Complexity and the Future of Innovation

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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*

Perspective of Technological Optimists

- 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 natural resource depletion by innovation and increasing technological efficiency?

Objectives

- Explore the origins of our system of innovation, and why it is possible.
- Address constraints to 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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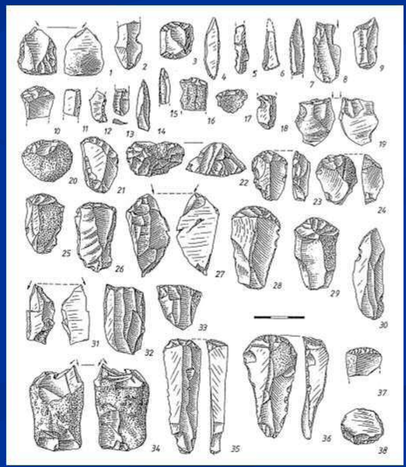
2. Today's institutionalized innovation is controlled by specific external conditions.
3. Our system of innovation is self-perpetuating under those conditions.
4. The continuity of today's system depends on the continuity of those conditions.

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*: 300,000 years.
  - Periods of tens of thousands of years of little technological change.



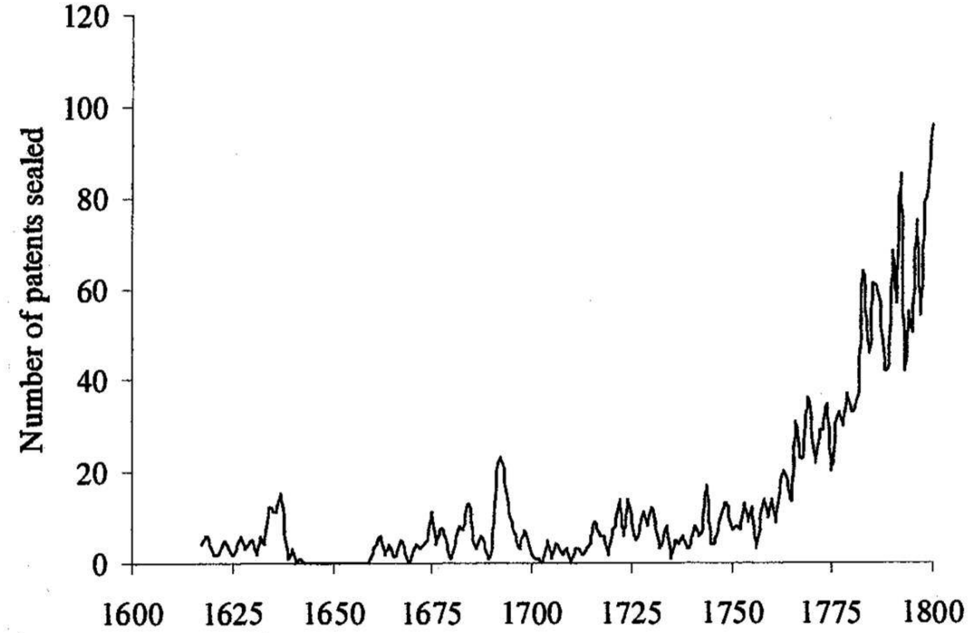
Recent History

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

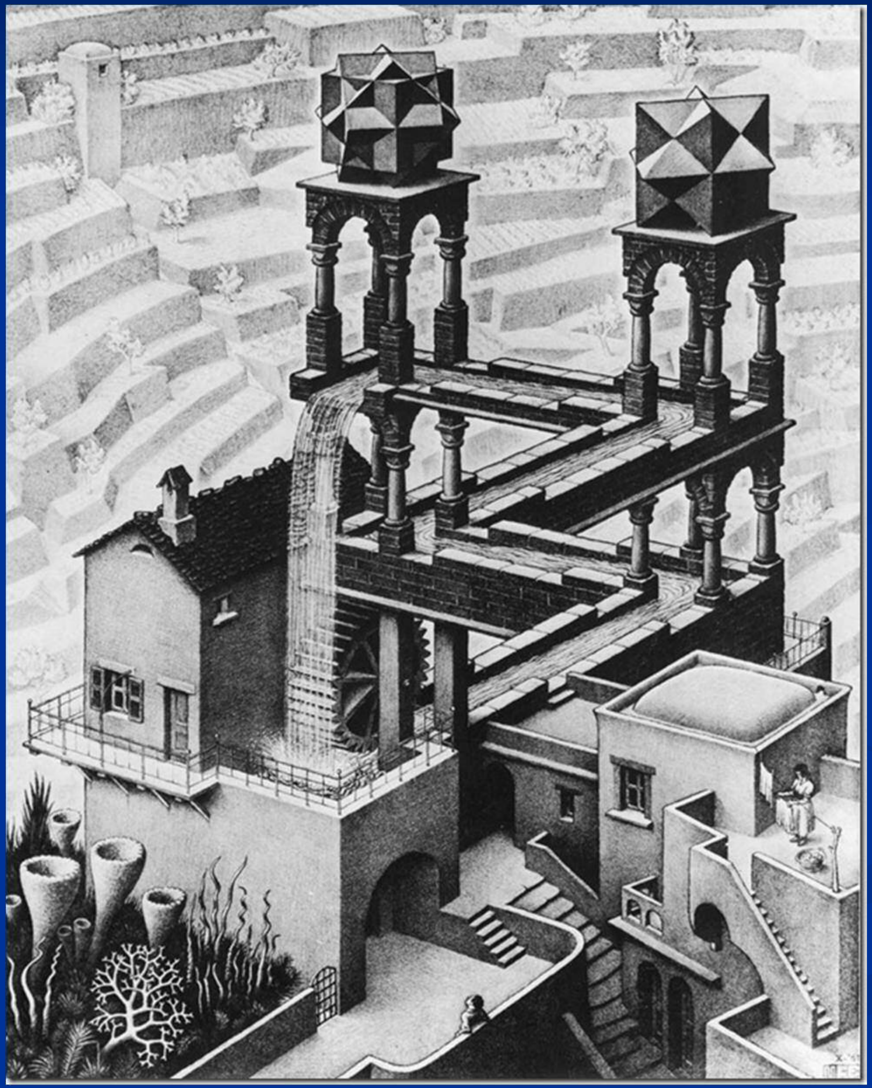
1. High-frequency innovation is **<u>not</u>** an innate characteristic of human societies.

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.

Self-Perpetuating Forever?

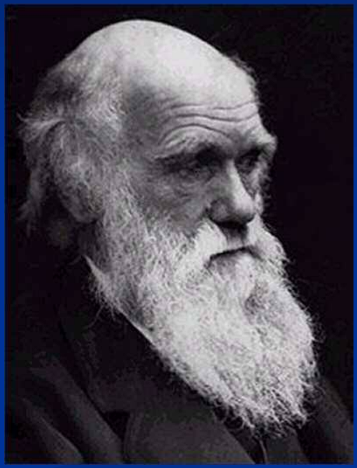


Continuity of Our System of Innovation Requires:

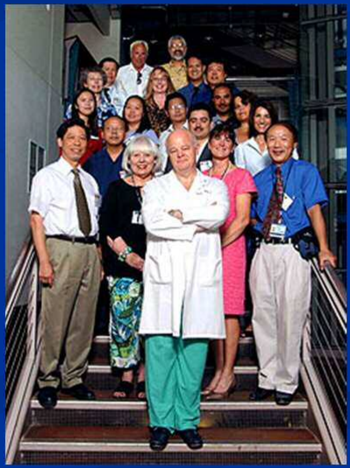
1. Continued inexpensive energy—energy a small part of economy, allowing for discretionary spending and high complexity in our way of life.
2. Constant or increasing returns to innovation.

Evolution of Innovation

- From lone-wolf genius…

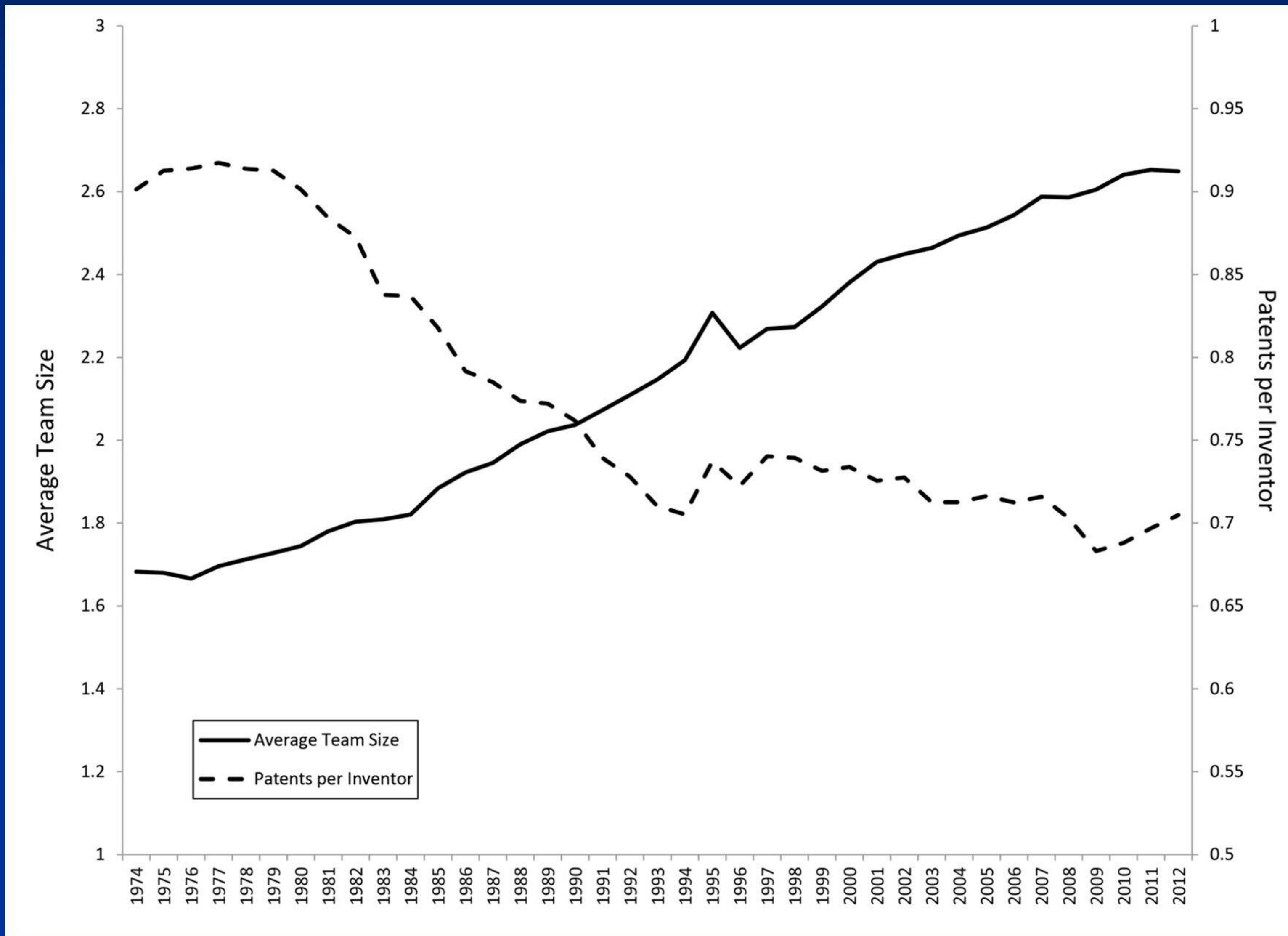


- to complex, interdisciplinary teams. (Google search on "research team" returned >61,000 images.)

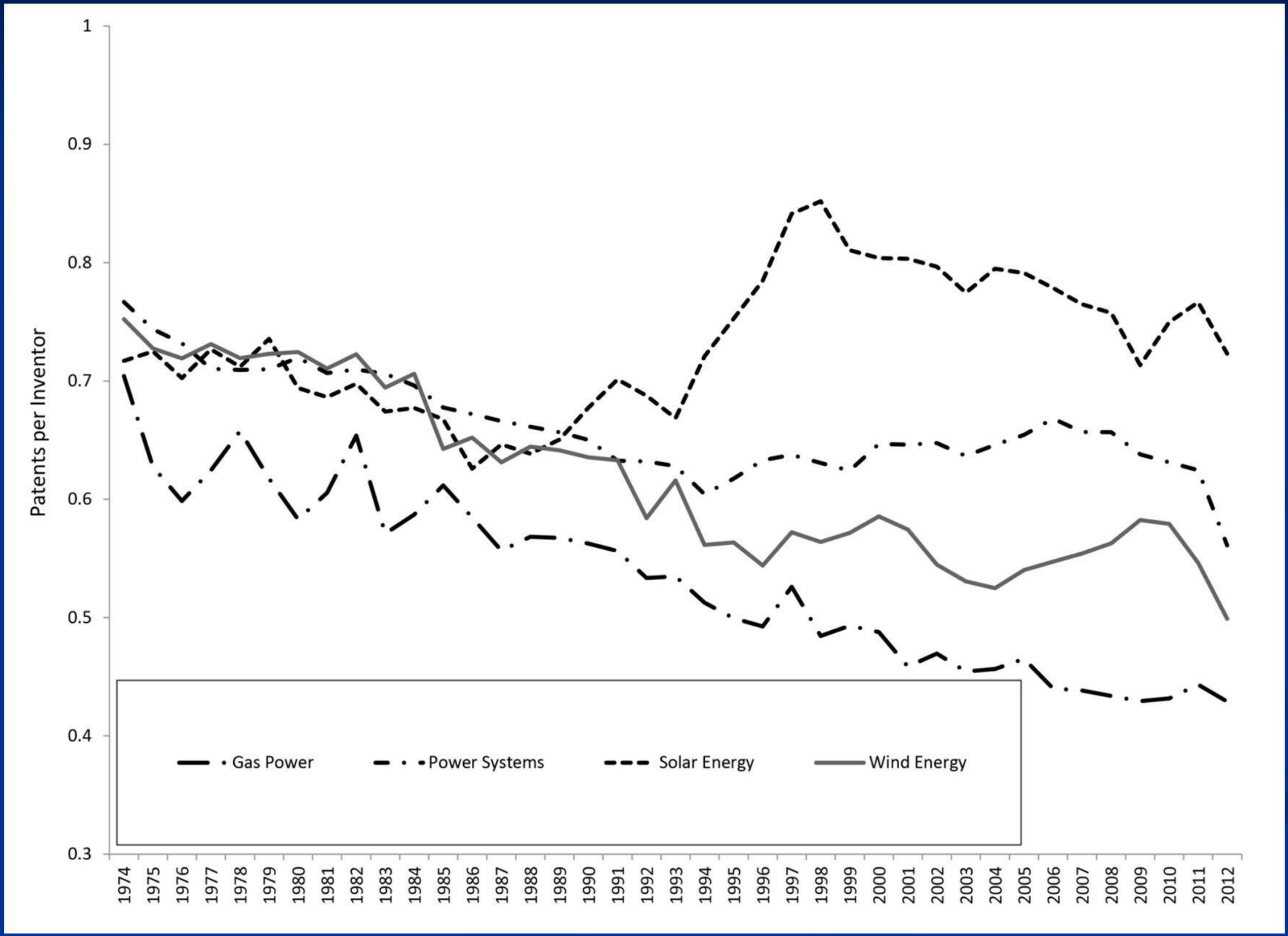


Productivity of Innovation Declining

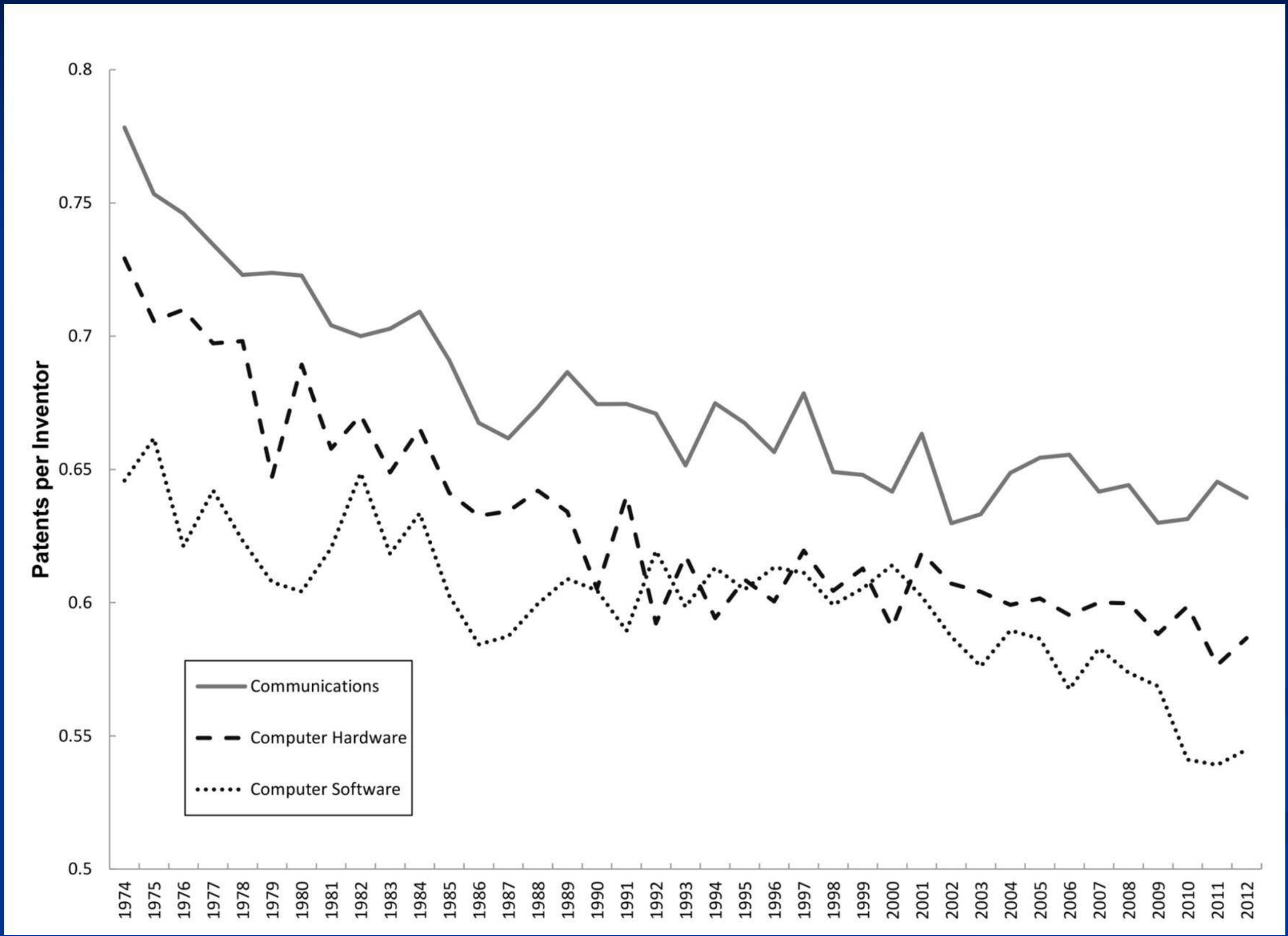
(Tainter et al. 2018)



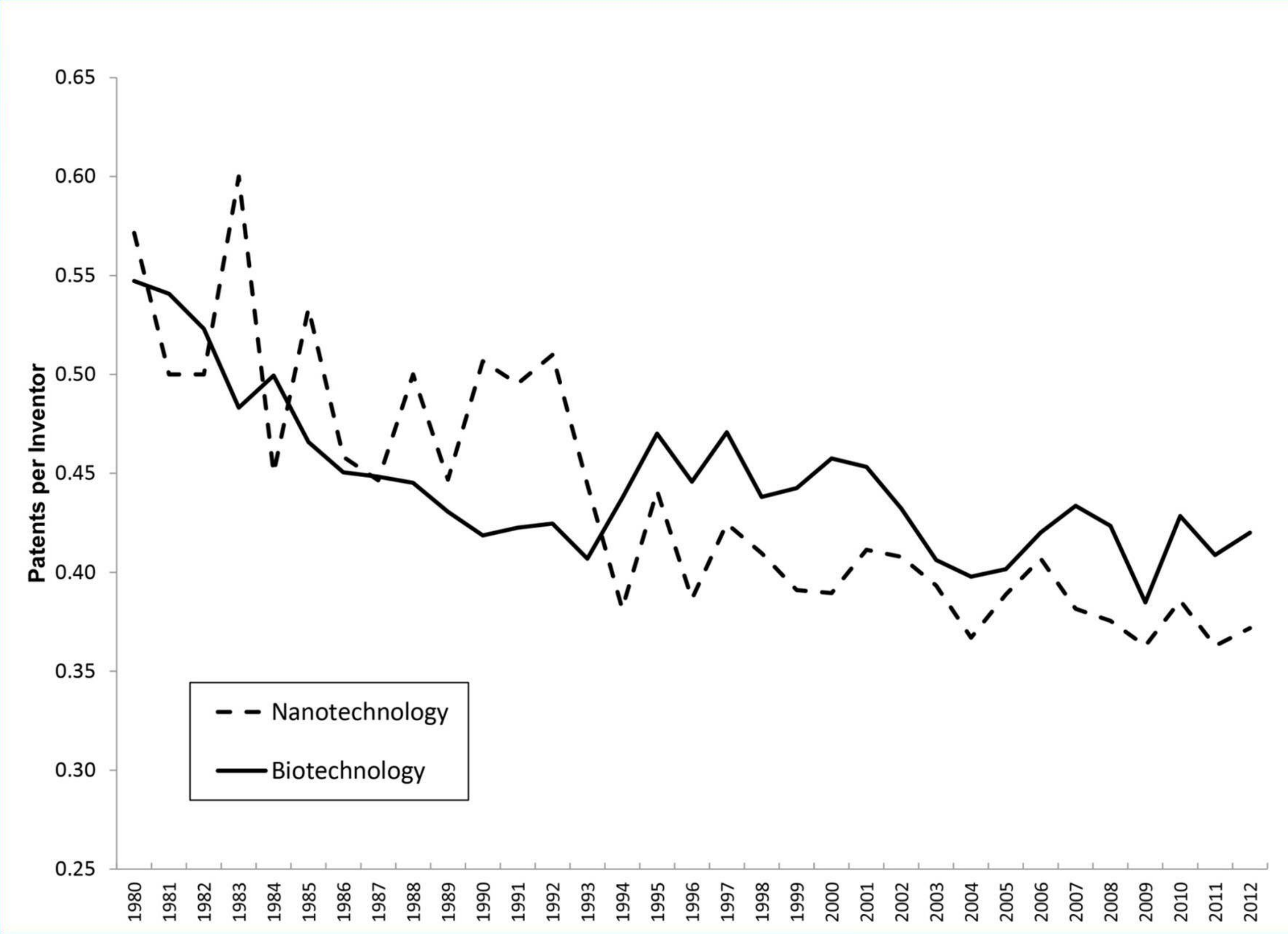
Energy Sector



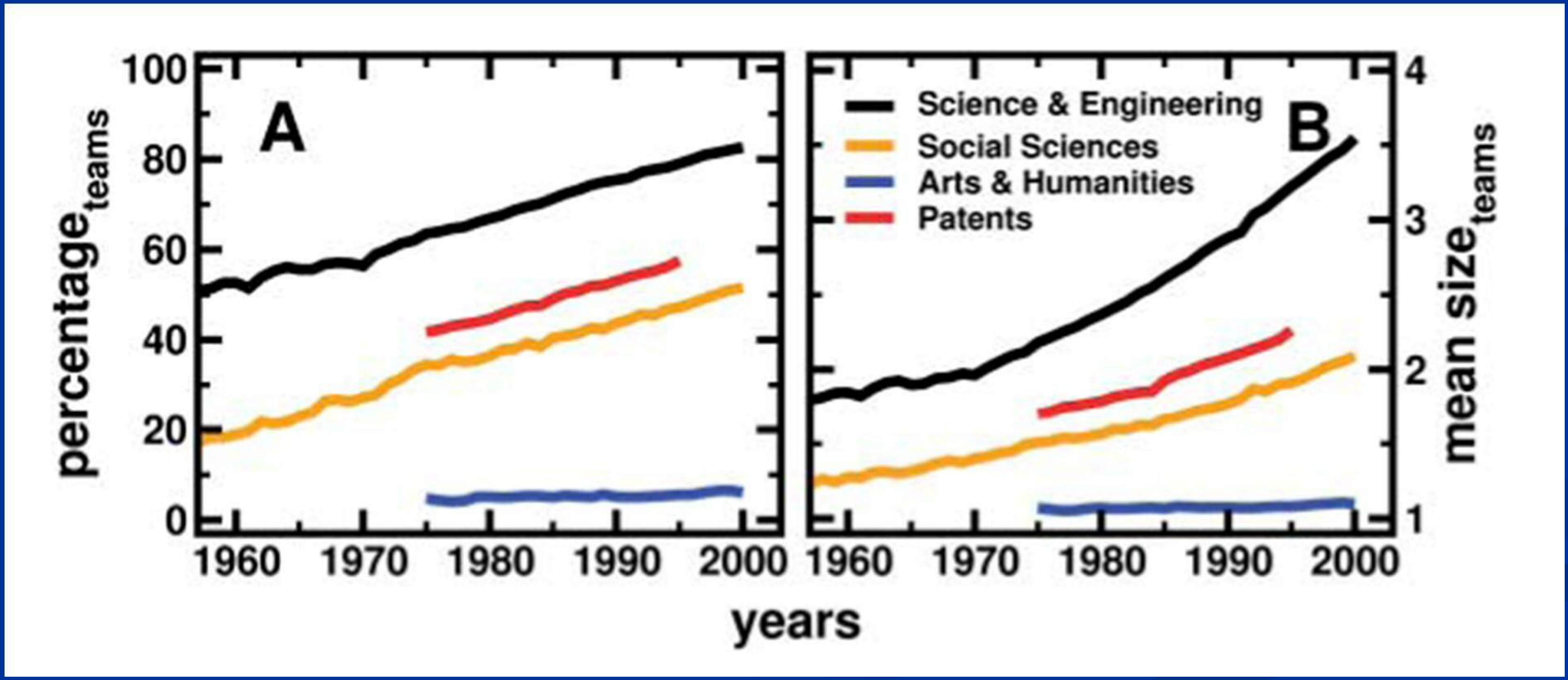
Information Technology



Nanotech & Biotech



Wuchty, Jones, Uzzi. The Increasing Dominance of Teams in the Production of Knowledge. *Science* 316 (2007).



Roderick Eggert, 2014

- 1980s cell phones used ~30 elements from the periodic table.
- 2014 smart phones used 60-70 mineral-derived elements.
- 1980s—a typical household used ~30 elements. In 2014 General Electric used 70 of first 83 mineral elements of the periodic table.

Moore's Law

--Number of transistors on a chip doubles ~ every 2 years (misquoted as 18 months), while the cost of a computer is halved.

--Great!! Except that it takes 18 times as many researchers to continue Moore's Law as it did in the 1970s.

--Constant exponential growth of 35% per year.

--Research productivity declines 7% per year.

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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- 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?