The Fundamental Question of Sustainability

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Scientific Optimism

Advances in science will…bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression.

–Vannevar Bush, *Science, the Endless Frontier* (1945)

Concepts of the Future I

"No society can escape the general limits of its resources, but no innovative society need accept Malthusian diminishing returns" (Barnett and Morse 1963: 139)

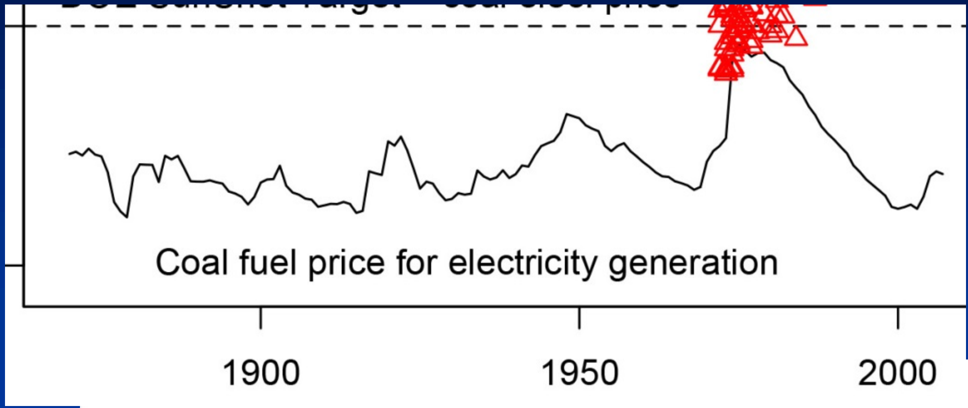
"By allocation of resources to R&D, we may deny the Malthusian hypothesis and prevent the conclusion of the doomsday models" (Sato and Suzawa 1983: 81)

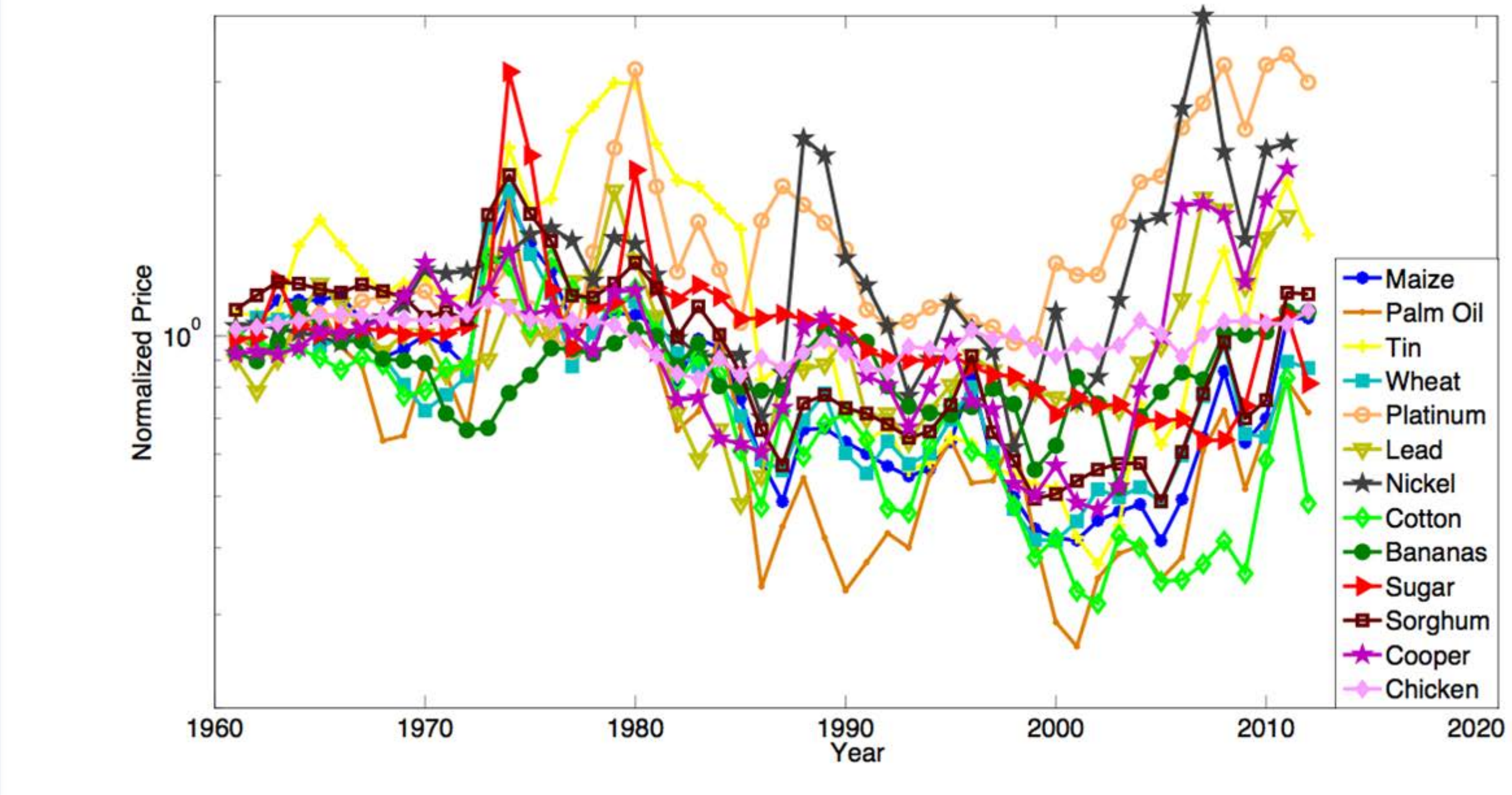
Concepts of the Future II

A modern societal collapse would be "triggered ultimately by scarcity of environmental resources"

—Jared Diamond, *Collapse*

Commodity Prices (Doyne Farmer)





Perspective of Some Economists

- Principle of Infinite Substitutability.
- Resources are never scarce, just priced wrong.
- As resources become scarce and rise in price, the market signals that there are rewards to innovation. New resources or technologies emerge.
- **Sustainability is therefore not an issue.**

The Fundamental Question of Sustainability

Will we always be able to offset resource depletion by innovation and increasing technological efficiency?

Objectives

- Explore the origins of our system of innovation, and why it is possible.
- Address how long it might continue.

Our Biases

- Since we live in a period of institutionalized innovation, we assume unconsciously that high-frequency innovation is normal.
- We have developed ideologies to legitimize our current way of life, exemplified in terms like "progress" and "opportunity."

Main Points

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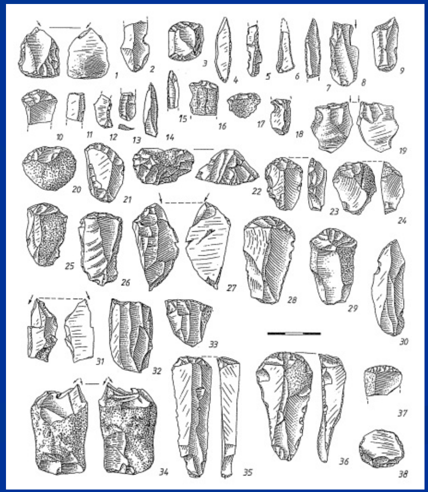
2. Today's institutionalized innovation is controlled by specific external conditions.
3. Our system of innovation is self-perpetuating under those conditions.
4. The continuity of today's system depends on the continuity of those conditions.

History <u>Not</u> Characterized by High Rates of Innovation

Innovation Frequency

- Human ancestors: 4 million years.
  - Periods of hundreds of thousands of years of little technological change.
- *Homo sapiens*: 200,000 years.
  - Periods of tens of thousands of years of little technological change.



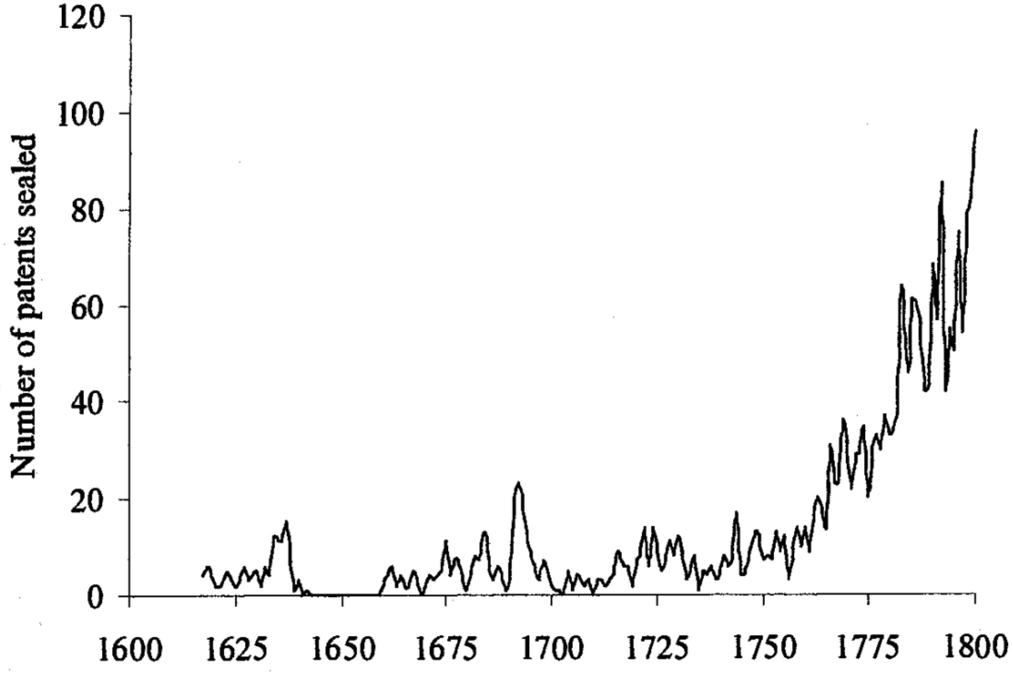
Recent History

Periods of hundreds to thousands of years with little technological change in many areas of life.

Why?

- 90% of subsistence economies involved production of energy, mainly agriculture. There was little wealth to support innovators, or for education.
  - Land transport costs high.
  - Peasants had little money to buy manufactured items.
    - Exception: Salient innovations in the military sphere.
- Innovation increases complexity. People had found technological solutions that worked.
- Under conditions of low population and much land, there was little need to innovate. Ancient states *encouraged* cultivation and population growth.

High-Frequency Innovation Recent
(chart by Roger Fouquet)



Source: MacLeod (1986)

Figure 8.6 The Number of Patents Granted, 1616–1800

Important Points

1. High-frequency innovation is **<u>not</u>** an innate characteristic of human societies.

2. Such an unusual characteristic can exist only in specific historical circumstances.

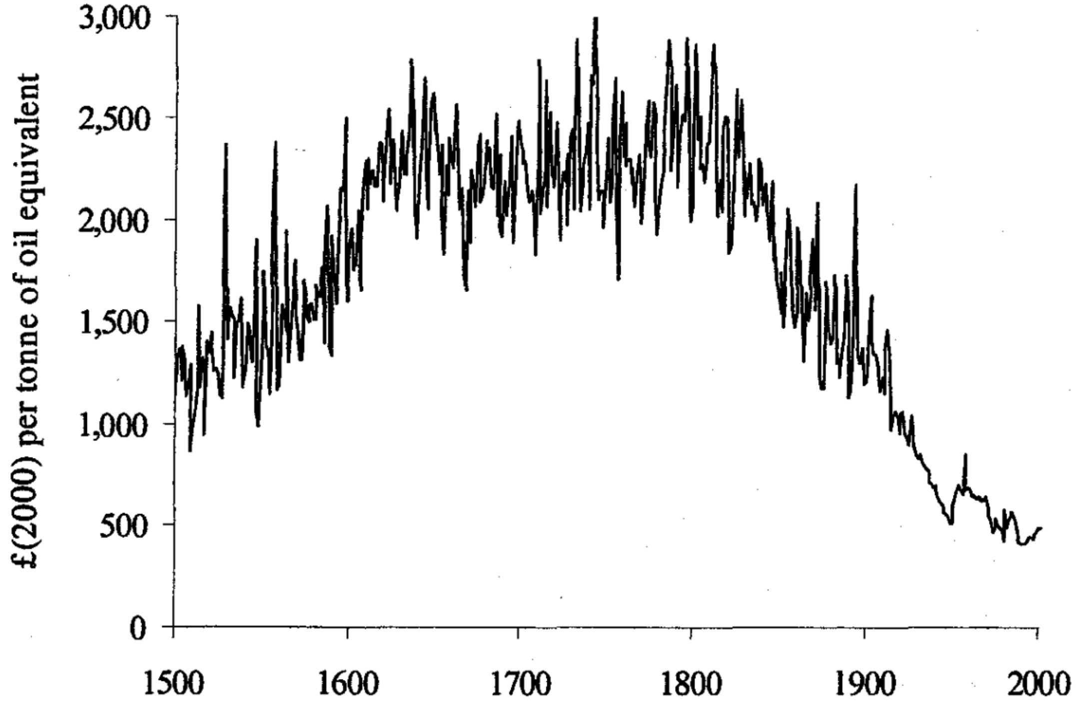
Specific Conditions of Innovation

1. Inexpensive energy, permitting high societal complexity and discretionary consumption.

2. Profit seeking.

3. Competition forcing continual innovation.

Inexpensive Energy
(chart by Roger Fouquet)

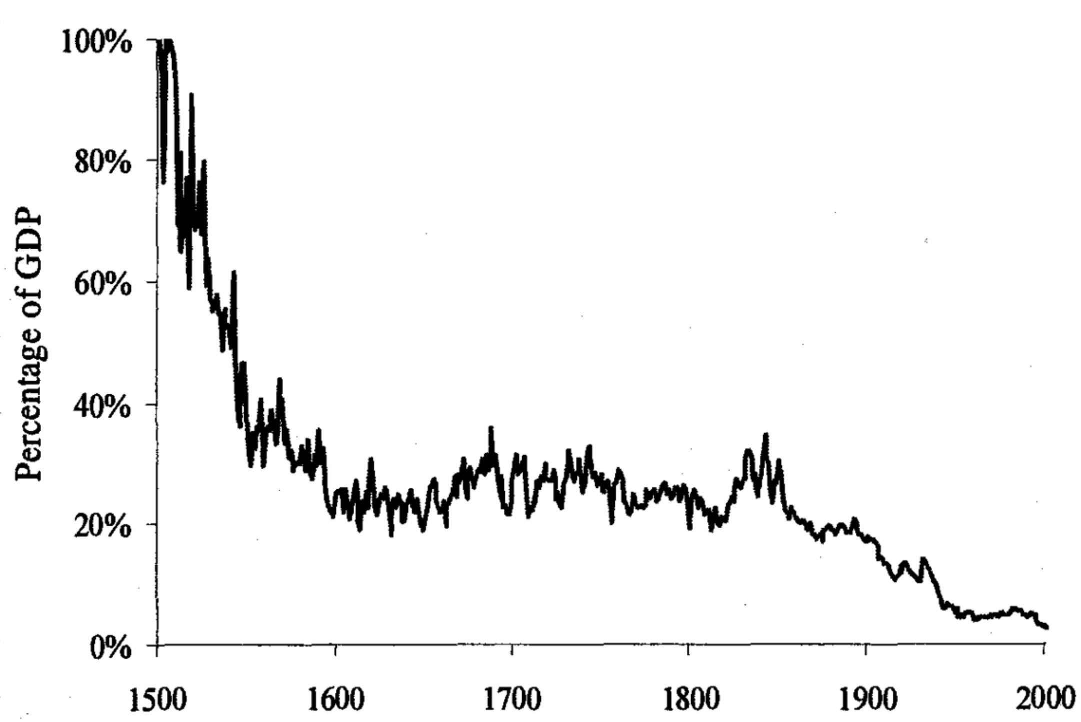


Source: see Chapters 4-7 and Data Appendix

Figure 8.4 The Average Price of Energy (£(2000) per toe), including Agricultural Products, 1500–2000

Energy a Smaller Part of Economy

(chart by Roger Fouquet)



Source: see Chapters 4-7 and Data Appendix

Figure 9.6 Non-Domestic Power Expenditure relative to Total GDP, Percentage, 1500–2000

4. System Self-Perpetuating

- Profit seeking unlikely to disappear.
- Competition spurs innovation.
- Increasing societal complexity and investment in innovation affordable with inexpensive energy.

Self-Perpetuating Forever?

Continuity of Our System of Innovation Requires:

1. Continued inexpensive energy—energy a small part of economy, allowing for discretionary spending and high complexity in our way of life.
2. Constant or increasing returns to innovation.

Energy Returned on Energy Invested

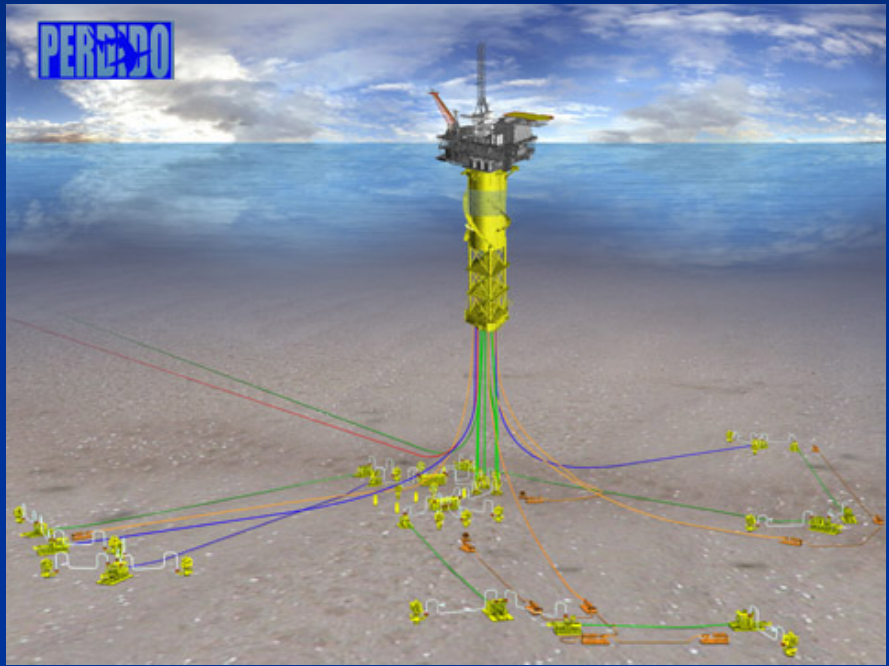
$$\text{EROI} = \frac{\text{kcal of fuel extracted}}{\text{kcal of direct and indirect energy required to locate, extract, and refine that fuel}}$$

(Hall, Cleveland, and Kaufmann 1992)

EROI is the key to our future energy.

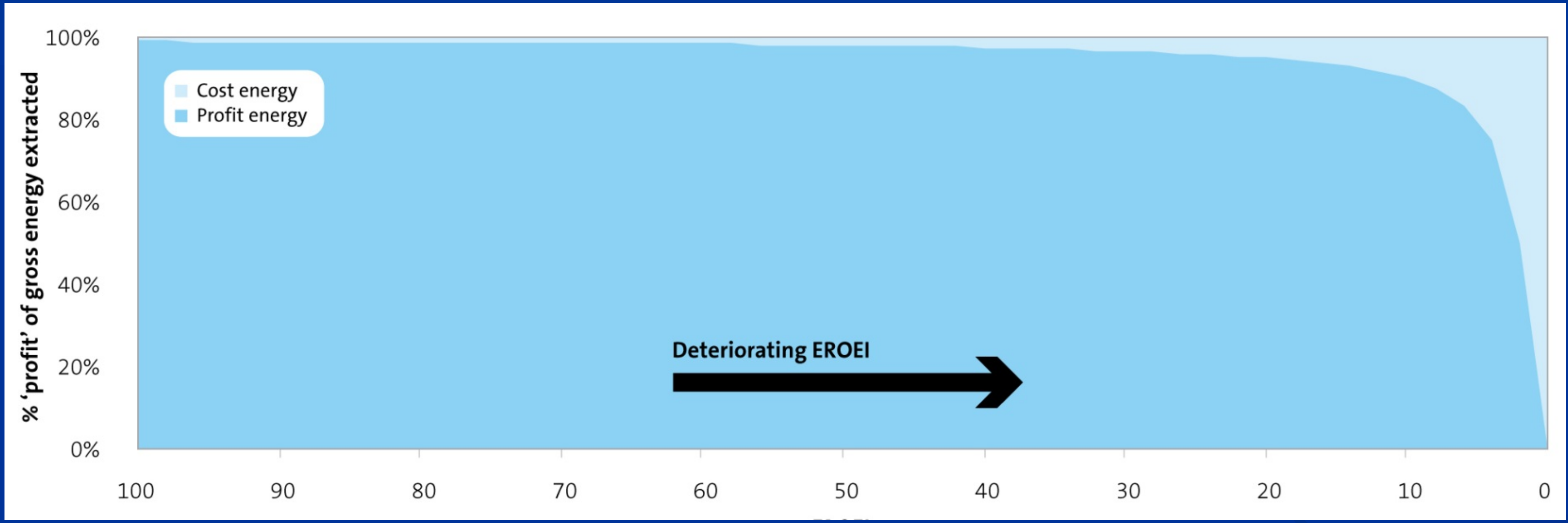
U.S. Petroleum: EROI

- Oil and Gas:
  - 1940s: 100:1
  - 1970s: 23:1
  - Today: 15:1
  - Tar Sands: 3:2



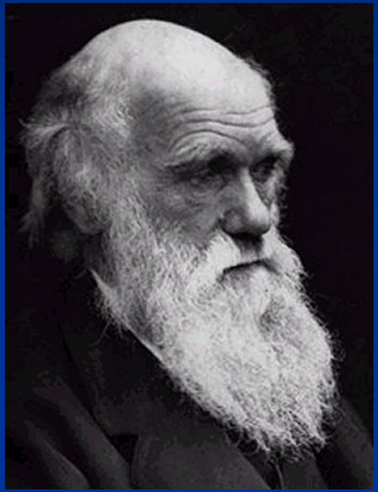
- As easiest reserves depleted, trend is irreversible.
- Low EROI petroleum requires complex and costly technology, and large amounts of capital.

The Energy Cliff

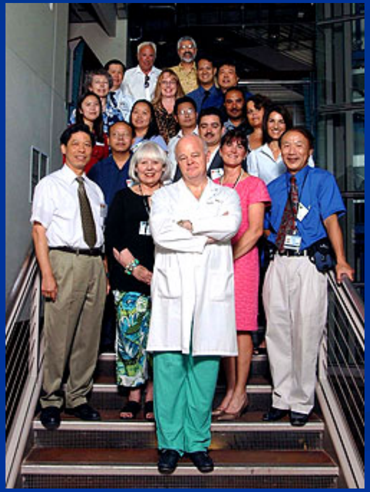


Evolution of Innovation

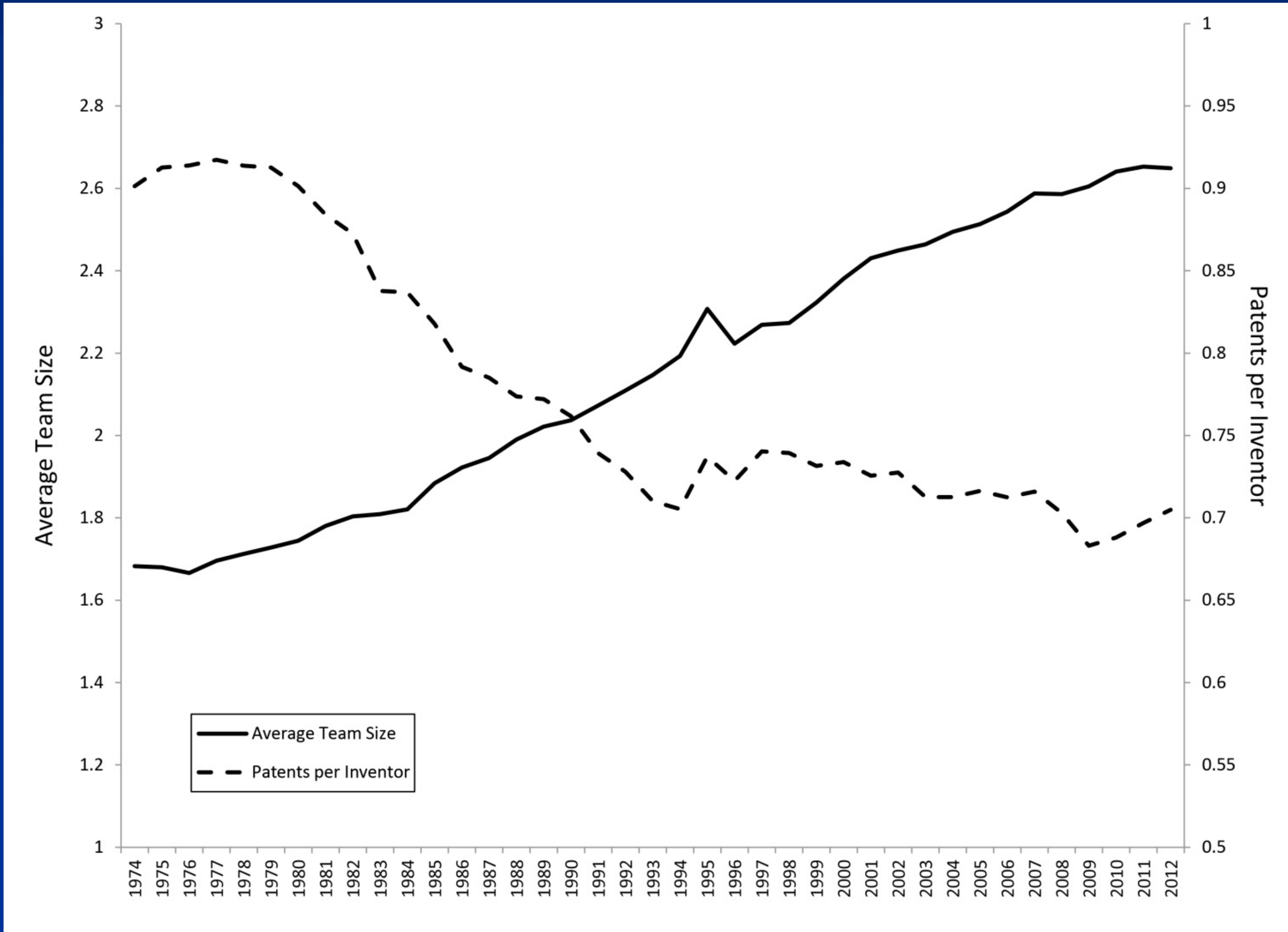
- From lone-wolf genius…



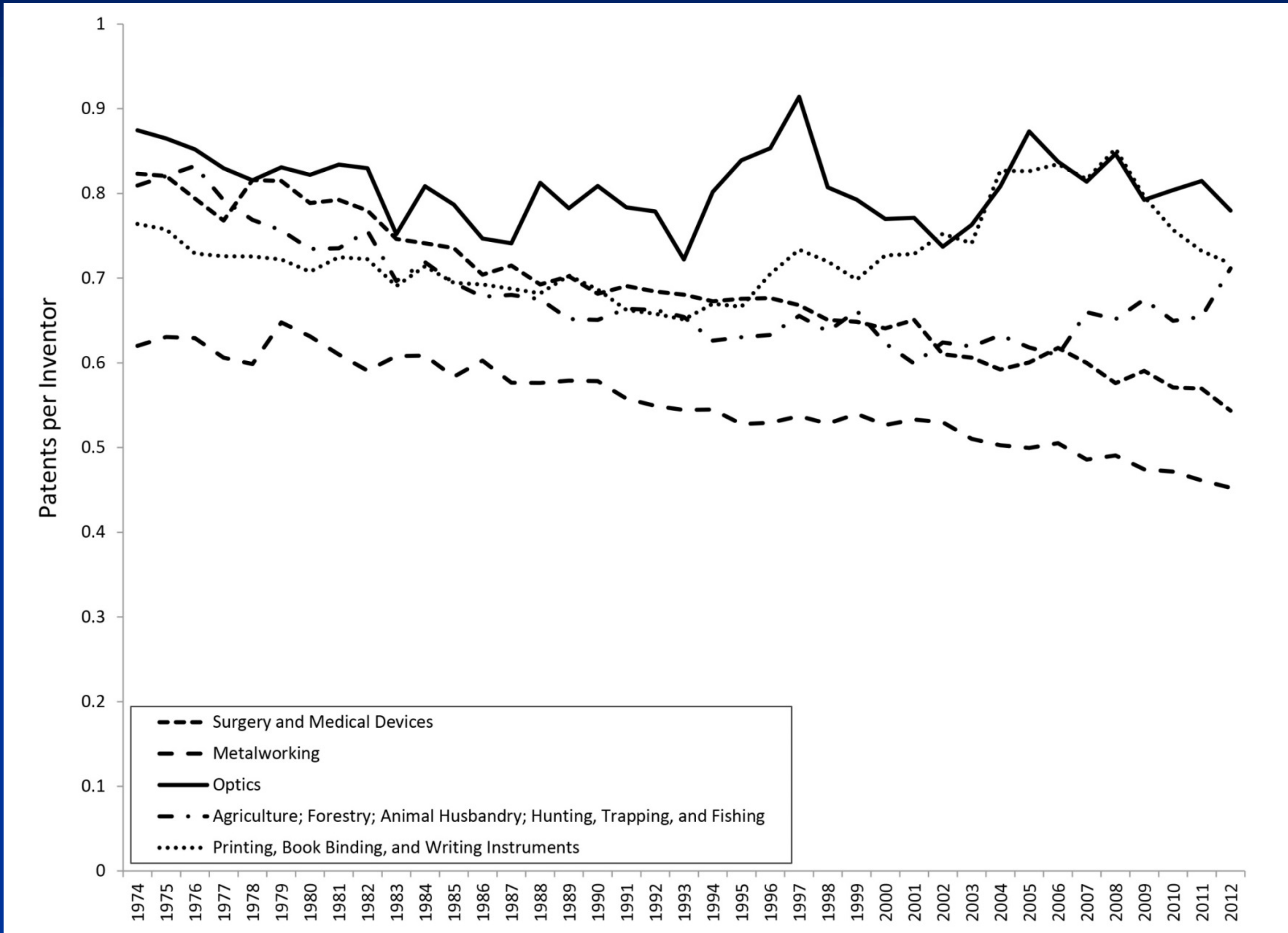
- to complex, interdisciplinary teams. (Google search on "research team" returned >61,000 images.)



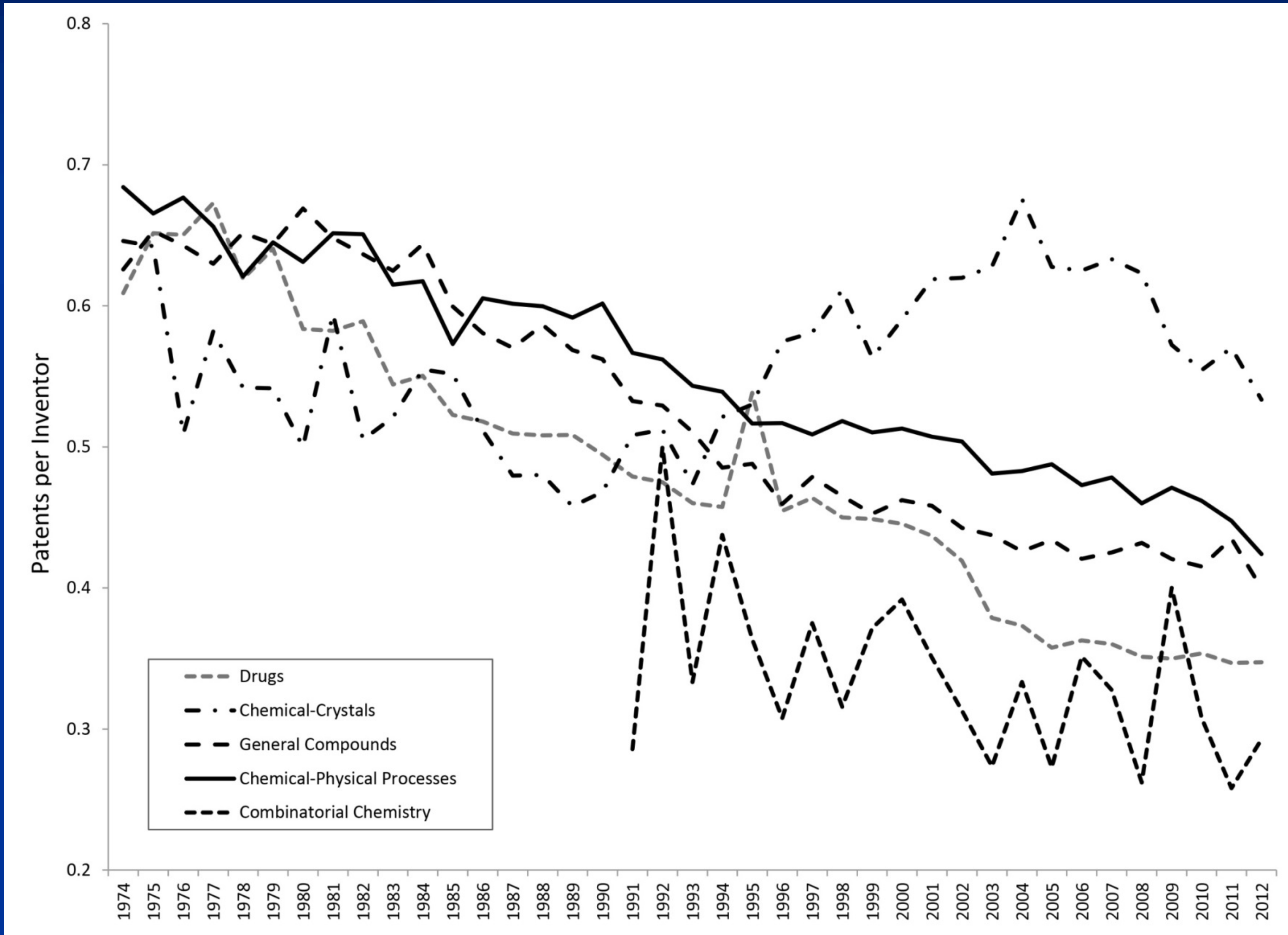
Productivity of Innovation Declining
(Tainter et al. 2018)



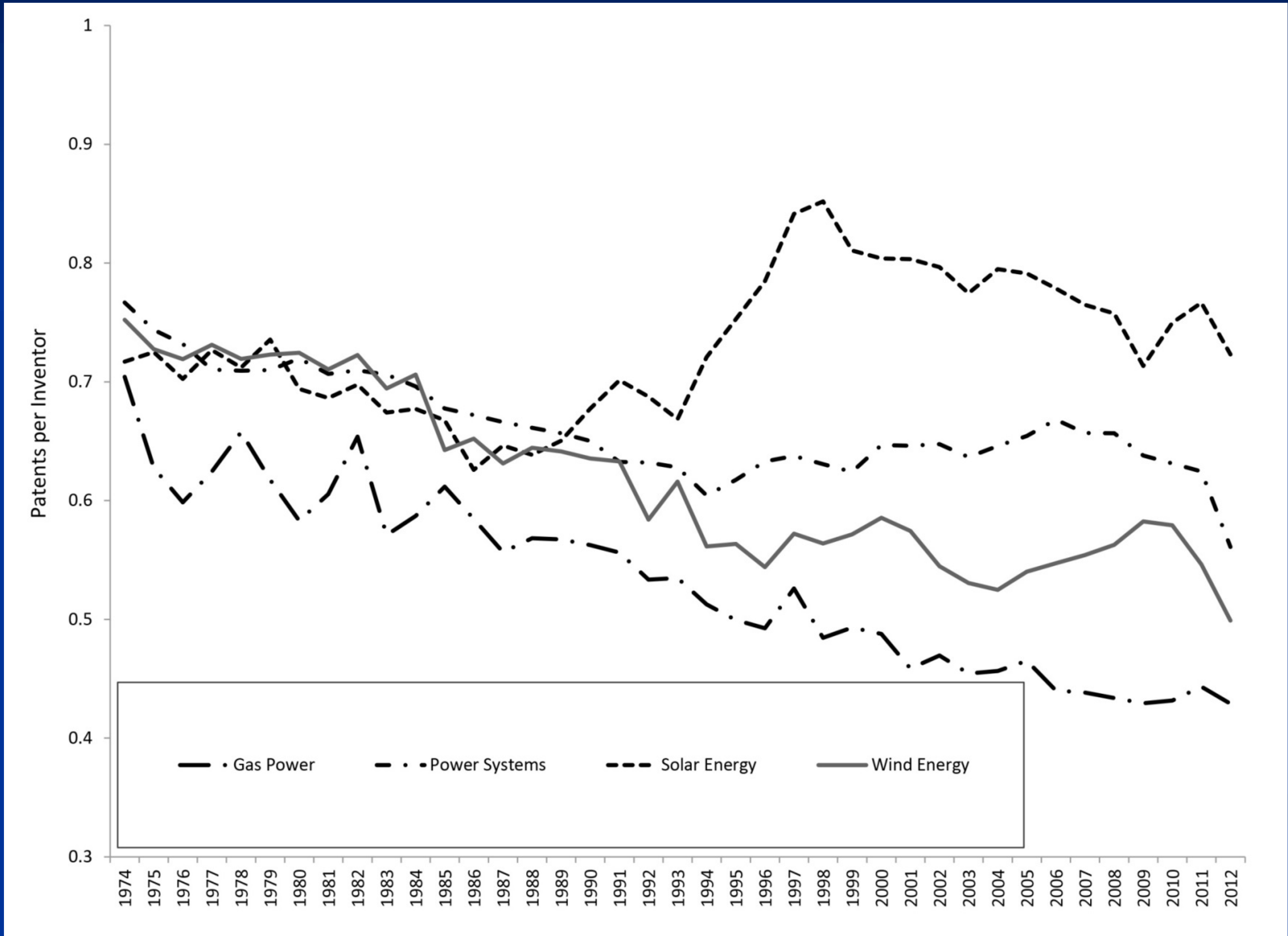
Older Tech Sectors



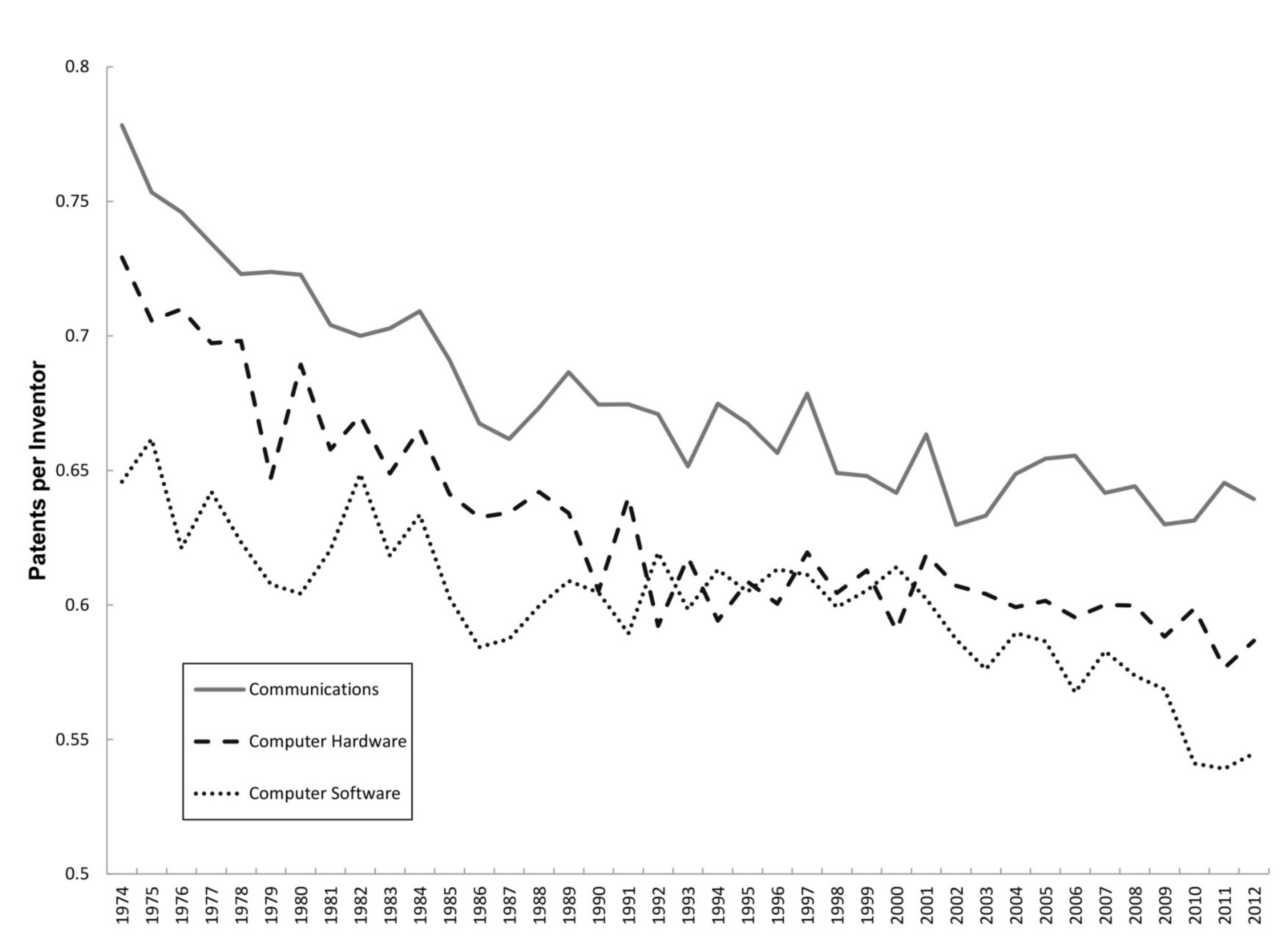
Drugs & Chemicals



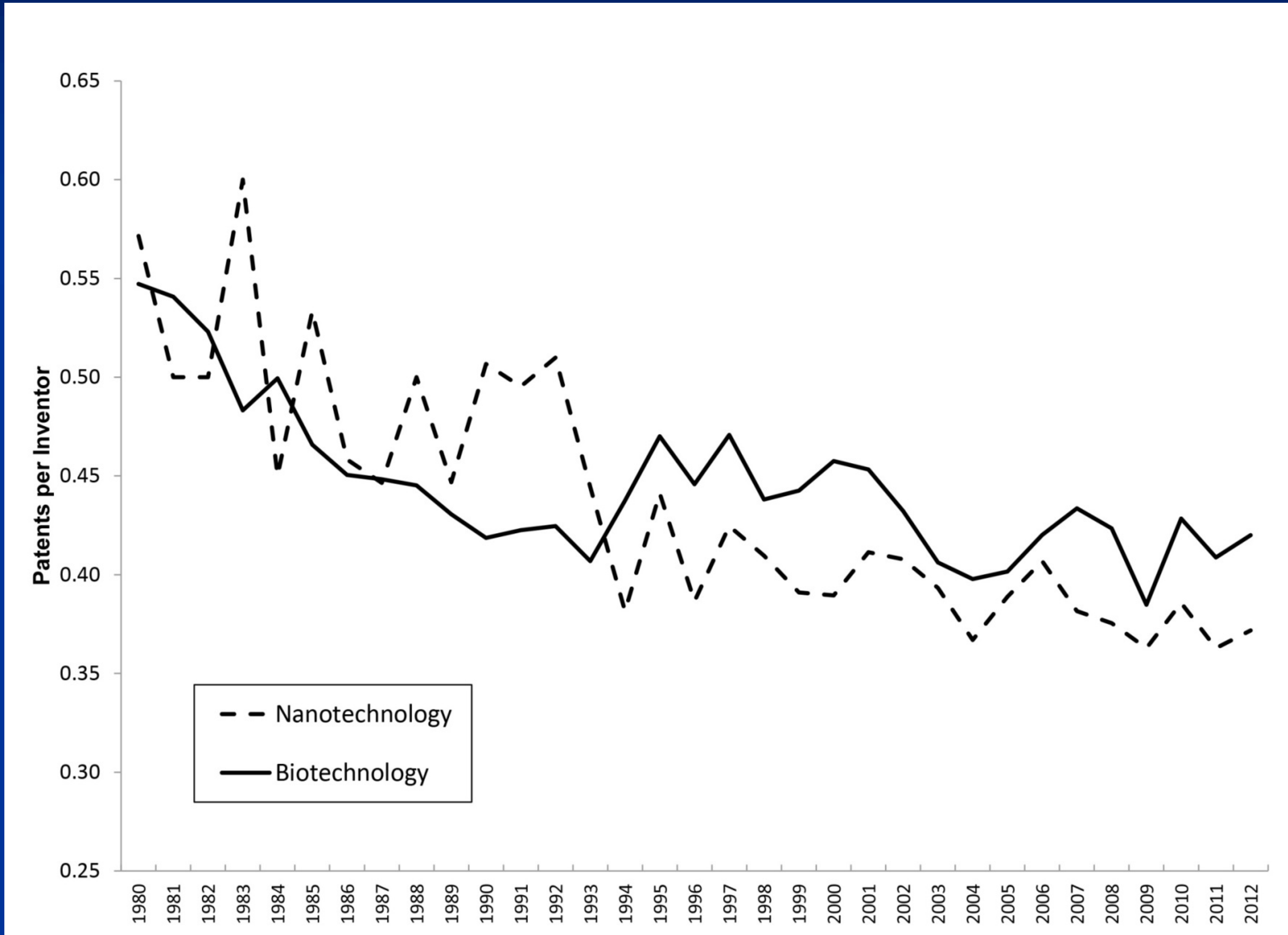
Energy Sector



Information Technology

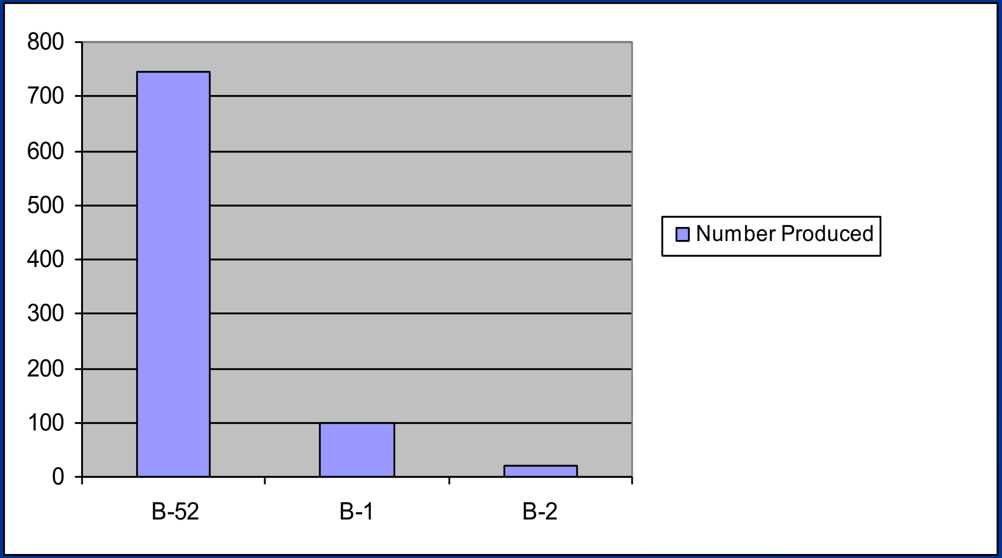


Nanotech & Biotech



Diminishing Returns to Innovation: One Example

"[S]ince 9/11, a near-doubling of the Pentagon's modernization accounts – more than $700 billion over 10 years in new spending on procurement, research and development – has resulted in relatively modest gains in actual military capability….[M]ore and more money is consumed by fewer and fewer platforms that take longer and longer to build."



Sec. of Defense Robert Gates

24 May 2011

The Future of Innovation

"In…science we are involved in a technological arms race: with every 'victory over nature' the difficulty of achieving the breakthroughs that lie ahead is increased."

–Nicholas Rescher (1980)

"It is clear that [science] cannot go up another two orders of magnitude as [it has] climbed the last five….Scientific doomsday is therefore less than a century away."

–Derek de Solla Price (1963)

Implications

- Barring unforeseen developments, our system of innovation is heading in the direction of becoming either unproductive or unaffordable.
- We have plucked much of the low-lying fruit in the area of knowledge production. Fundamental discoveries like electricity and penicillin no longer wait to be made.
- As research problems grow increasingly intractable, the complexity of the research enterprise increases, leading to diminishing returns to research investments.
- We have the impression of continued progress because the scale of the research enterprise has grown so large—and it has been proposed to grow larger still.

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Historical Conditions Underpinning Innovation Will Not Continue

- Declining EROI and increasing resource costs will reduce discretionary spending.
- Increasing complexity and costs will limit energy production, curtailing growth.
- Increasing complexity and costs of innovation, and diminishing returns, will curtail investment in innovation.
- By the end of this century, our system of innovation will look very different, if it endures in anything like its present form.

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- Or is our system of innovation vulnerable to its own decline, mirroring the decline of the factors that make it possible?
- Can we sustain our way of life if our system of innovation declines?