Citations Received			Probability > 100 citations		
	Team	Solo	Team/Solo	Team	Solo	Team/Solo
Science and Engineering	11.95	4.55	2.63	1.21%	0.28%	4.25
Social Sciences	8.74	3.31	2.64	0.59%	0.13%	4.57
Patents	6.66	5.64	1.18	0.025%	0.015%	1.65

- Teams have a large and increasing advantage in producing the highest impact ideas

When in life is one most innovative?

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:

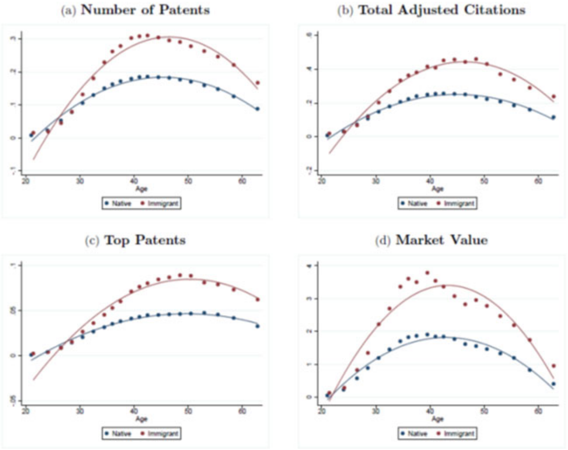
1) Deductive reasoning (e.g., Galenson and Weinberg 2005)
2) Transformative thinking (e.g., Planck 1949, Weinberg 2007)
3) Energy / Time (e.g. Jones et al. 2014)

…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.)

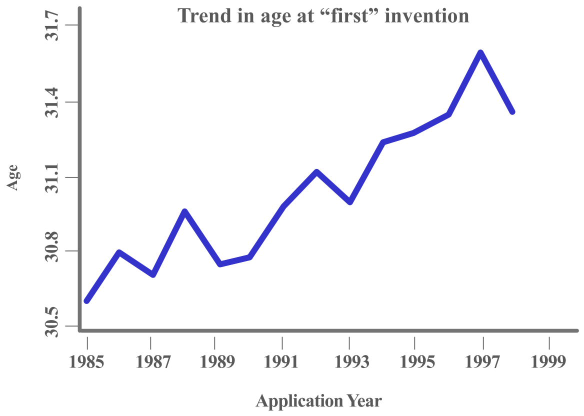
Science, Invention, and the Life-Cycle Peak

❖ Bernstein et al. (2019): U.S. patent data, virtually all U.S. inventors



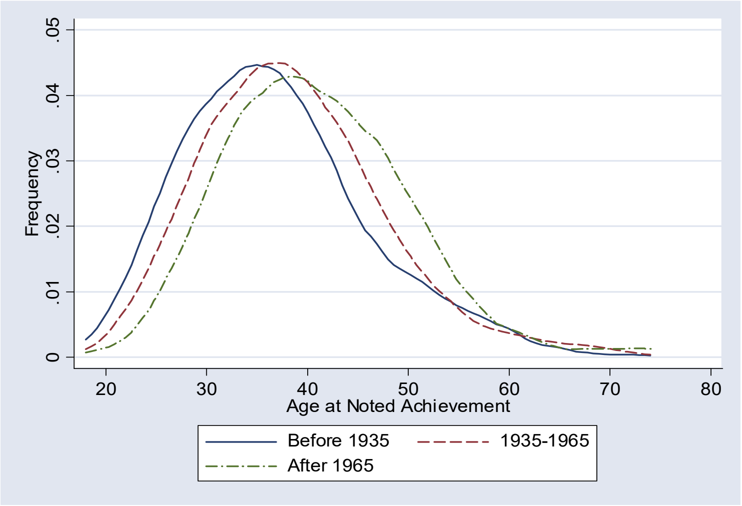
❖ Jones, Reedy, Weinberg (2015): Review literature on scientists. *Middle age peak is a universal finding*.

But Dynamic in Age



- Age at first patent is going up (Source: Jones 2009)
- Return to cumulativeness in understanding life-cycle creativity

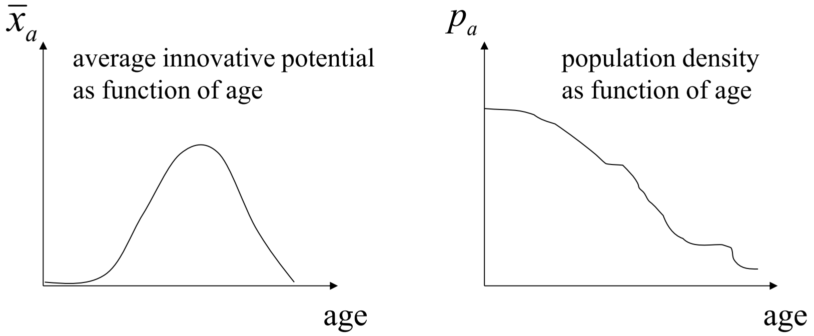
The Shifting Life Cycle Peak



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

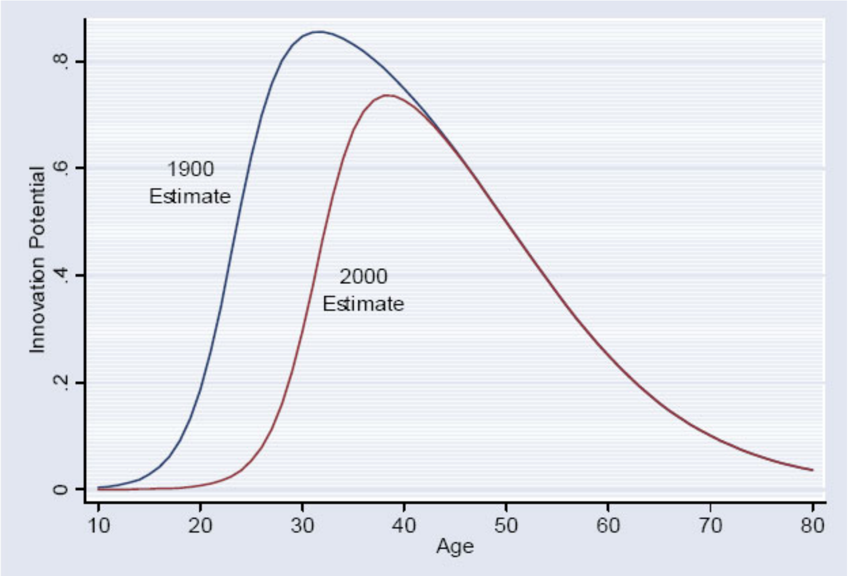
The Shifting Age Distribution of Great Invention

- ❖ Why this aging pattern?
  - ❖ Hypothesis #1: Shift in life cycle productivity
  - ❖ Hypothesis #2: Aging population

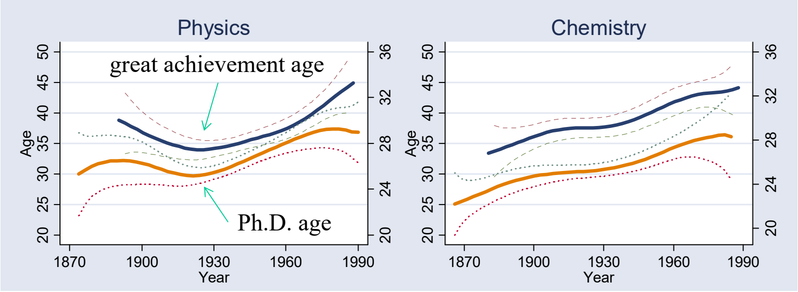


- ❖ If there is a shift in life-cycle productivity? If so, does it come early in life-cycle, late in life-cycle, or both?

Age: Estimated Shift in Innovation Potential



The Physics Experiment

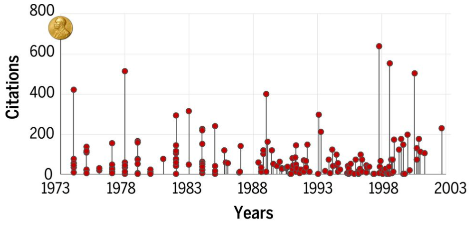


- Early 20th century physics experienced the quantum mechanics revolution, a broad shift in foundational knowledge
- The age at Ph.D. and great achievement in physics, and only in physics, fell during that time

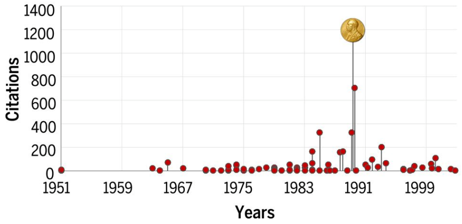
---

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)



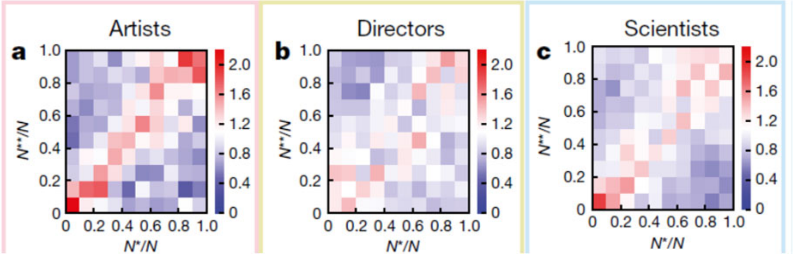
Wilczek
(Physics Nobel)



Fenn
(Chemistry Nobel)

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:
  - It appears that the quantity of your work bunches in middle age (middle age peak)
  - But the quality of your work peaks randomly in sequence of your work (random impact rule) and tends to bunch up (hot streaks)

END