Research to Innovation:
Future Directions for Systems and Control

2018 ACC Workshop

From Theory to Practice in Control: Enhancing Innovation and Impact

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Outline

Research to Innovation

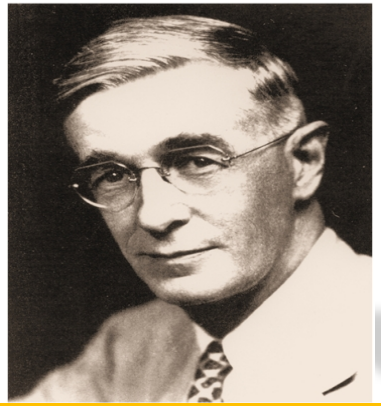
Recent Trends in Innovation

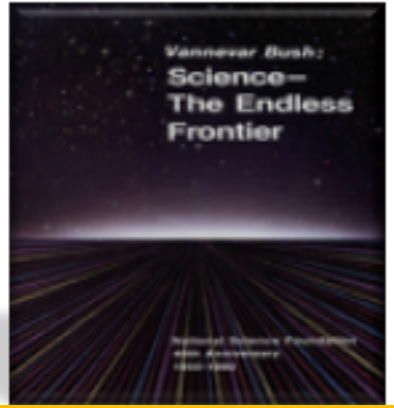
Implications for Future Directions in Systems and Control

Conclusions

Research to Innovation

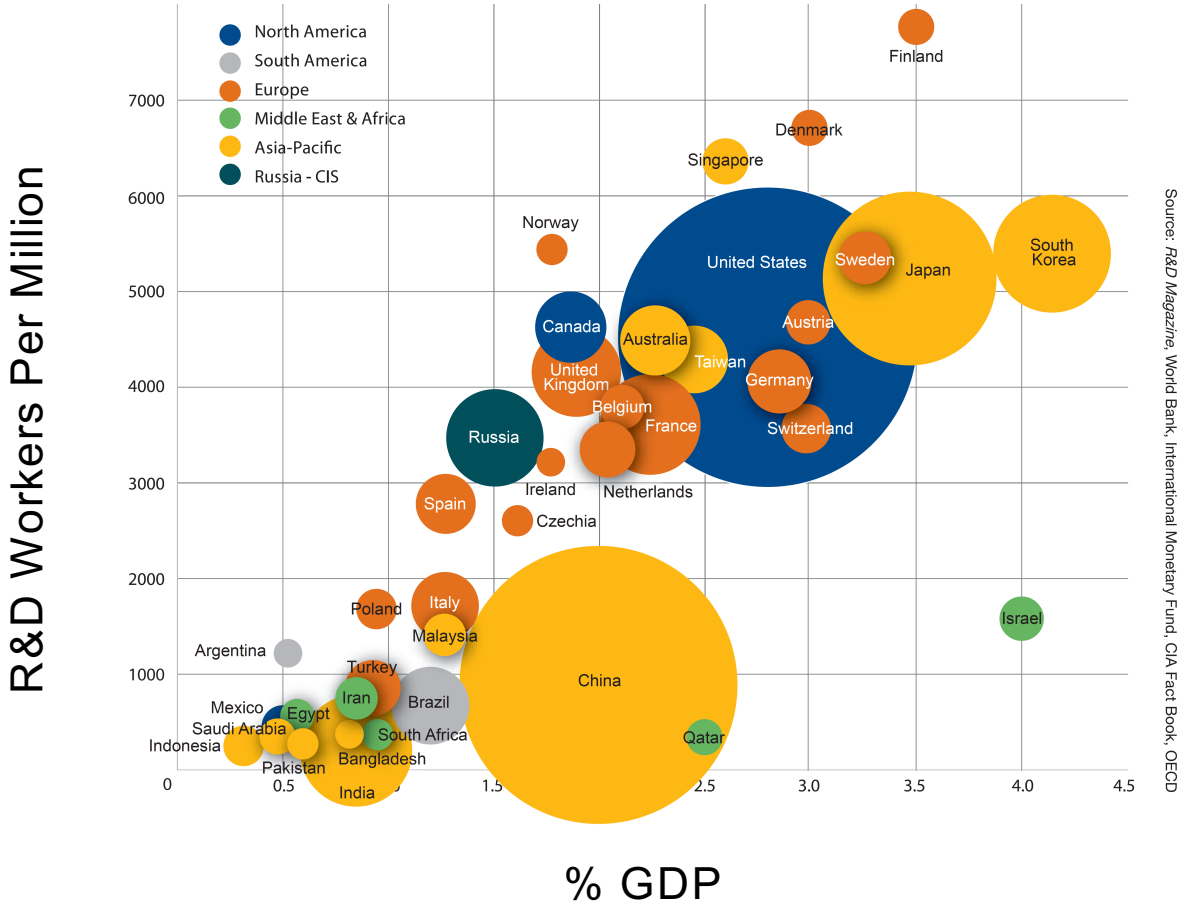
- New knowledge leads to societally useful innovations
- Tremendous acceleration after the industrial revolution
- Rise of science and engineering research ecosystem after the 2nd world war





Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress.

Global R&D Expenditures

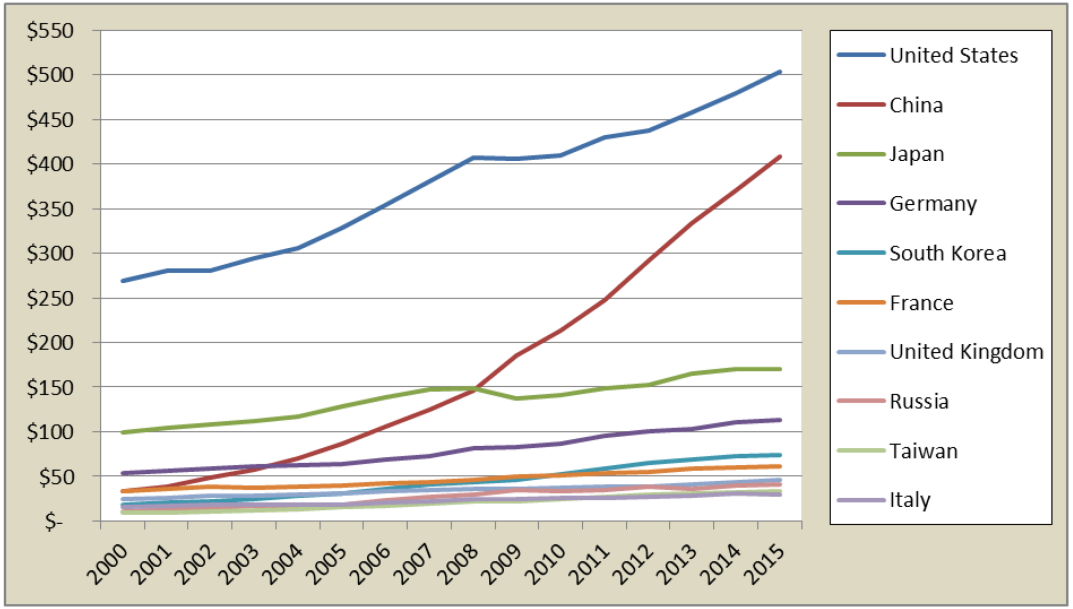


Source: R&D Magazine

Global R&D Expenditures

Figure 2. R&D Expenditures of Selected Countries, 2000-2015

(in billions of current PPP dollars)



Total R&D Expenditures in

2018 - $2.1T

(in PPP)

Source: CRS analysis of Organization for Economic Cooperation and Development, OECD.Stat database, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB.

Notes: PPP = Purchasing Power Parity. PPP is used to determine the relative value of different currencies and to adjust data from different countries to a common currency allowing direct comparisons among them.

How does Innovation Show up in Economic Data?

Landmark article on economic growth theory by the Nobel prize winning economist Robert Solow in 1956

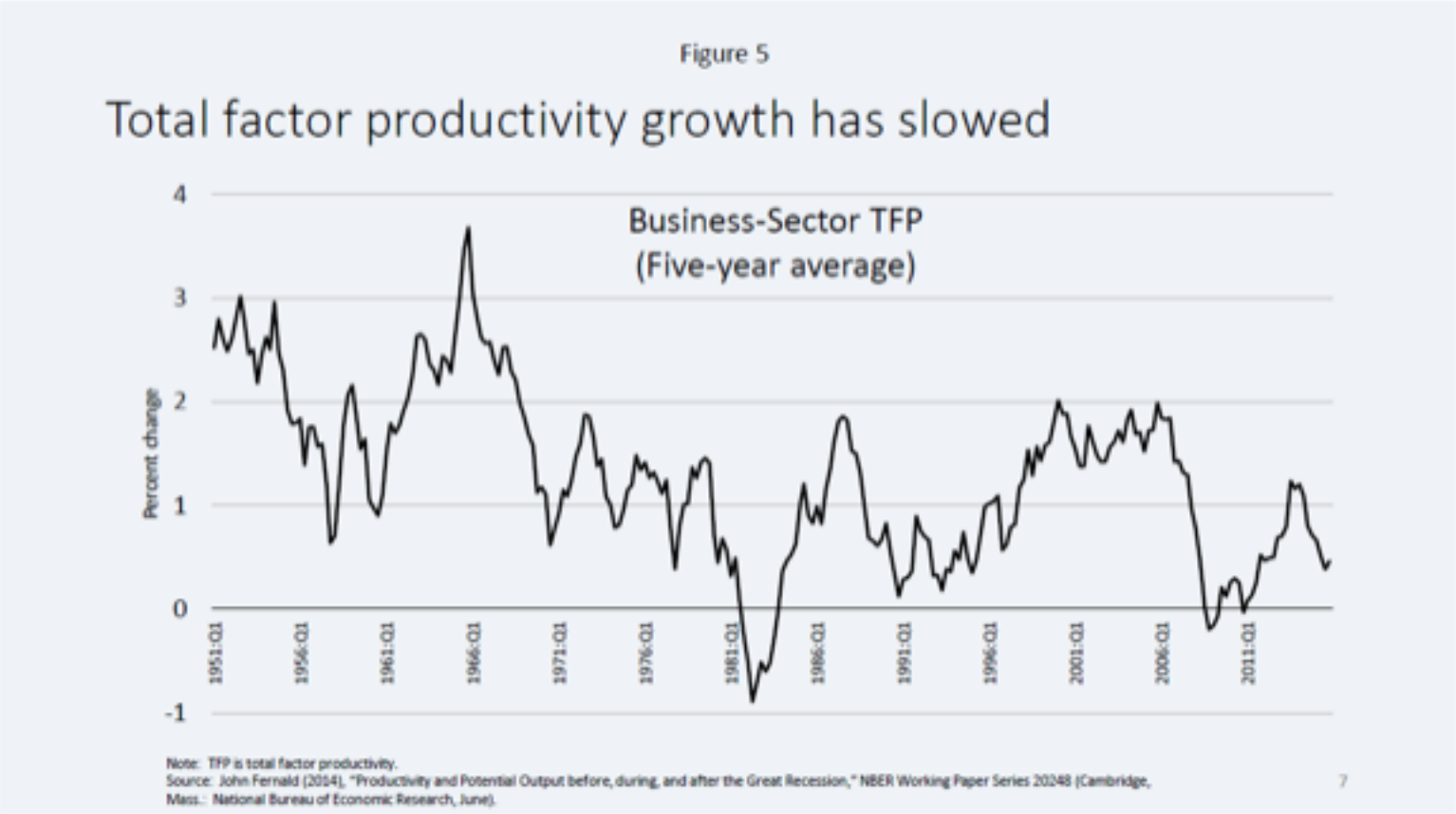
Total Factor Productivity: Portion of output not explained by inputs into the production process

Known as ***Solow residual***

TFP – Attributed to technological innovation

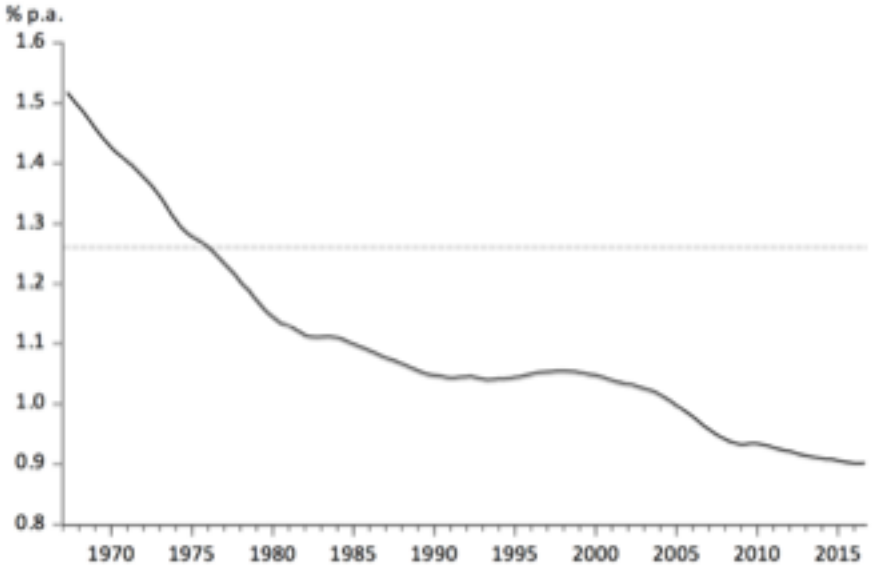
Literature on endogenous growth theory in economics

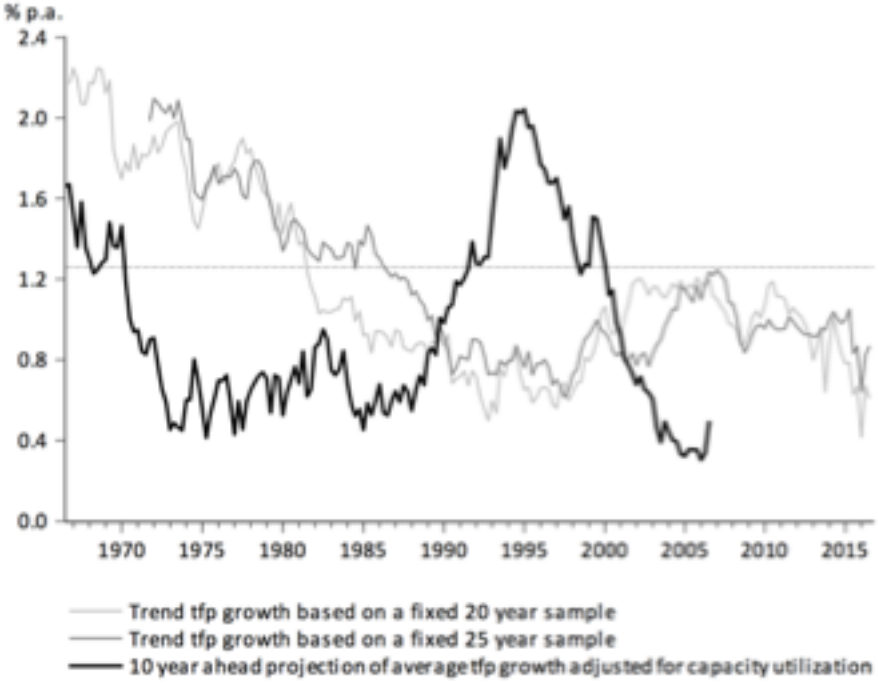
TFP Decreasing Trend



Source: Federal Reserve

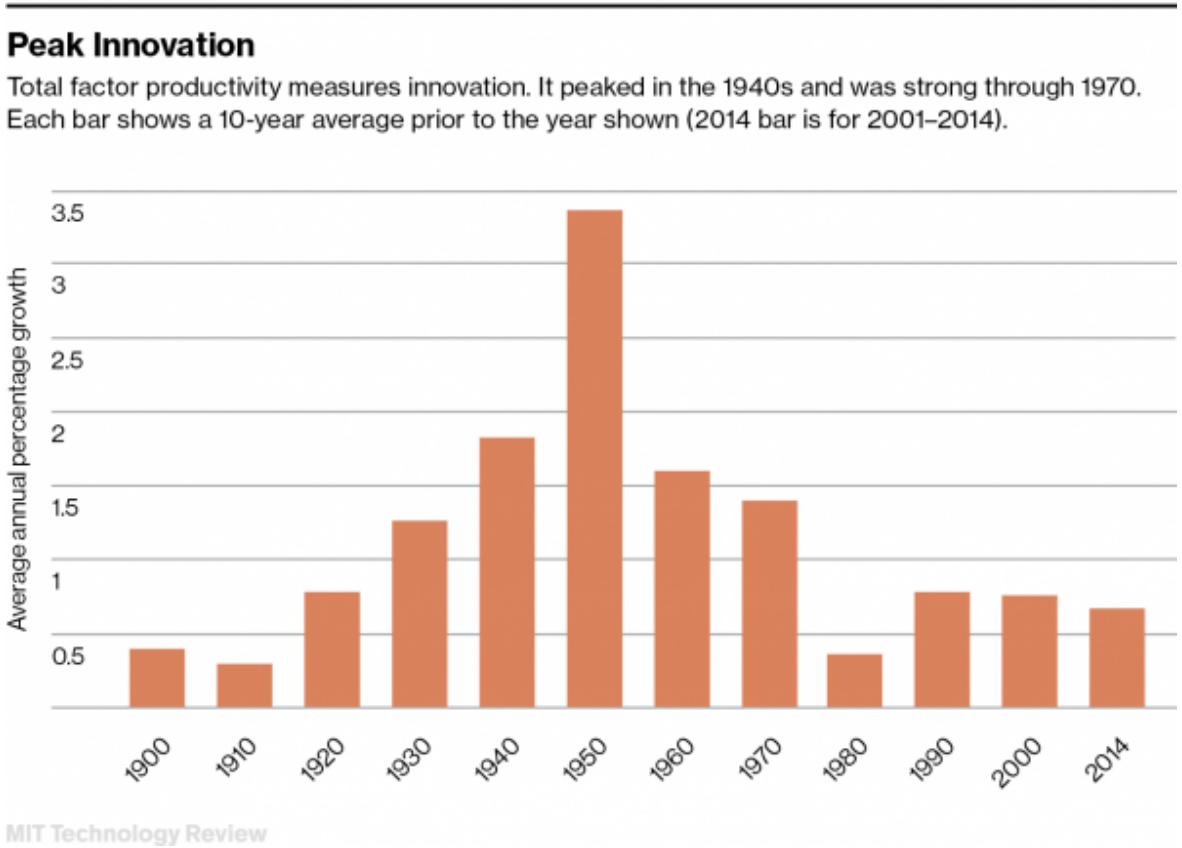
Smoothed TFP Trend





Craft and Mills, 2017

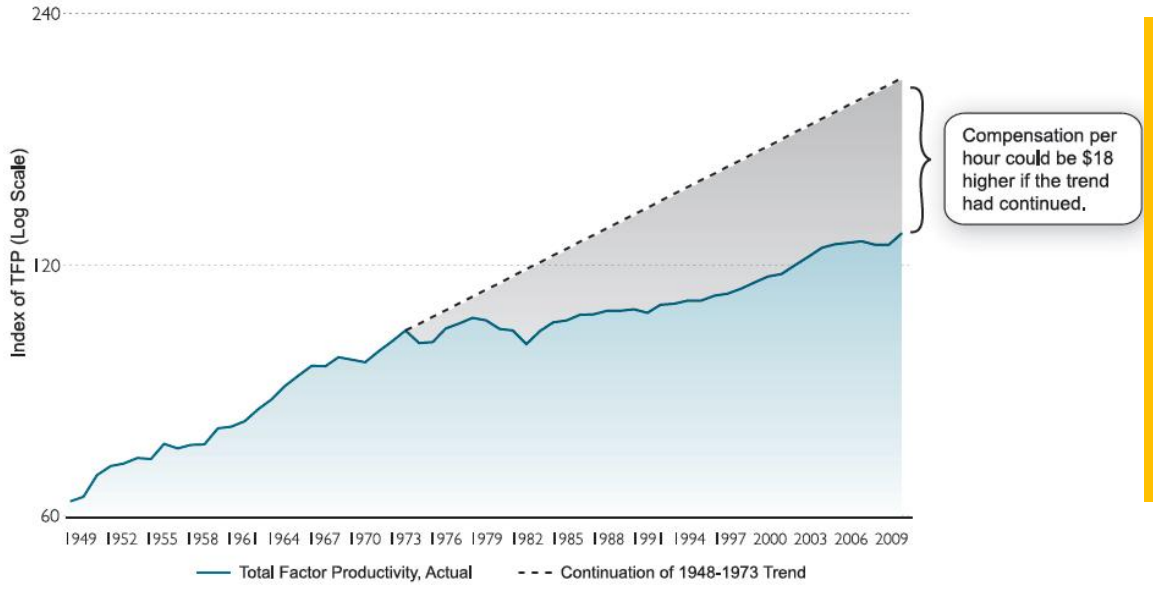
TFP by Decade



Source: MIT Technology Review

TFP Growth Slowdown has Material Impact

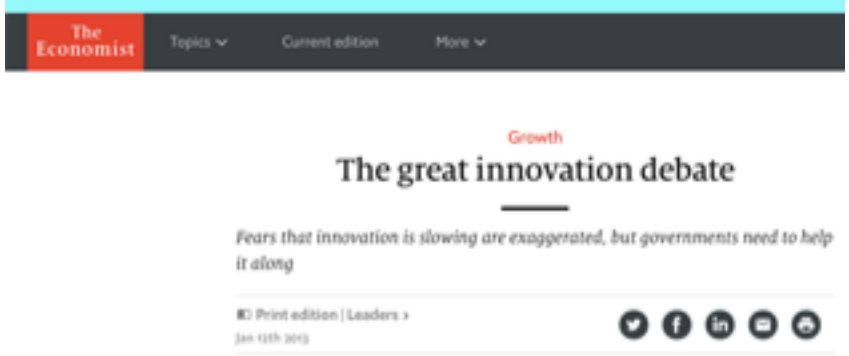
FIGURE 7.
Total Factor Productivity



Source: BLS and Hamilton Project Calculations.

"Productivity isn't everything, but, in the long run, it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker."

Paul Krugman



Divergence of opinions:

Camp A: Innovations of late 20th - early 21st century period are not as impactful as those in the mid 19th – early 20th century periods

Camp B: Best is yet to come --- it takes time for society to absorb new technologies

Camp C: There is a measurement problem and GDP is a flawed measure of progress

It is Getting Harder to Innovate

Figure 1: Aggregate Data on Growth and Research Effort

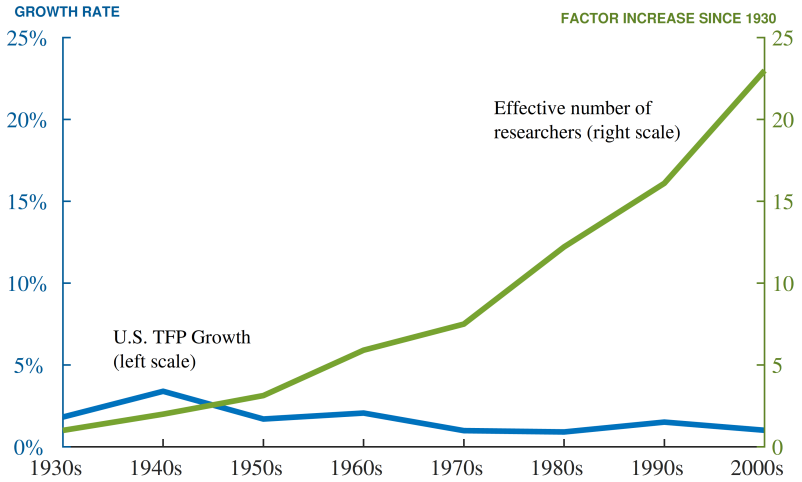
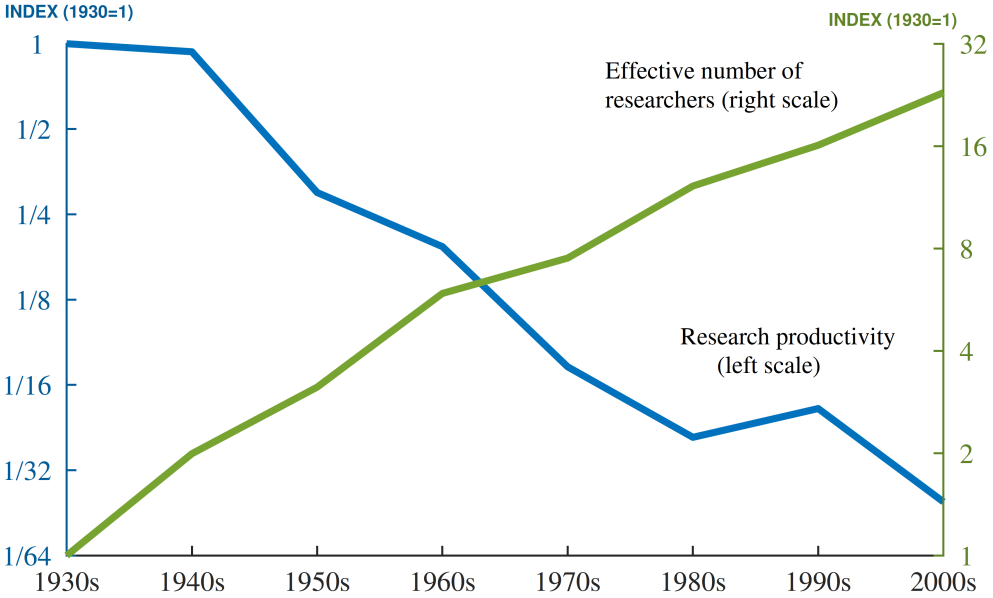


Figure 2: Aggregate Evidence on Research Productivity

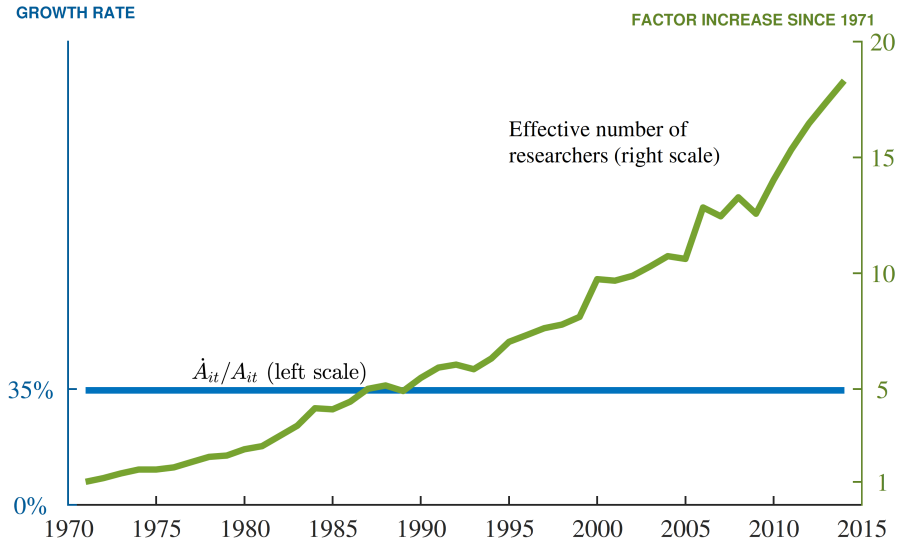


Note: Research productivity is the ratio of idea output, measured as TFP growth, to research effort. See notes to Figure 1 and the online data appendix. Both research productivity and research effort are normalized to the value of 1 in the 1930s.

Source: Are Ideas Getting Harder to Come by, Bloom et al, 2017

Case of Semiconductor Technology

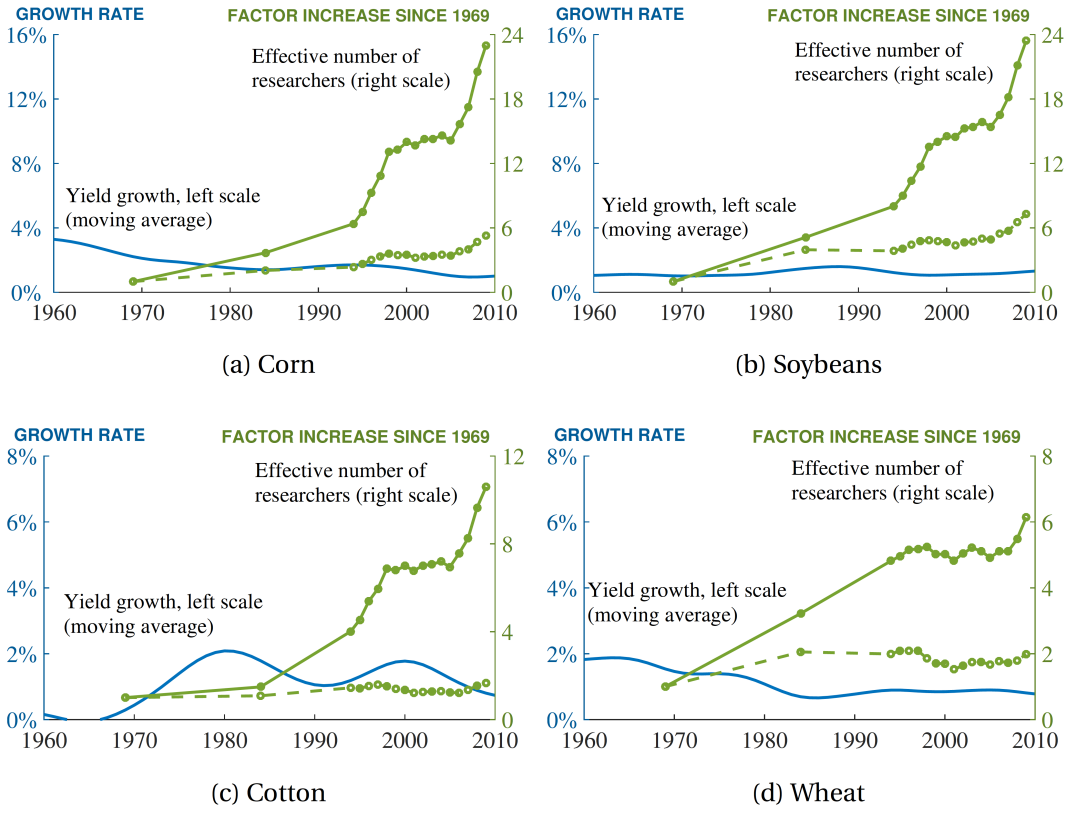
Figure 4: Data on Moore's Law



Note: The effective number of researchers is measured by deflating the nominal semiconductor R&D expenditures of key firms by the average wage of high-skilled workers. The R&D data includes research by Intel, Fairchild, National Semiconductor, Texas Instruments, Motorola, and more than two dozen other semiconductor firms and equipment manufacturers; see Table 1 for more details.

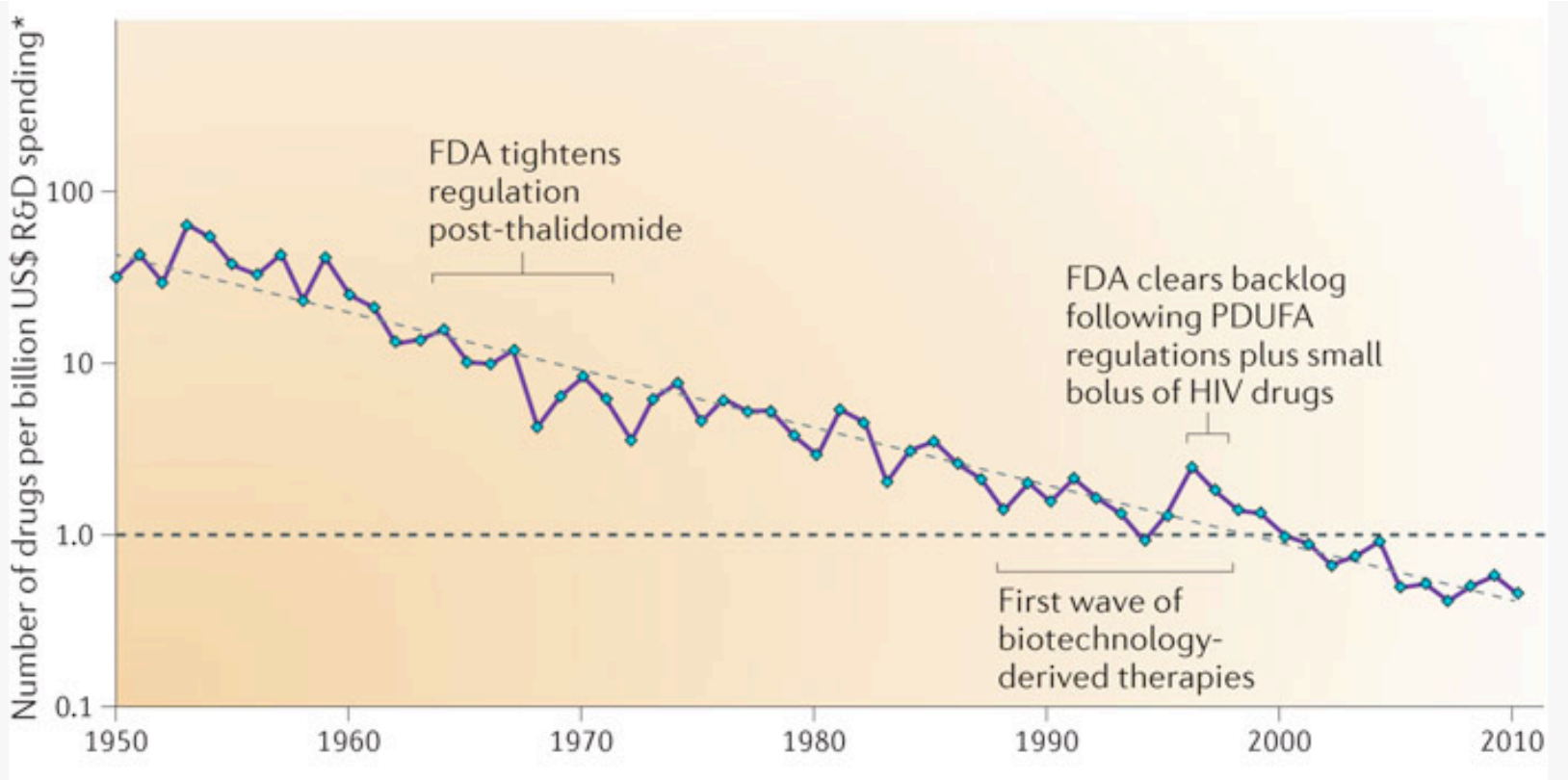
Source: Are Ideas Getting Harder to Come by, Bloom et al, 2017

Case of Agriculture Crops



Source: Are Ideas Getting Harder to Come by, Bloom et al, 2017

EROOM's Law



Scannell et al, Nature Reviews Drug Discovery, 2012

Need for Innovation has Never Been Greater

NAE Grand Challenges

GRAND CHALLENGES FOR ENGINEERING


Make solar energy economical


Provide energy from fusion


Develop carbon sequestration methods


Manage the nitrogen cycle


Provide access to clean water


Restore and improve urban infrastructure


Advance health informatics


Engineer better medicines


Reverse-engineer the brain


Prevent nuclear terror


Secure cyberspace


Enhance virtual reality


Advance personalized learning


Engineer the tools of scientific discovery

GRAND CHALLENGES FOR ENGINEERING

UK Industrial Strategy: the Grand Challenges

- Growing the Artificial Intelligence and data driven economy
- Clean growth
- Future of mobility
- Ageing society

https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges

EU Horizon 2020 Grand Challenges

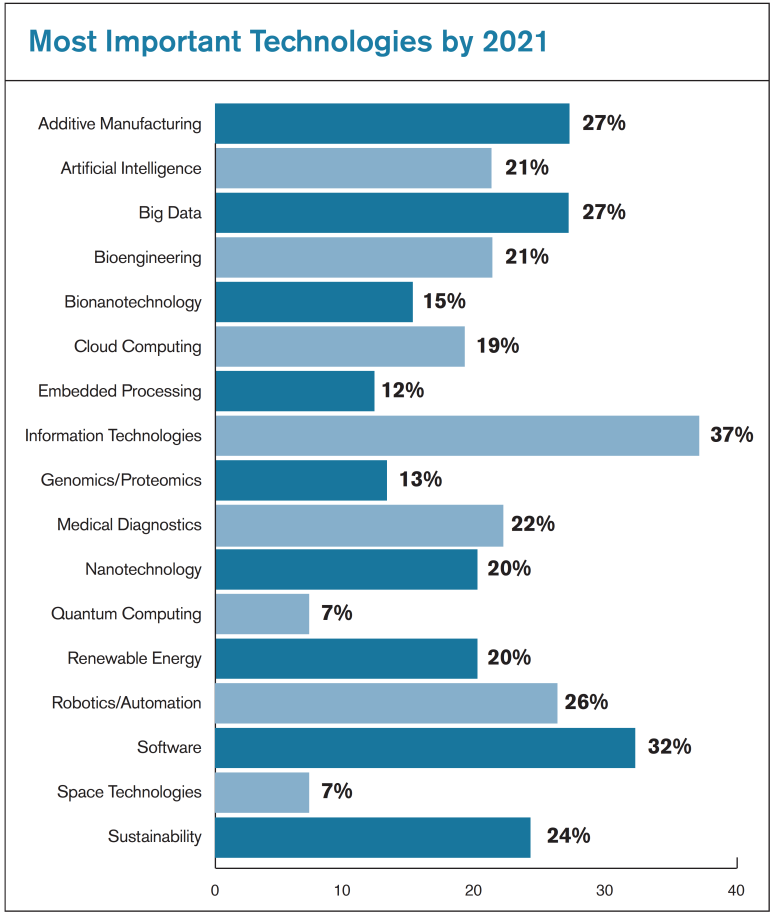
- Health, demographic change and wellbeing;
- Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy;
- Secure, clean and efficient energy;
- Smart, green and integrated transport;
- Climate action, environment, resource efficiency and raw materials;
- Europe in a changing world - inclusive, innovative and reflective societies;
- Secure societies - protecting freedom and security of Europe and its citizens.

https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

UN Sustainable Development Goals

Source: UN

And a Flood of New Technologies



Source: Global R&D Forecast

Recent Trends in Research to Innovation

Linear Model of Research to Innovation is Wrong

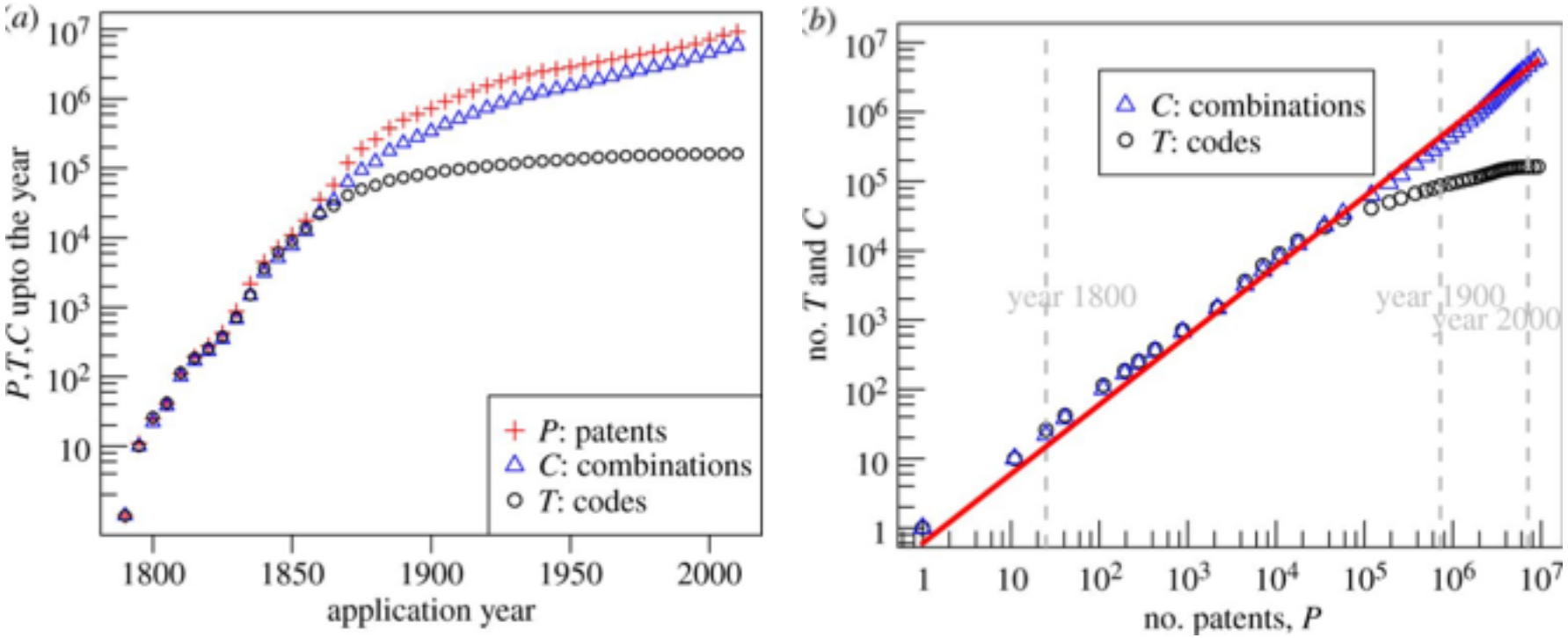
Linear model: discovery made – private sector productizes and commercializes

Reality: numerous, interconnected feedback loops and iterations between basic research, prototypes, development and commercialization

Misunderstanding of this interconnection causes major losses in efficiency and productivity

Historical examples go back to the industrial revolution era where the inventions preceded science, e. g., thermodynamics came after steam engines

Technology Innovations Increasingly have a Combinatorial Nature



Source: H. Youn et al, J. Royal Society Interface, 2015

Examples of Recent Successes

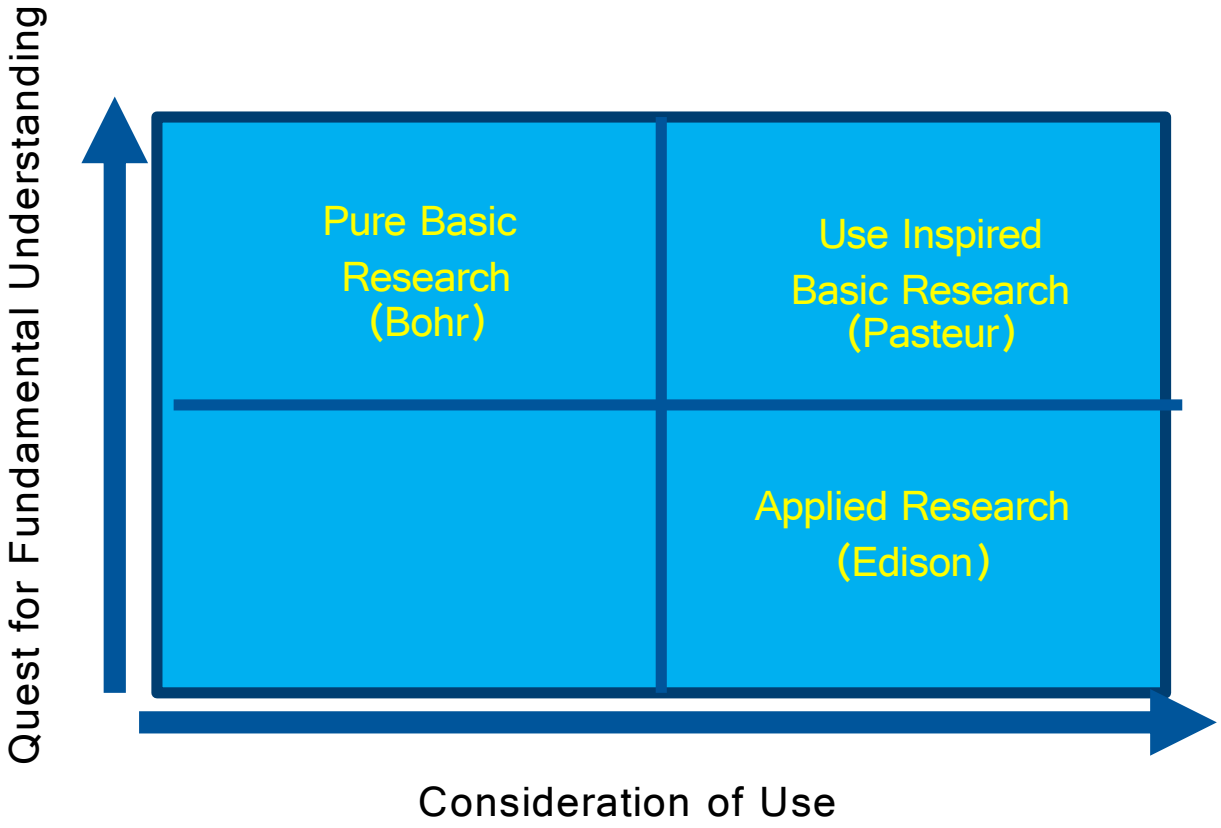
Magnetic Resonance Imaging (MRI)

Internet technologies

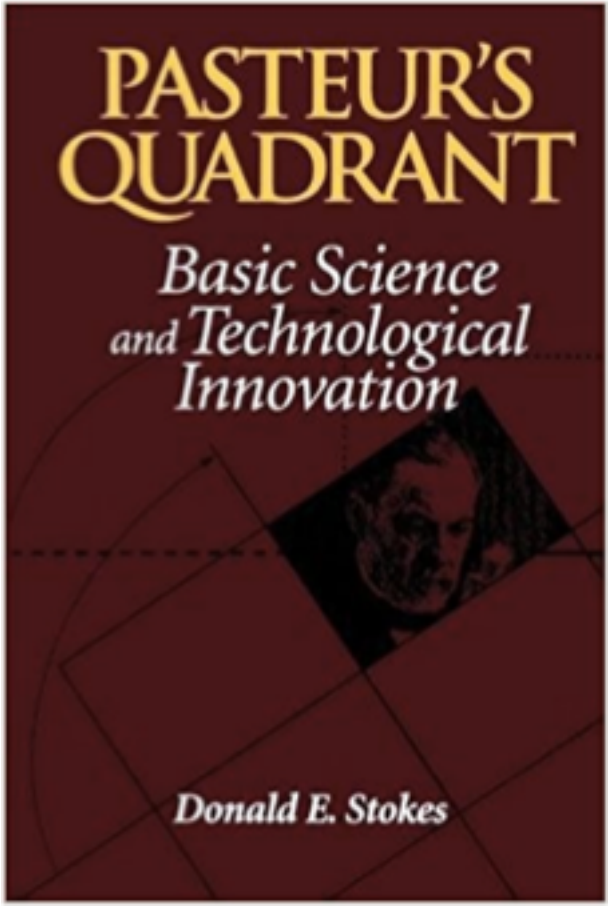
Solar Photovoltaics

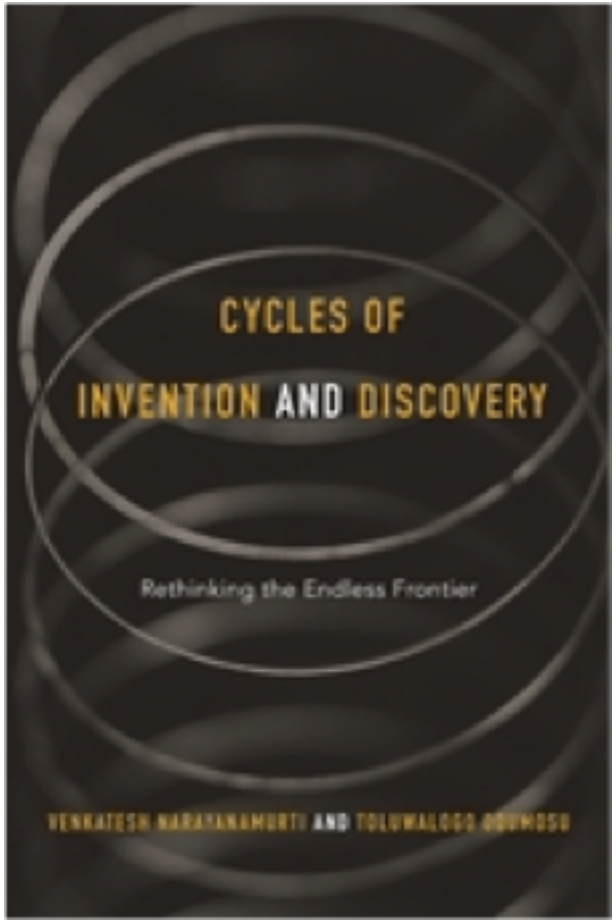
Laser surgery

Research: Pasteur's Quadrant



Source: D. Stokes, 1997


PASTEUR'S QUADRANT
Basic Science and Technological Innovation
Donald E. Stokes


CYCLES OF
INVENTION AND DISCOVERY
Rethinking the Endless Frontier
VENKATESH NARAYANAMURTI AND TOLUWALOGO ODUMOSU

GUIRR WORKSHOP

Highly Integrative Basic and Responsive Research (HIBAR): Partnerships for Discovery and Innovation

June 27, 1:30-5:10 pm

Washington, DC

Can we systematically accelerate the process of research driven innovation?

NSF Innovation Corps Program

Research advances

+

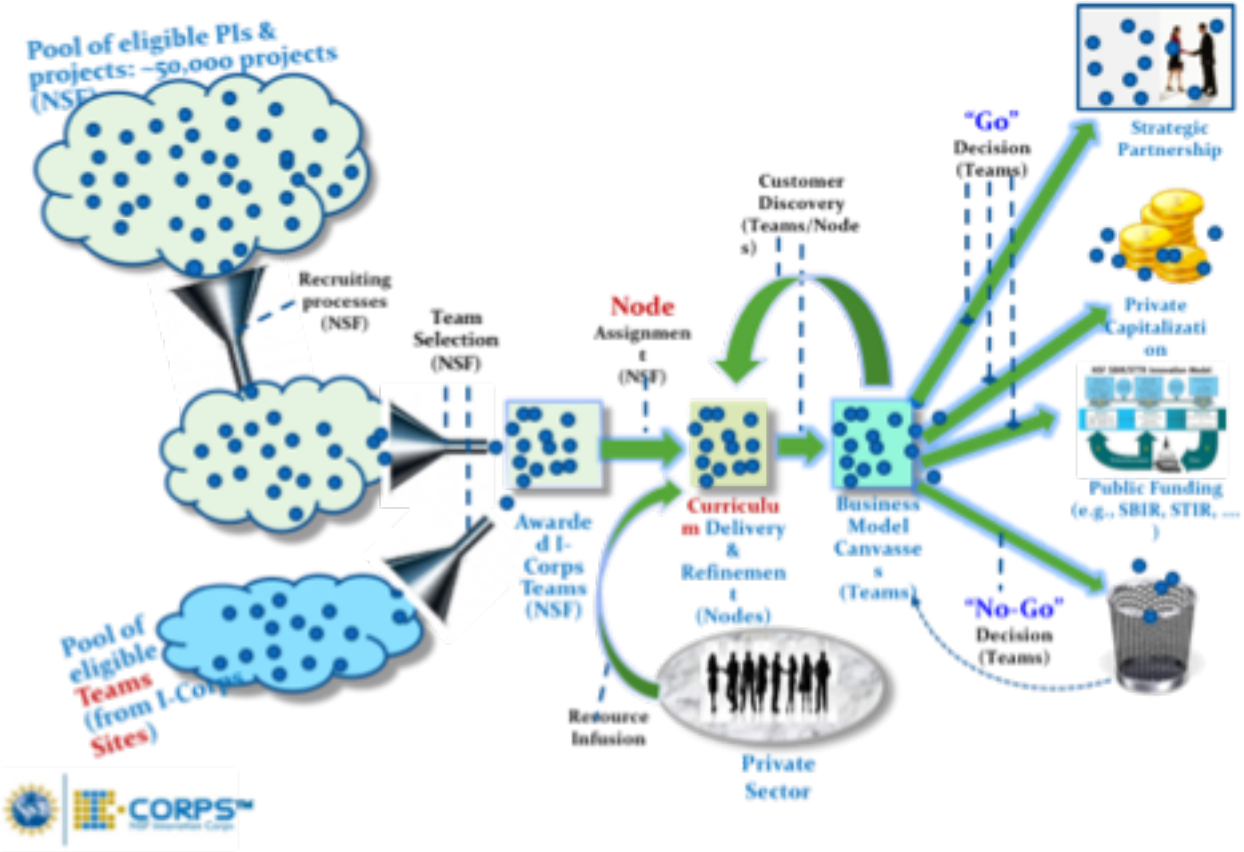
Lean startup principles

+

Experiential education for faculty and students

Heart of the program: 100 customer interviews

NSF Innovation Corps Program



Value Creation Best Practices: C. Carlson

Less than 10% of company and national R&D has substantial value for stakeholders

Value creation playbook by C. Carlson

NABC Framework – **Need**, Approach, Benefit/Costs, Competition

Technologies + market/societal need + key insight + multidisciplinary collaboration

Value creations forums – team feedback in an NABC framework

An **iterative** process to create an important innovation as against solving an interesting problem

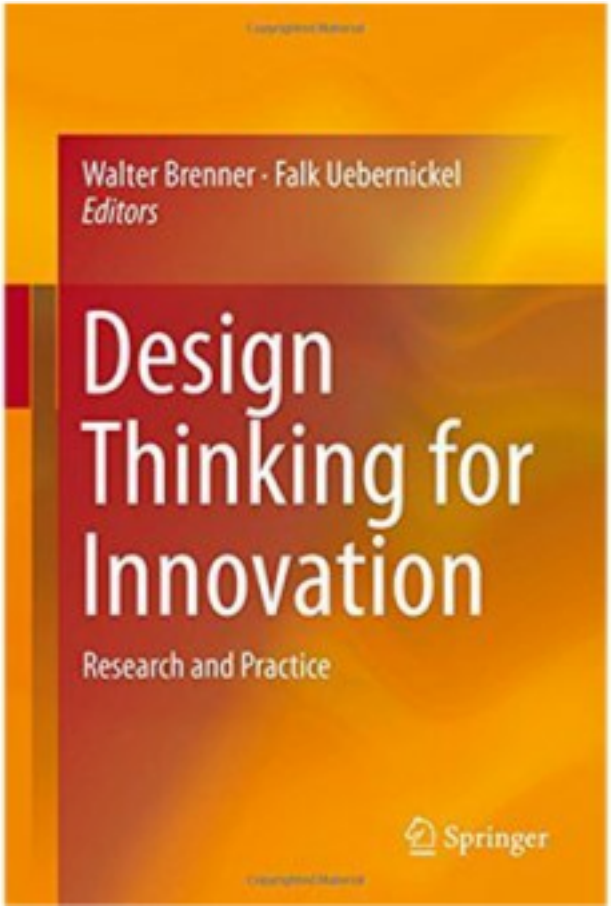
Design Thinking

Major trend in improving product/service design

Human centered innovation

Stanford D-School, IDEO

Potential for application to the research process



Implications for Future of Systems and Controls Research

Annual Reviews in Control 43 (2017) 1–64

Contents lists available at ScienceDirect

Annual Reviews in Control

journal homepage: www.elsevier.com/locate/arcontrol

Review article

Systems & Control for the future of humanity, research agenda: Current and future roles, impact and grand challenges

Francoise Lamnabhi-Lagarrigue[a,*], Anuradha Annaswamy[b], Sebastian Engell[c], Alf Isaksson[d], Pramod Khargonekar[e], Richard M. Murray[f], Henk Nijmeijer[g], Tariq Samad[h], Dawn Tilbury[i], Paul Van den Hof[j]

Emerging and Aspirational Visions

Smart-X

- Smart manufacturing, Industry 4.0
- Smart grid, renewable energy, carbon capture and sequestratio
- Smart and connected vehicles, future of urban transportation
- Smart cities
- Smart and connected health

Healthy aging and wellness

Food-energy-water nexus

High quality personalized education

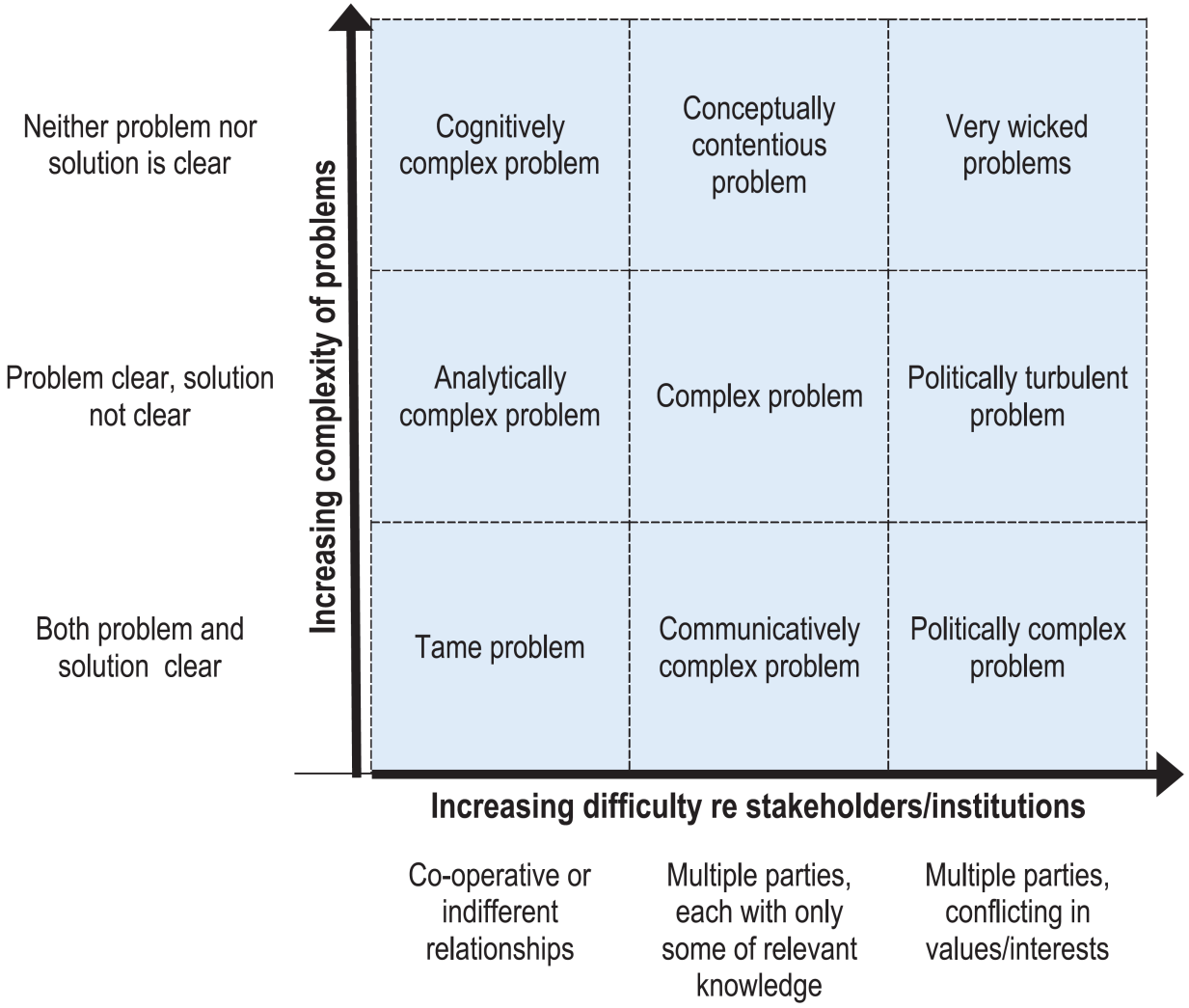
Grand Challenges are often Wicked Problems

Wicked problems … there is no clear stopping rule … working on it more … better solution … no single right answer … every attempt can matter because it affects the things people depend upon.

Rittel and Weber, 1973

Characteristics of Wicked Problems

- No definite formulation of a wicked problem.
- No stopping rules.
- Solutions are not true-or-false, but better or worse.
- No immediate and no ultimate test of a solution to a wicked problem.
- Do not have an enumerable (or an exhaustively describable) set of potential solutions
- Every wicked problem is essentially unique.
- Causes can be explained in numerous ways.



Alford and Head, 2017
Wicked and less wicked problems: a typology and a contingency framework
Policy and Society, 36:3, 397-413

Controls will need to be integrated with complementary disciplines and technologies

Information and communications technologies

Electronic, materials, and nanotechnologies

Biotechnologies: genetic, ohmic, synthetic, …

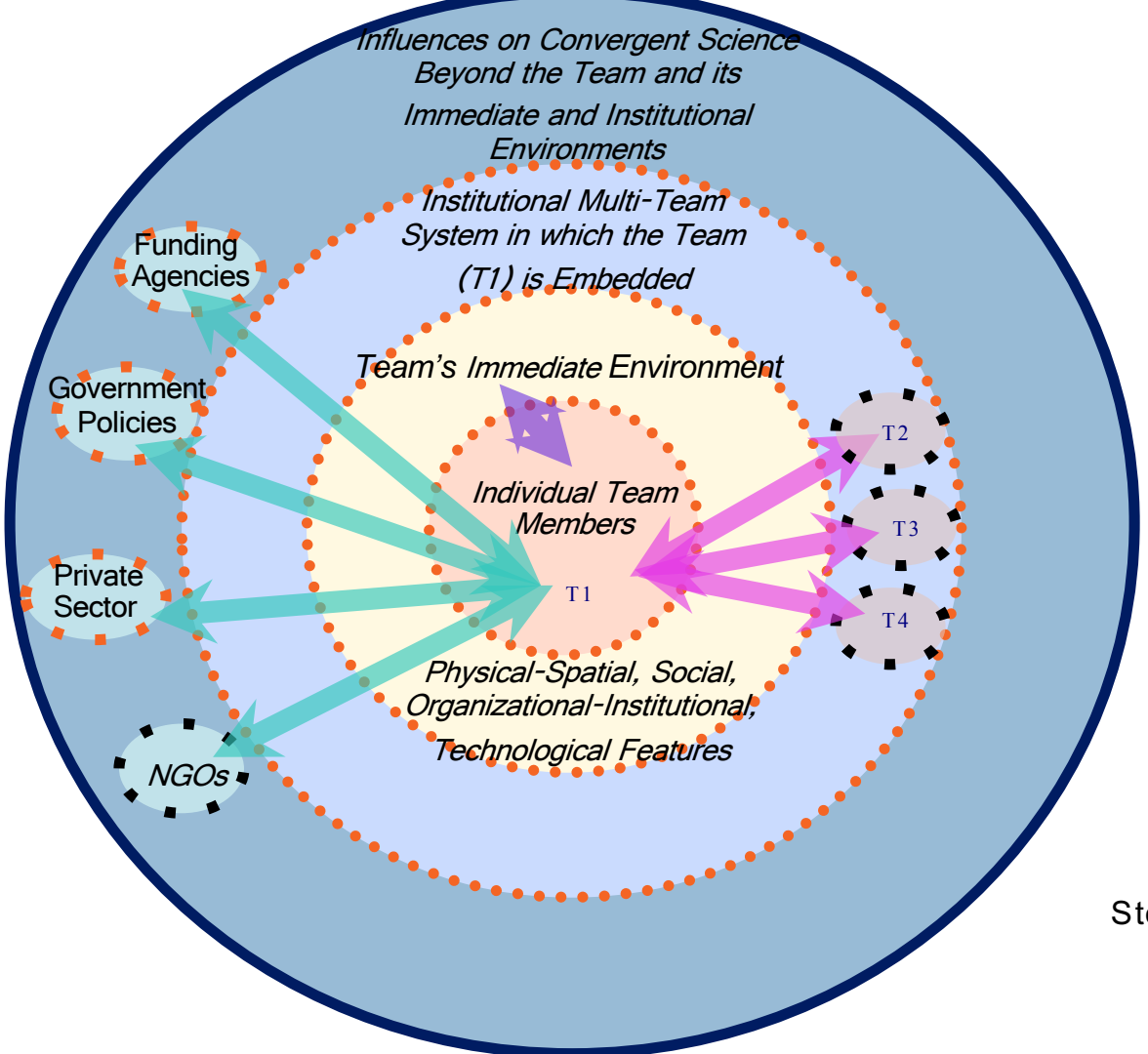
Social sciences, humanities, creative arts, …

Dimensions of Team Science

- Diversity of team members
- Disciplinary integration
- Team size
- Goal alignment
- Permeable boundaries
- Geographic proximity
- Task interdependence

a new interdisciplinary field . . . aims to better understand … team-based research and practice and to identify the unique outcomes of these approaches … (Stokols et al.)

Source: Enhancing Effectiveness of Team Science, NRC, 2015



Stokols, 2018

Improving Team Effectiveness

- Team processes
- Team composition
- Team professional development
- Leadership for team science
- Support for virtual collaboration
- Organizational support for team research

Source: Enhancing Effectiveness of Team Science, NRC, 2015

We will need to support and encourage a healthy and diverse ecosystem of systems and controls research

Balance internally driven deep disciplinary research against use-inspired transdisciplinary collaborative research

Create opportunities for robust cross-fertilization

Balance the values and culture of the field to be better positioned for collaboration with other disciplines and people

Take steps to reduce wasted efforts in research

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Comments

Ideas

Questions?

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