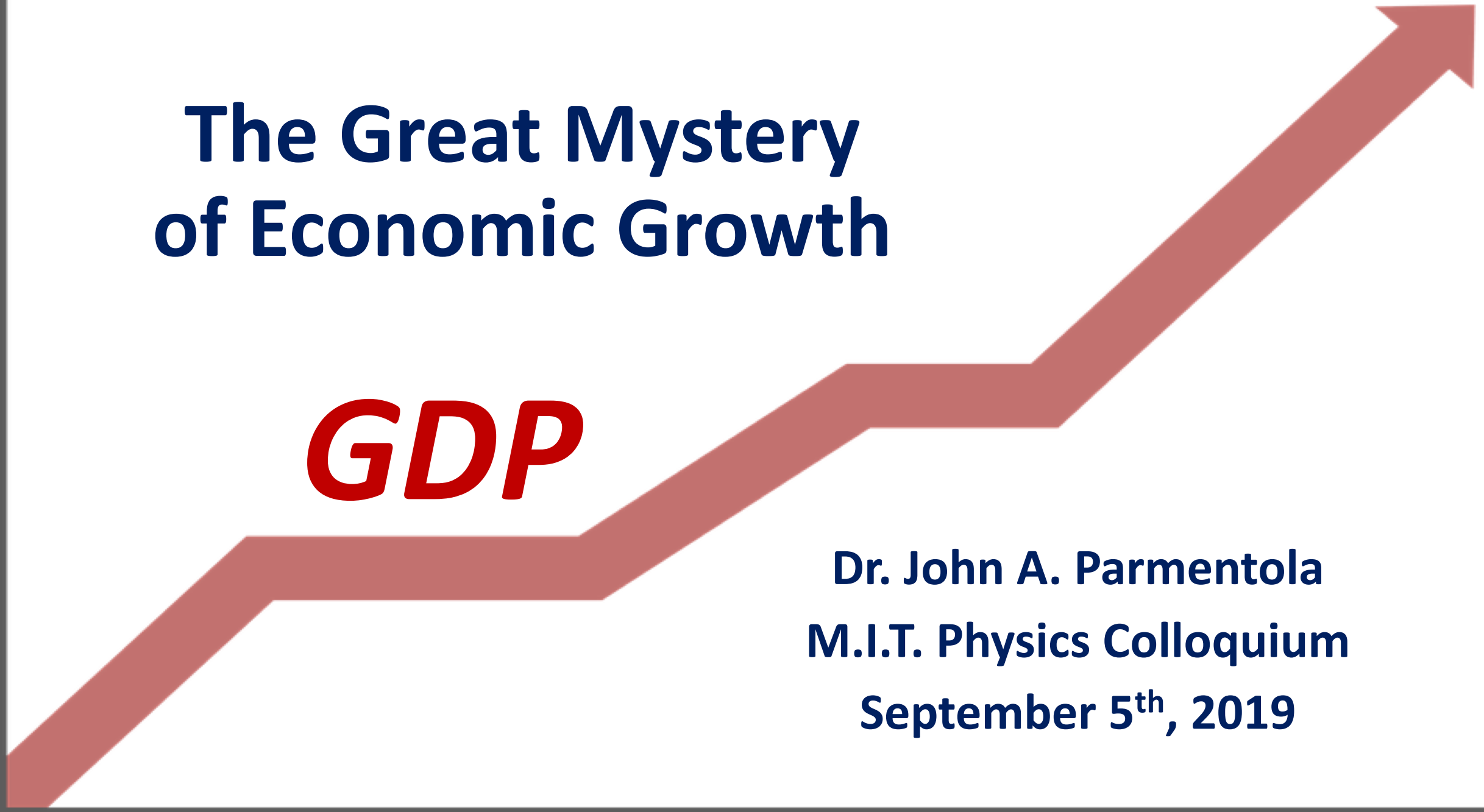
The Great Mystery of Economic Growth

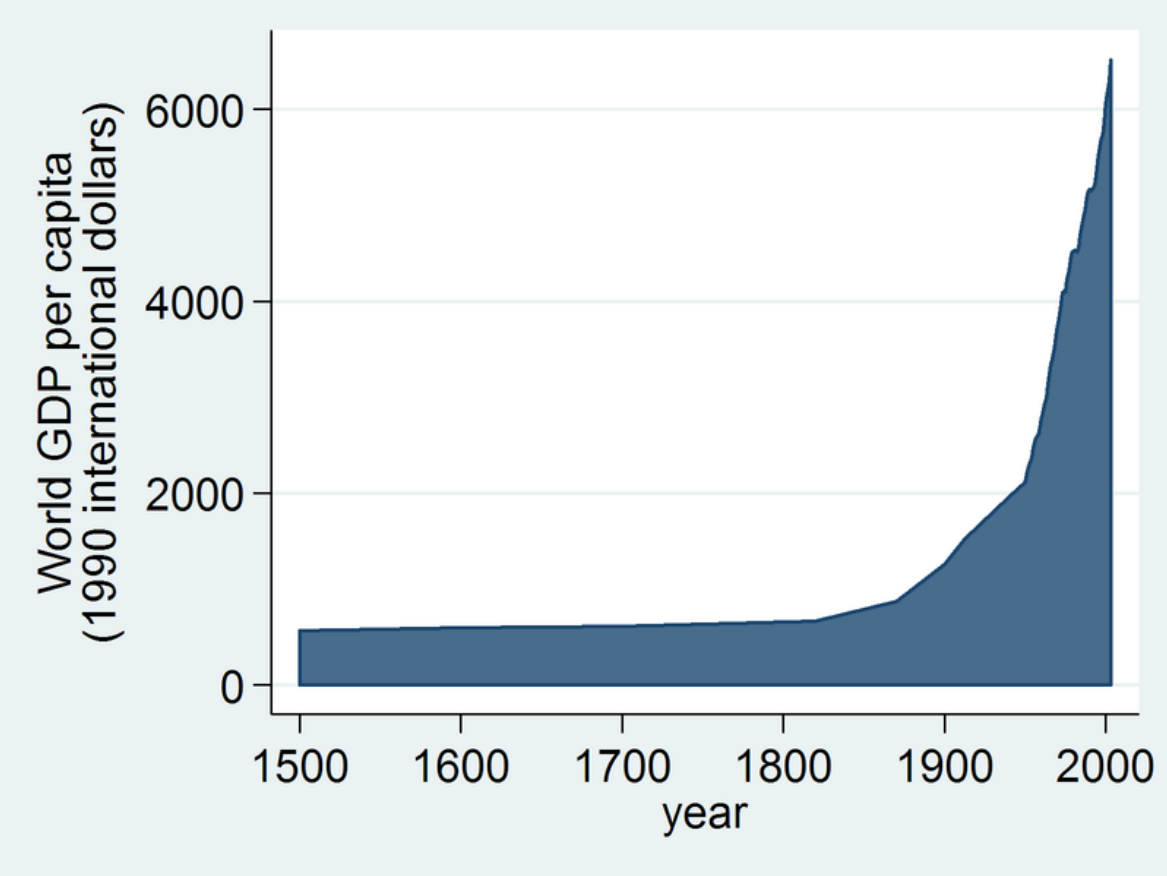


Dr. John A. Parmentola

M.I.T. Physics Colloquium

September 5th, 2019

This rise in the standard of living (GDP/capita) was caused by things having no commercial value!

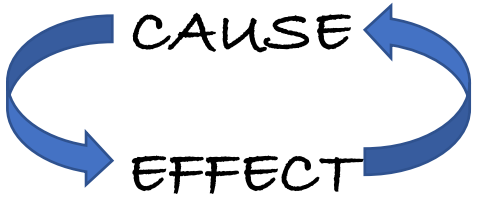


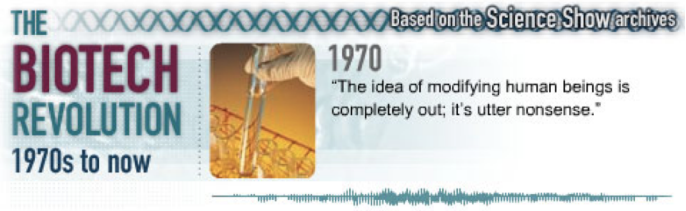
Technology amplified production, reduced time, increased precision, and provided many unique products for consumption

Talk outline

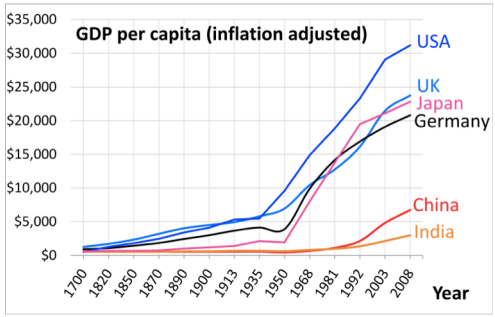
- What is the cause of technology revolutions and why should you care?
- Examples of how this cause created technology revolutions?

Digital & Communication





- How this cause made the U.S. the world economic and military power after WWII?



- Factors that have reduced the role of this cause in creating growth opportunities

What is the cause of technology revolutions?

- The cause is not:
  - Technology
  - Invention or innovation
  - Competitive tax system, competitive free market, reduced trade barriers, deregulation, interest rates, money supply, job creation, population, immigration, human capital, free speech, freedom and liberty, natural resources, capital investment, law, risk-taking, policy, etc.

Invention →  → Innovation

450-ton mining truck

- All technology revolutions have been caused by the discovery of new materials and new knowledge about the natural world that enables their exploitation
  - Chemical elements and the theory of chemical reactions
  - Temperature resistant materials and the theory of heat
  - Conducting materials and the laws of electricity and magnetism
  - Electromagnetic waves and the theory of wave propagation
  - Semiconductors and atomic theory
  - Genetic material and the theory of the genetic code

Electrification of the world

- This was largely a result of investments by governments and wealthy patrons in human curiosity throughout human history

New knowledge expands human imagination as to what is possible, feasible, and practical

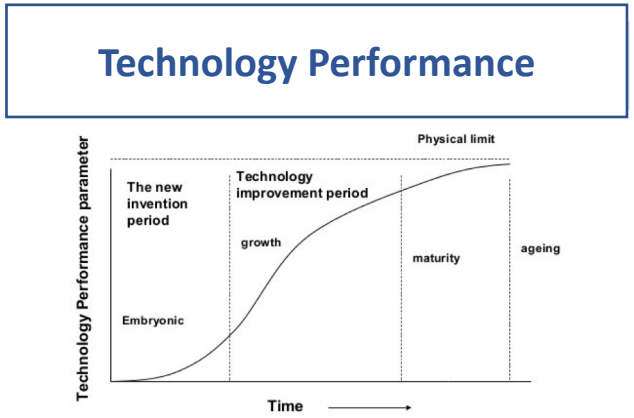
Why should you care about the cause?

- All technologies eventually run out of performance headroom and there are currently signs in major industries that performance improvements are becoming harder to realize

- Understanding the actual cause of technology revolutions can enable such revolutions to occur again

- Investing in the cause of technology revolutions is our responsibility to future generations so abundant opportunities exist for continuing prosperity

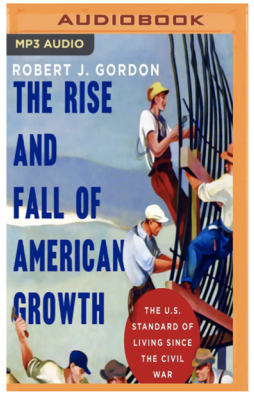
- Investing in the cause is our hedge against stagnation, which many believe is our current path

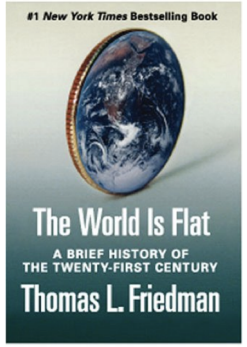


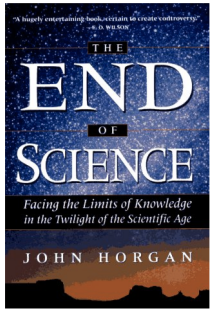
Over the last half-century, we have systematically made this cause less relevant to economic growth

Doom and gloom books

- *The Rise and Fall of American Economic Growth* by Robert Gordon
  - Since the 1970s, we have been practicing a form of incrementalism
  - No large scale examples like electricity, urban sanitation, chemicals and pharmaceuticals, the internal combustion engine, and modern communications
- *The World is Flat* by Thomas Friedman
  - The traditional competitive advantage of knowledge and innovation is shrinking
  - Once someone has demonstrated something based on established knowledge, another person on the other side of the globe can rapidly imitate or reproduce it
- *The End of Science* by John Horgan
  - Fundamental discoveries are over



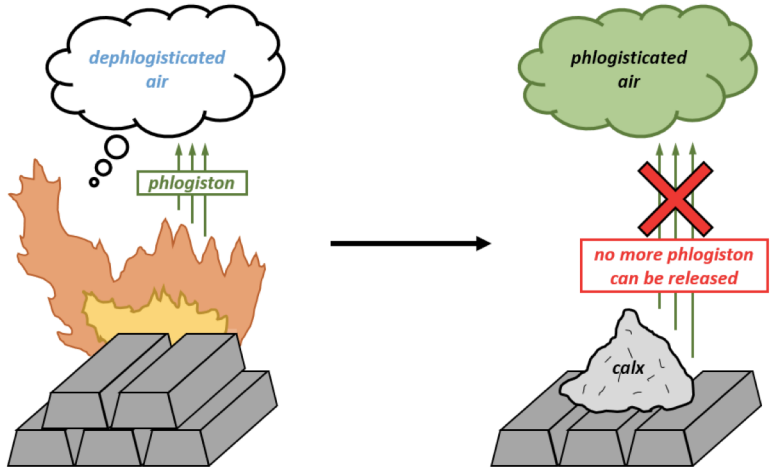




These and many other books identify the potential problem but not the solution

Technology revolutions

- Chemical revolution
  - During the 18th century fire was still a mysterious force
  - When wood burned, where did the wood go?
  - What caused rust to form and increase mass?
  - A new substance was proposed, phlogiston, that flowed in and out of materials
  - Heat was another mystery – Why did it flow from hot to cold and what was it?



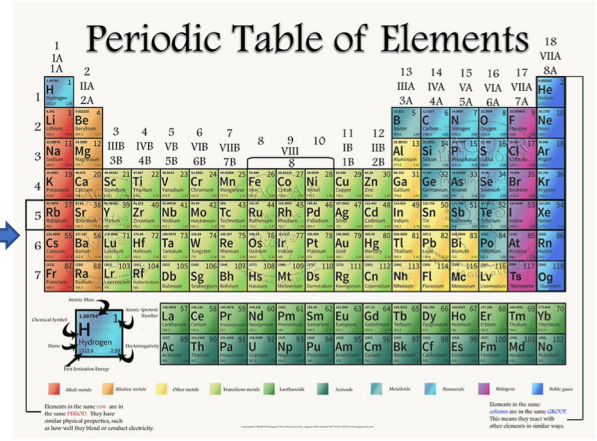
The debunking of phlogiston would give the world modern chemistry and understanding heat would advance heat engines and provide support for the existence of atoms

Technology revolutions (cont'd)

- Antoine Lavoisier (1742–1794) – The "Father of Modern Chemistry"
  - Disproved the existence of phlogiston through the conservation of mass
  - Properly identified some of the fundamental elements
  - Developed stoichiometry and the nomenclature to name new compounds

Antoine Lavoisier's 1789 classification of substances into four 'element' groups			
acid-making elements	**gas-like elements**	**metallic elements**	**earthy elements**
sulphur	light	cobalt, mercury, tin	lime (calcium oxide)
phosphorus	caloric (heat)	copper, nickel, iron,	magnesia (magnesium oxide)
charcoal (carbon)	oxygen	gold, lead, silver, zinc	barytes (barium sulphate)
	azote (nitrogen)	manganese, tungsten	argilla (aluminium oxide)
	hydrogen	platina (platinum)	silex (silicon dioxide)

150 years

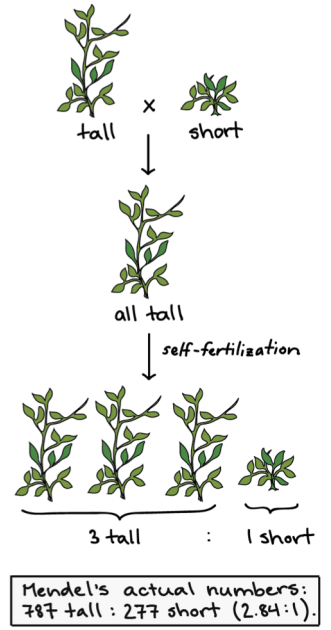


- Many that followed measured reaction rates, heat generated and required in chemical reactions, established efficient chemical processes, created chemical engineering, discovered all the fundamental elements, etc.

No one could have predicted that from 50 known elements and compounds in 1800 there would be 10 million today with the worldwide chemical industry generating $5T/year

Technology revolutions (cont'd)

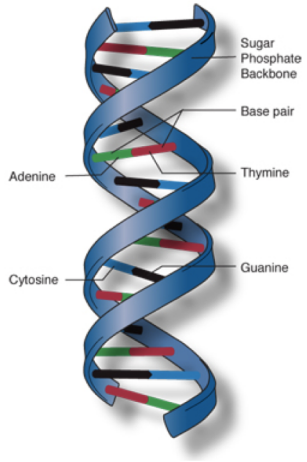
- **Biotechnology Revolution**
  - For millennia, the transfer of traits from parents to offspring was a mystery
  - In the 19th century, many believed that traits of offspring were a blend from the parents
  - An Augustinian friar, Gregor Mendel (1822–1884), while at St. Thomas' Abbey in Moravia turned this notion of blending on its head
    - Influenced by his Bishop, Mendel went from studying mice to pea plants
    - Pea plants have discrete binary characteristics
    - He discovered dominant and recessive traits
    - He concluded that there was material in living cells he called "factors" that carried the traits and there were two copies in each parental cell
    - From his work he formulated the laws of inheritance, which were rejected by his contemporaries
    - Mendel's work was forgotten but rediscovered in 1900
    - No one at the time could have predicted that Mendel's work would be the cause of a remarkable revolution



We now know that we share 96% of our genes with chimpanzees, we can discover our ancestry from a saliva sample, and by 2025 Biotech will generate over $700B per year worldwide

Technology revolutions (cont'd)

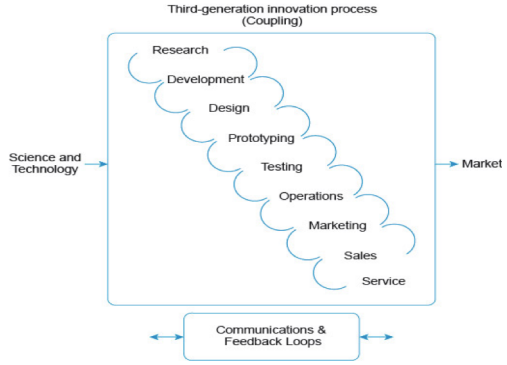
- However, the biotechnology revolution depended on something totally unrelated and also unpredictable
  - Wilhelm Roentgen discovered X-rays in 1895
  - Max von Laue proved in 1912 that X-rays were waves like ordinary light waves
  - Around the same time William Bragg and his son Lawrence worked out the the theory of X-ray crystallography
  - In 1951, Rosa Franklin using X-ray crystallography discovered the double helical structure of DNA
  - In 1953, Francis Crick, James Watson, and Maurice Wilkins confirmed the doubled stranded nature of DNA and more importantly explained how it worked
  - This gave birth to molecular biology: the role genes play in chemical processes within living things



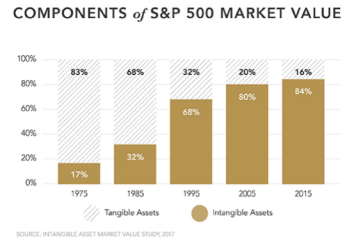
Technology revolutions are caused by unrelated unpredictable patterns in human history

Intangible Assets at Two Extremes

- Upstream we have discoveries in science, engineering, and mathematics
  - These are accessible to anyone and the competitive market cannot assign a commercial value to them
  - It has taken the U.S. Bureau Economic Analysis 40 years to assign a monetary value to them equal to the cost to produce them, which is just bookkeeping

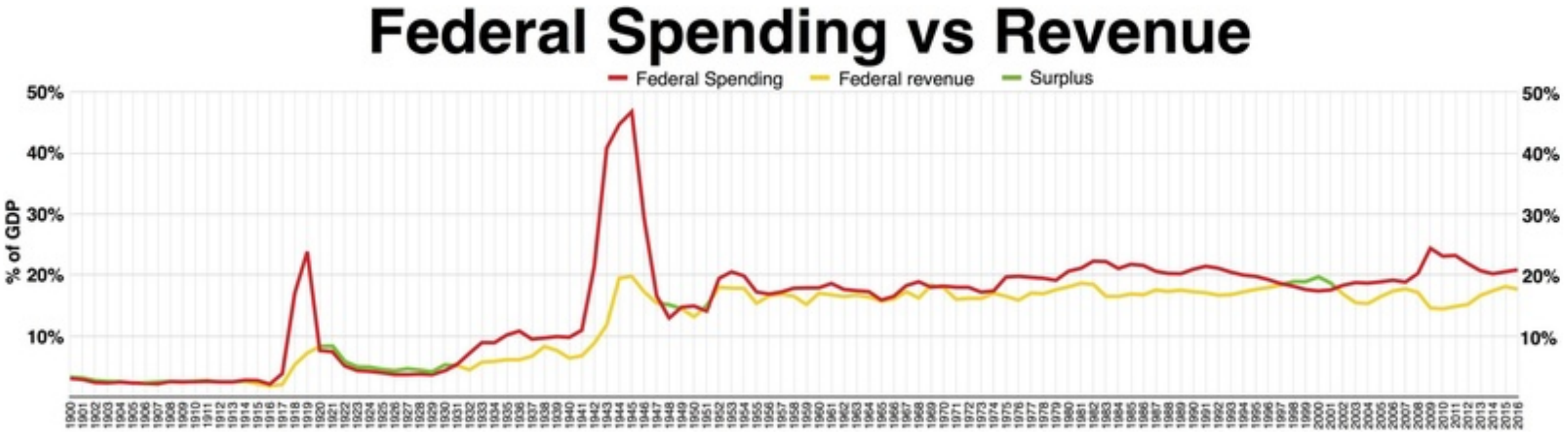


- Downstream we have proprietary Intellectual Property (IP)
  - Patents, trade secrets, knowledge from research and development (R&D), mathematical algorithms represented in software, business methodologies, etc.
  - This is Paul Romer's growth theory that enable businesses to have a semi-monopoly through knowledge or "non-rival partially excludable assets"



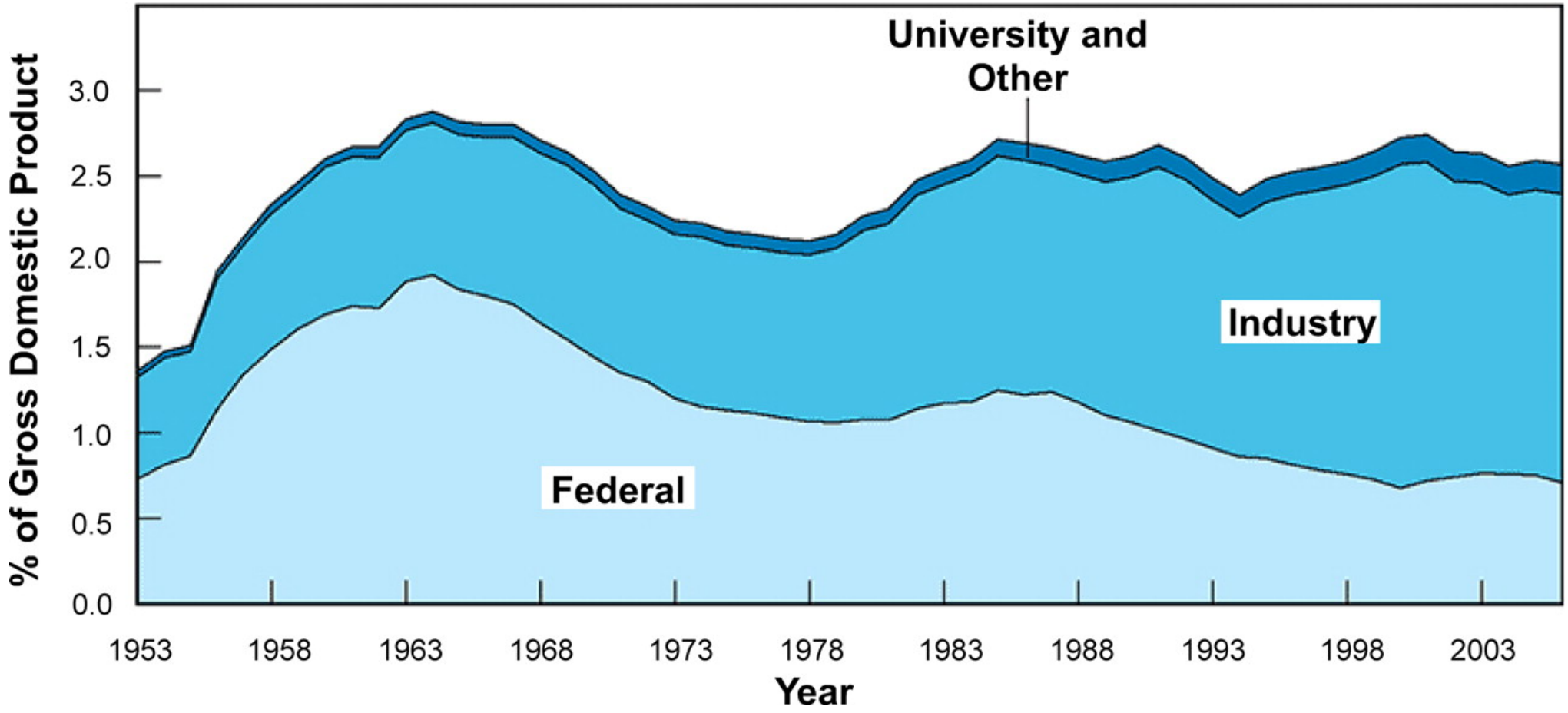
The private sector has no investment interest in upstream intangible assets, so the government must do what the private sector will not and cannot do

Since 1953, Federal spending percentage–wise has not changed much



What has changed is what we spend it on: social programs, defense, interest on the debt, and special interests, which are growing short-term needs

The U.S. becomes the world economic and military power after WWII



Up to about 1967 the Federal government dominated R&D spending, however, since 1967 R&D opportunities for economic growth have been reduced by about 65%!

Rebuilding our nation after WWII

- **Leadership with vision over a 20-year period**
  - A year before the end of WWII, FDR and Congress passed the GI Bill
  - Talented and knowledgeable Europeans sought freedom and liberty in the U.S.
  - Science ended the war with Japan
  - We had no competition with Germany and Japan destroyed
  - FDR tasked Vannevar Bush to create a science and technology plan for the nation – *Science: The Endless Frontier*
  - Truman followed through with Congress to create the NSF
  - Eisenhower followed through with Congress to create DARPA and NASA and expanded the national education system
  - JFK followed through with his journey to the moon and further expanded our education system





The threat of communism created urgency

Nature of the investments Up to 1967

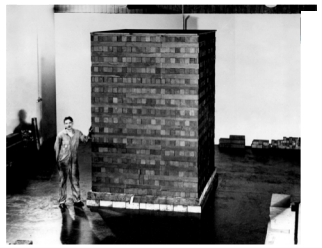
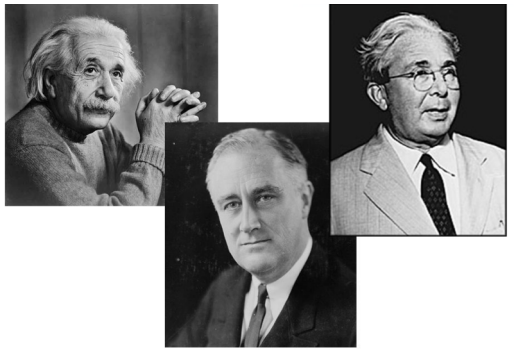
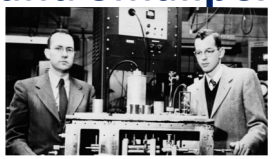
- In 1944, G.I. Bill established hospitals, made low-interest mortgages available, business loans, and granted stipends covering tuition and expenses for veterans attending college or trade schools
- Government funded R&D/GDP increased by nearly 200%
- Funding for universities increased by 700%
- The STEM workforce increased by 900% (0.2M to 2M)
- Federal development funding for industry increased by 250%
- Industry investment increased by 100%
- Federal spending on government R&D centers increased by 250% (2/3 development and 1/3 applied research)

This was a 20-year period of investment in people, equipment, and facilities through *risk-taking and policy* that created our nation's future

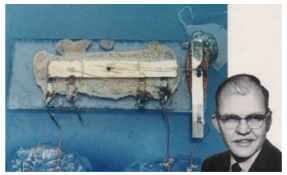
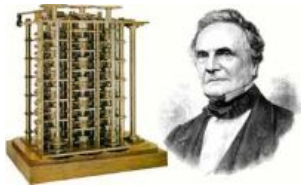
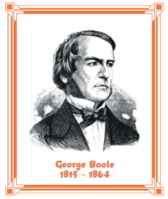
During and since WWII we have as a nation of creative, ambitious, and free people:

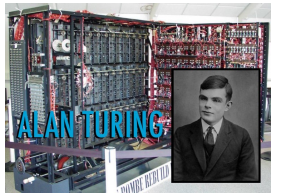
- Invented nuclear reactors
- Invented atomic & nuclear weapons
- Developed the use of radioactive substances to treat and cure diseases
- Developed vaccines, such as the Polio and Smallpox vaccines, to eliminate these diseases
- From basic science invented the laser
- From basic science invented a very small fast electronic switch, the transistor
- Adapted an invention from lithographic printing to the mass manufacture of microelectronic circuits
- Developed computers that can be reprogrammed in real time through changes in software stored in memory
- Invented the first supercomputer
- Developed the first robotic systems driven by AI
- Invented the first virtual reality environments

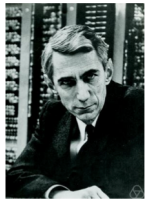


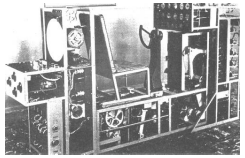







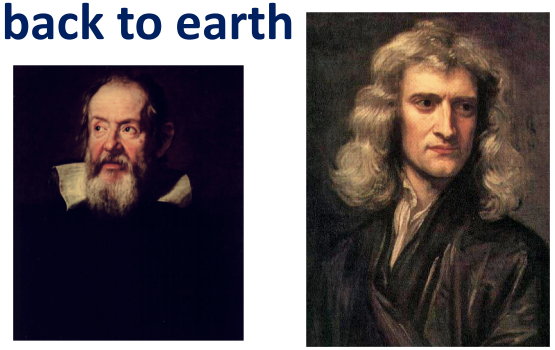


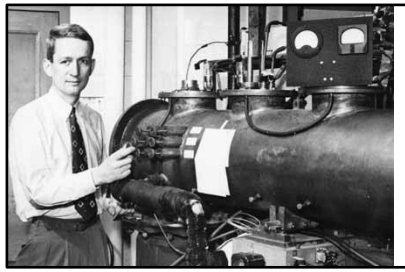
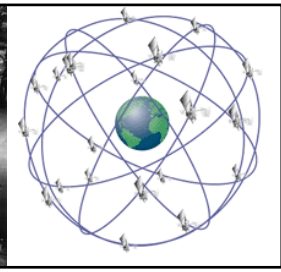
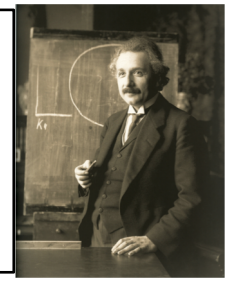


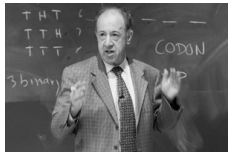



During and since WWII (cont'd)

- Put men on the moon and returned them safely back to earth
- From basic science invented the most accurate timepiece in human history, the atomic clock
- Created a system of satellites, GPS, that can locate anyone and anything anywhere on earth
- From basic science invented magnetic resonance imaging that has advanced medical diagnoses
- Created the Internet to connect everyone on the planet
- Discovered the third elemental form of carbon, Fullerene, that launched the nanotechnology revolution
- Pioneered molecular biology and genetic engineering
- Decoded the information stored in the Human Genome, the code of life
- Since 1950, been awarded more than 250 Nobel Prizes in physics, chemistry and medicine; and many, many more

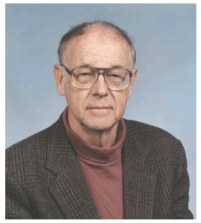




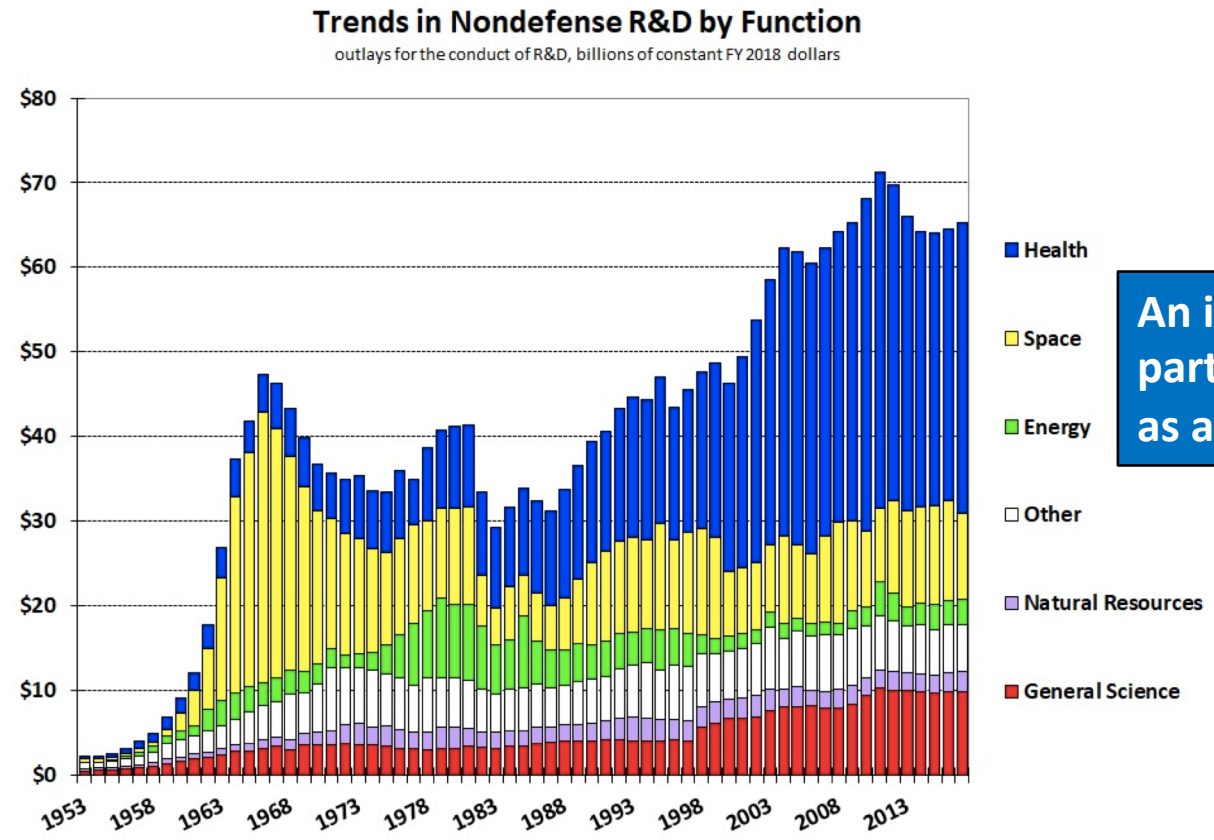


Felix Bloch (1905-1983)

Edward Mills Purcell (1912-1997)


These are all connected to unrelated unpredictable patterns in human history largely funded by governments and wealthy patrons

An echo from the past

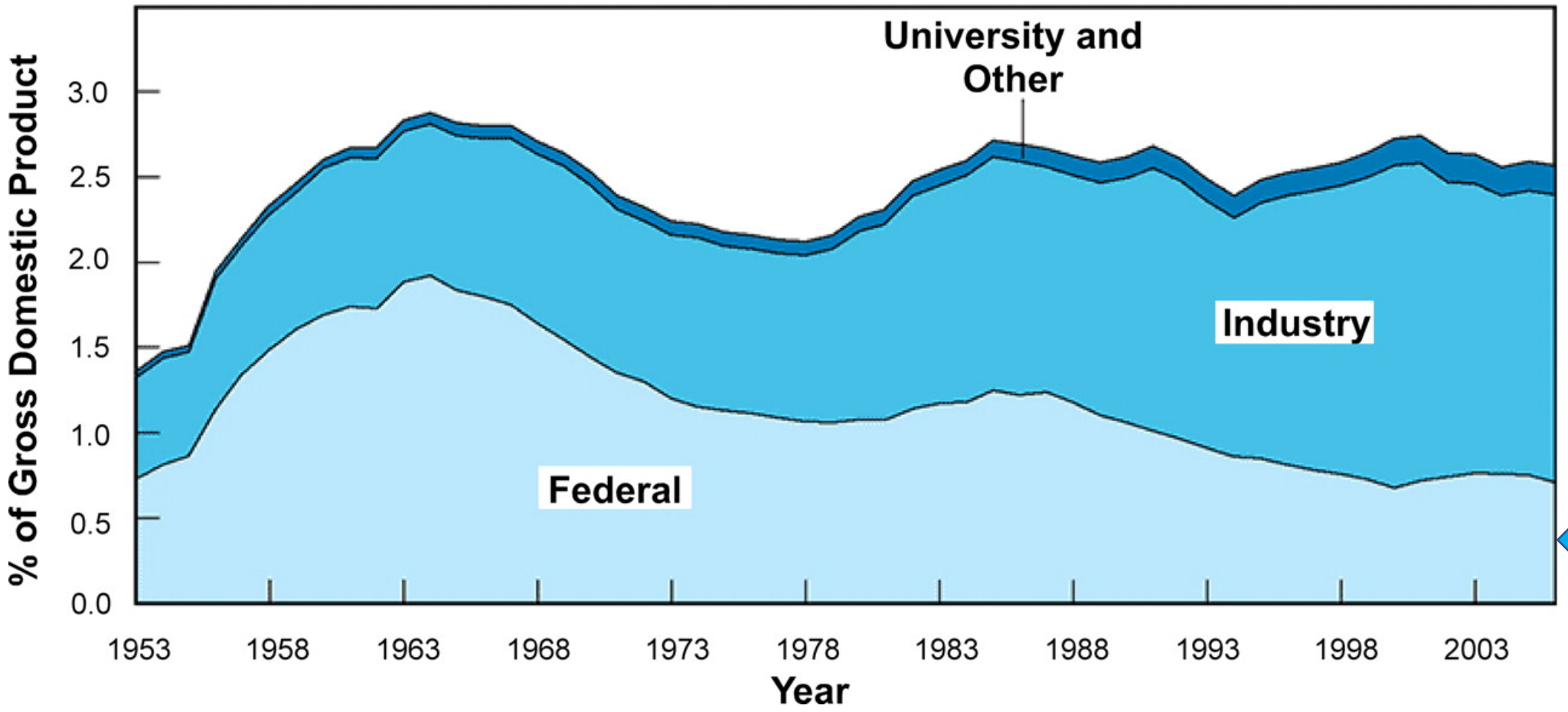


Source: AAAS, based on OMB Historical Tables in *Budget of the United States Government FY 2019*. Some Energy programs shifted to General Science beginning in FY 1998. © 2018 AAAS

An increase of 350% and the only part of the R&D budget to increase as a percentage of GDP

The 1973 War on Cancer reduced risk for the private sector by educating a new workforce and heavily investing in health science and technology

We are a development culture that values efficiency and incrementalism

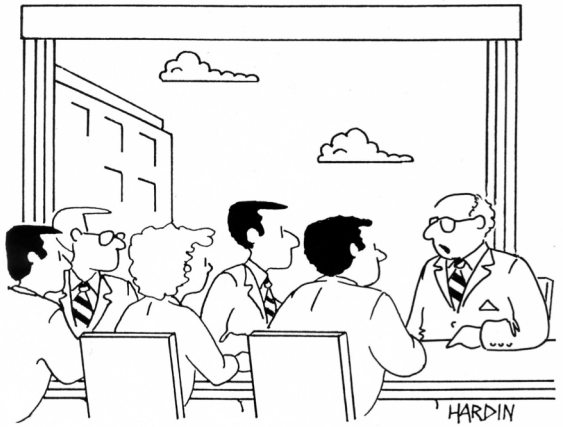


In FY2018, non-defense R&D is 0.3% of GDP

Industry spends 3 times the amount on R&D compared to Federal, largely short-term D, and government R&D is about 50% defense R&D, which is also largely D

Our current risk-averse culture

- If I give you money what am I going to get and when am I going to get it?
  - The pursuit of new knowledge cannot answer any part of this question
    - The whole point of discovery is to figure out what the "what" is
    - Because you do not know what the "what" is you cannot predict the "when"
    - Therefore the cost to figure out the "what' is also uncertain
- This way of approaching investment is pervasive throughout the private sector and our government
  - This is a culture that either uses other people's money to reduce risk or pursues incrementalism to avoid risk
  - Efficiency in the use of money is the priority
  - This means largely investing in improvements in what we know



It is what we do not know that is more important to our future than what we know

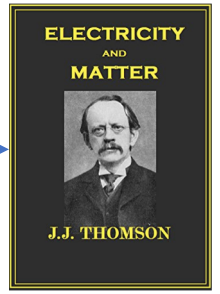
Timescales for success

- Election for politicians is:
  - Two years for the House
  - Six years for the Senate
  - Four years for the Presidency
- For the private sector success is:
  - Quarterly reports of profit/loss
  - At best 5 years for Venture Capital
- For the military success is:
  - Fulfilling urgent needs at all times especially when we are at war
  - Efficiency in operations
  - Promotion measured in years
- For special interests success is:
  - Annual lobbying of Congress

Gilbert & the electron

About 300 years

J.J. Thomson



Faraday & semiconductors

About 100 years

Schrodinger & Heisenberg

Mendel & genes

About 100 years

Politicians, private sector, military, and special interests are all aligned with short-term goals

Current culture has made research largely irrelevant

- As the legendary Louisiana politician Huey Long once said regarding Congressional Earmarks:

  "Those of you who come in with me now will receive a big piece of the pie. Those of you who delay, and commit yourselves later, will receive a smaller piece of the pie. Those of you who don't come in at all will receive – Good Government!"

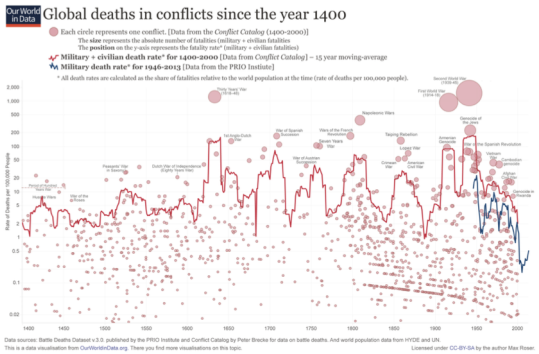
- The cost of FY 2019 Earmarks is $15.3 billion or half the basic research budget
- Politicians cannot rely on "unpredictable research results"

  to gain votes and increase jobs, business creation, and exports for which

  politicians can claim credit but "they" are the cause of growth
- The private sector cannot count on them for quarterly rates

  of return but "they" create opportunities for growth
- The military cannot rely upon them to defend our nation and

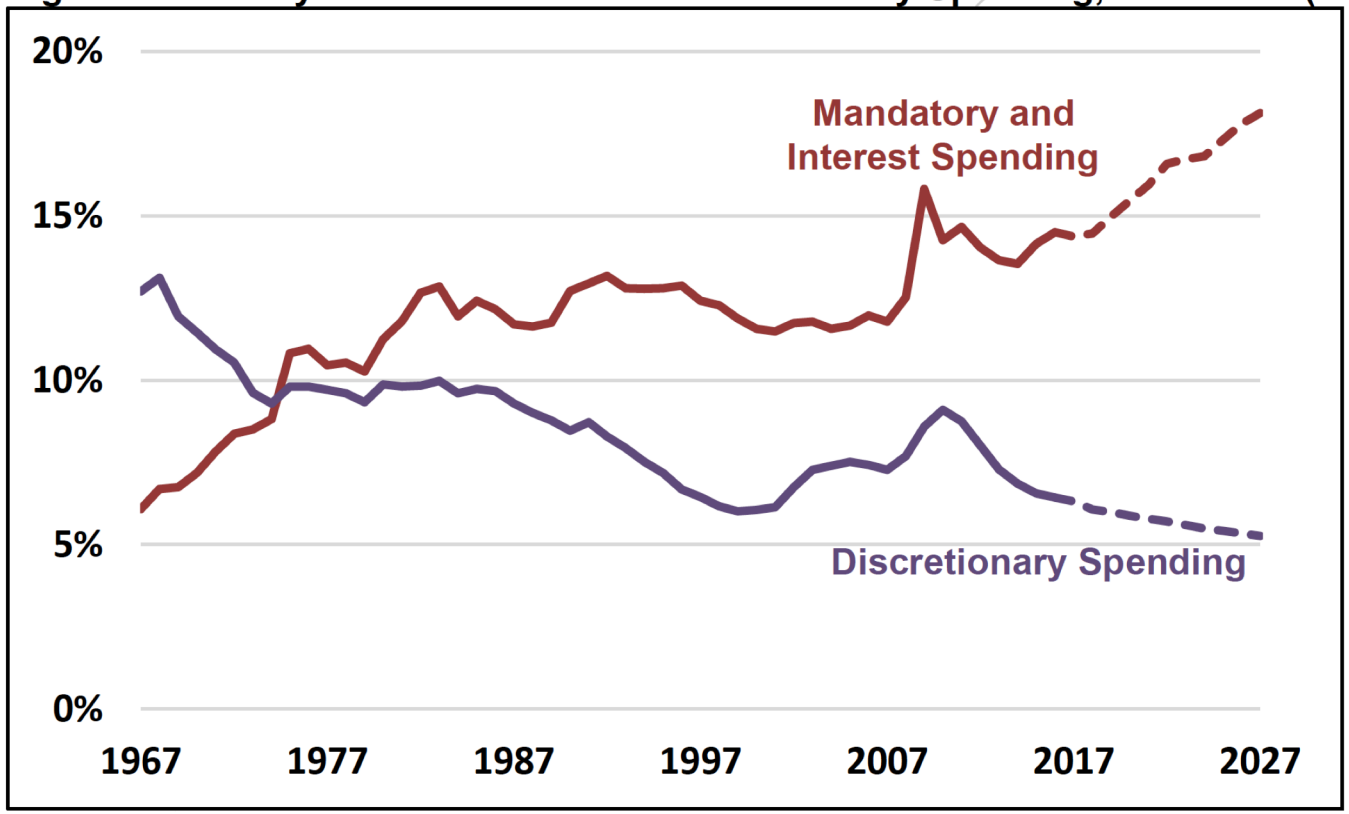
  win wars but "they" have dramatically reduced casualties



Politicians take from R&D, especially R, because it is politically the least risky and expedient thing to do

The threat to creating pathways to future economic growth and future military capabilities

Fig. 4: Mandatory and Interest Versus Discretionary Spending, 1967-2027 (Percent of GDP)



Source: Congressional Budget Office.

Increasing short-term needs

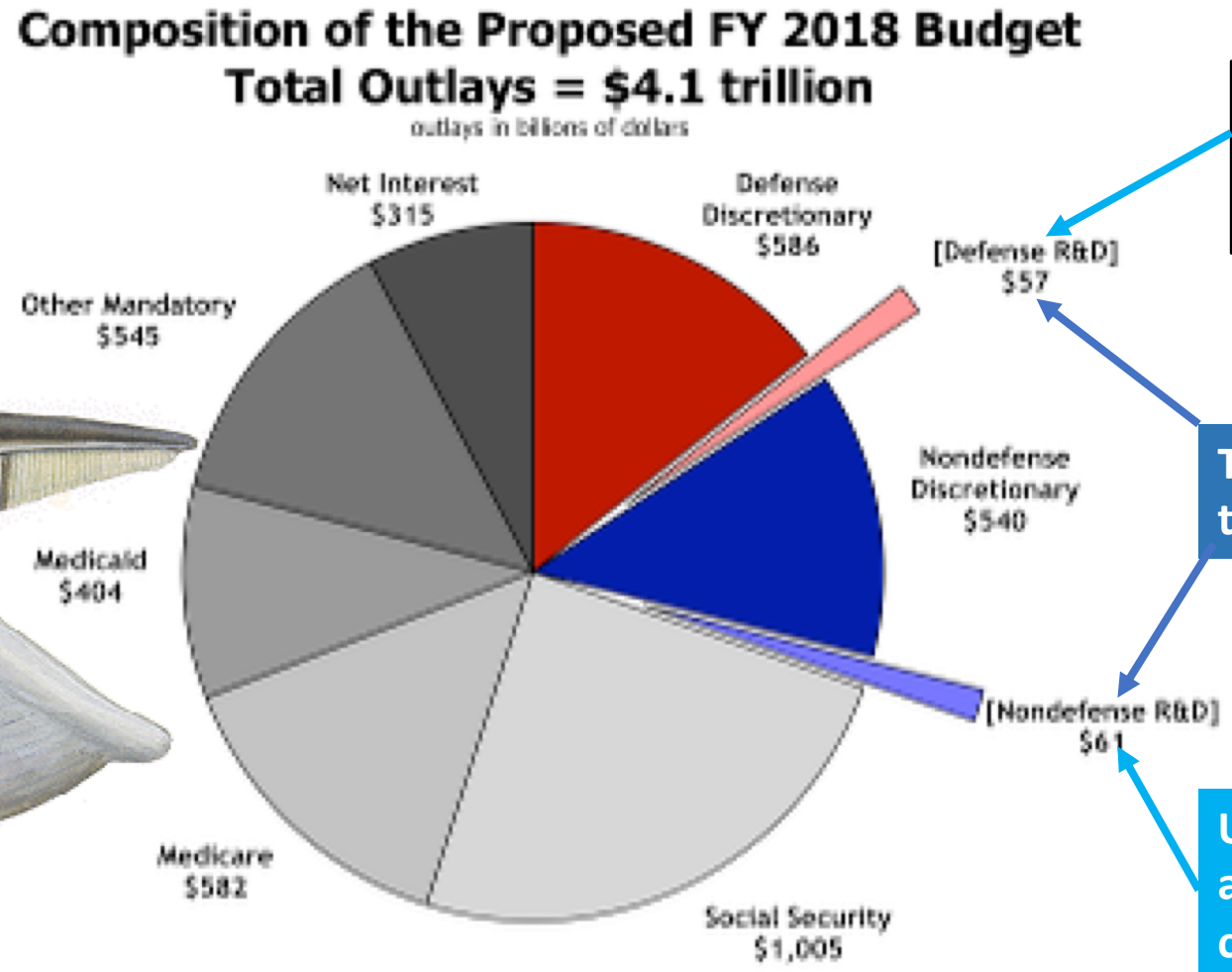
In 2019, total defense spending is 70% of all discretionary spending

Basic research excluding health science is 0.09% of GDP

Short-term needs cannot create economic growth or future military capabilities

A whale swallowing a Tic Tac

Courtesy of the Center for Coastal Studies



This is dominated by a hierarchical authoritarian culture of efficiency

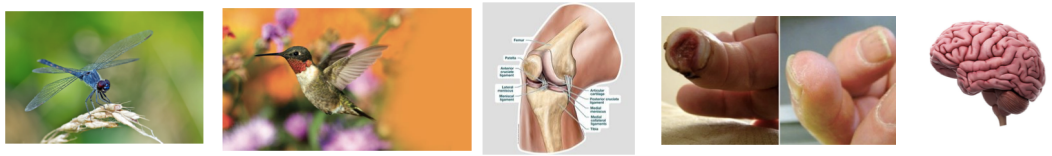
These are the investments to create our future

Under pressure for results and investments are constrained by political factors

Solution

- As history shows, borrow from the future but invest in the cause of economic growth that has potential to payback more than what was borrowed – *create unrelated unpredictable patterns*
- Adopt a Future Economic Opportunities Index (FEOI) as a matter of government policy
  - The ratio of federal R&D spending to GDP
  - Increase this to just 2% over 15 years from 0.6% today
  - Utilize all the intellectual capacity in our nation free from politics to define the 5 star questions at the frontiers of science, engineering, and mathematics
  - Assess the state of the experimental art and theory to determine opportunities for the advancement of knowledge in strategic R&D areas

- Leverage the large investment in genomic science by pursuing the science of all living things (SALT)
  - The living world sets the scale for capability performance from the TOP!



Our government is not structured to pursue the science of all living things

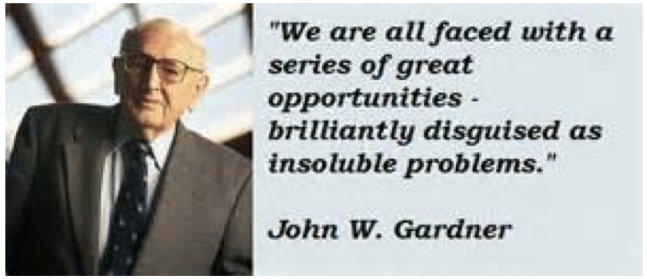
Some wisdom

“He who possesses most must be most afraid of loss.”

Leonardo da Vinci

“We pay a heavy price for our fear of failure. It is a powerful obstacle to growth. It assures the progressive narrowing of the personality and prevents exploration and experimentation. There is no learning without some difficulty and fumbling. If you want to keep on learning, you must keep on risking failure all your life.”

John W. Gardner



“Imagination is more important than knowledge”

A. Einstein