Technology and Innovation Management

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Science, Technology, and Innovation
(the ‘macro’ story)

The AI research frontier: China and USA

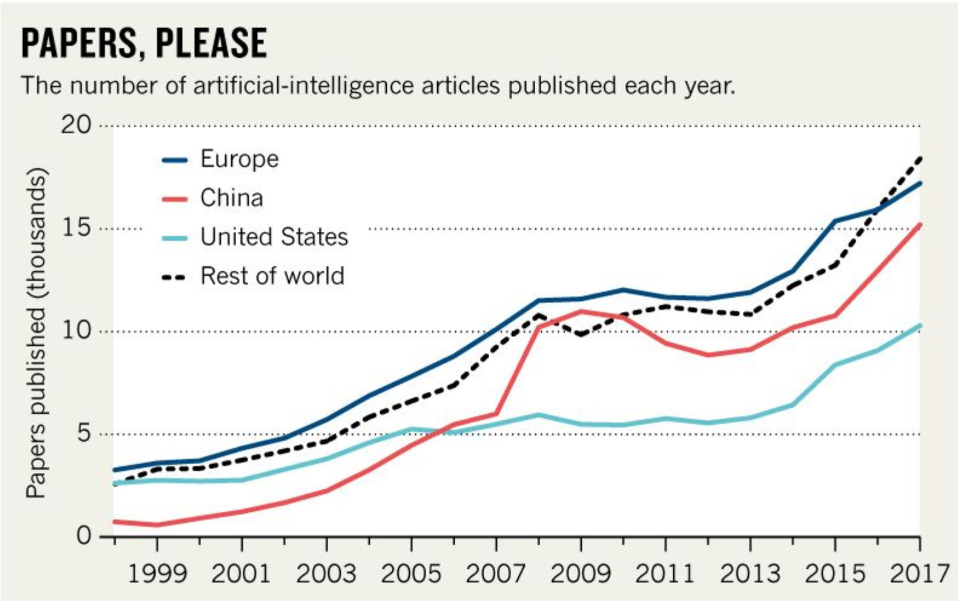
China is about to overtake America in AI research

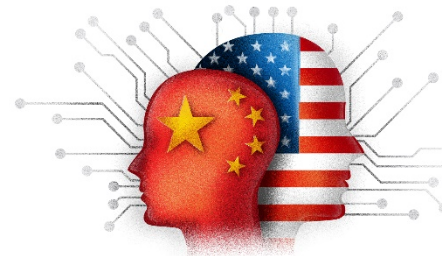
China will publish more of the most-cited 50 percent of papers than America for the first time this year

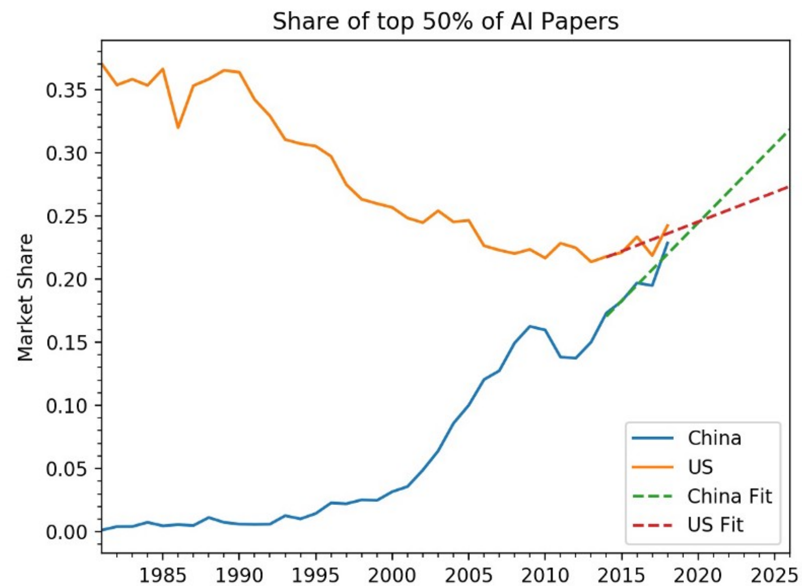
(The Verge, 2019)

Source: Google images

Leading in the AI frontier – research quantity



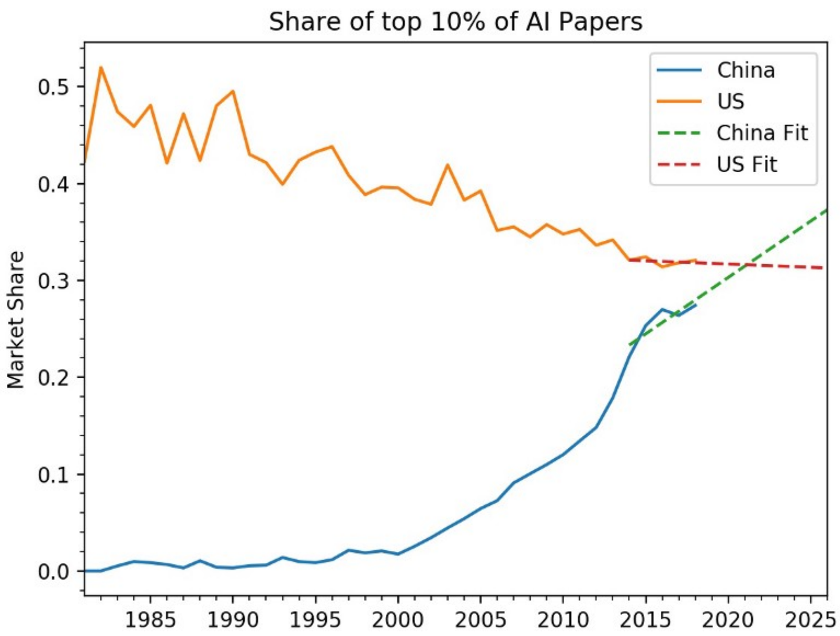


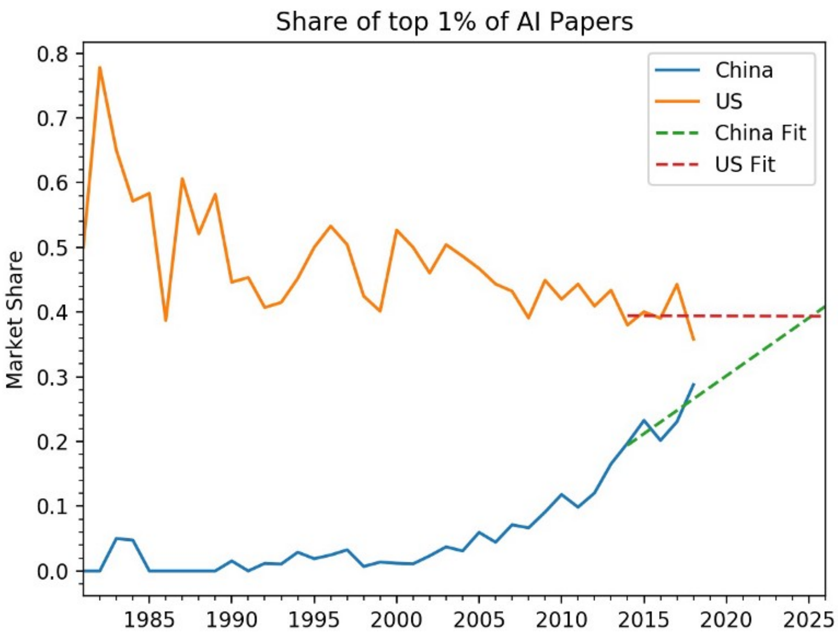


- China is surpassing the U.S. in total numbers of publications and share of top 50% papers

Source: Nature, Allen Institute for Artificial Intelligence, Google images

Leading in the AI frontier – research quality





- China is expected to surpass the U.S. in share of top 10% and top 1% of AI publications

Source: Allen Institute for Artificial Intelligence

Science, Technology, and Innovation
(the ‘macro’ story)

Learning objectives

Key concepts

- Long waves of economic development

The long term view: technology and growth

- Some evidence, at various levels of analysis

Emerging issues

- Decreasing investments in R&D? Discussion

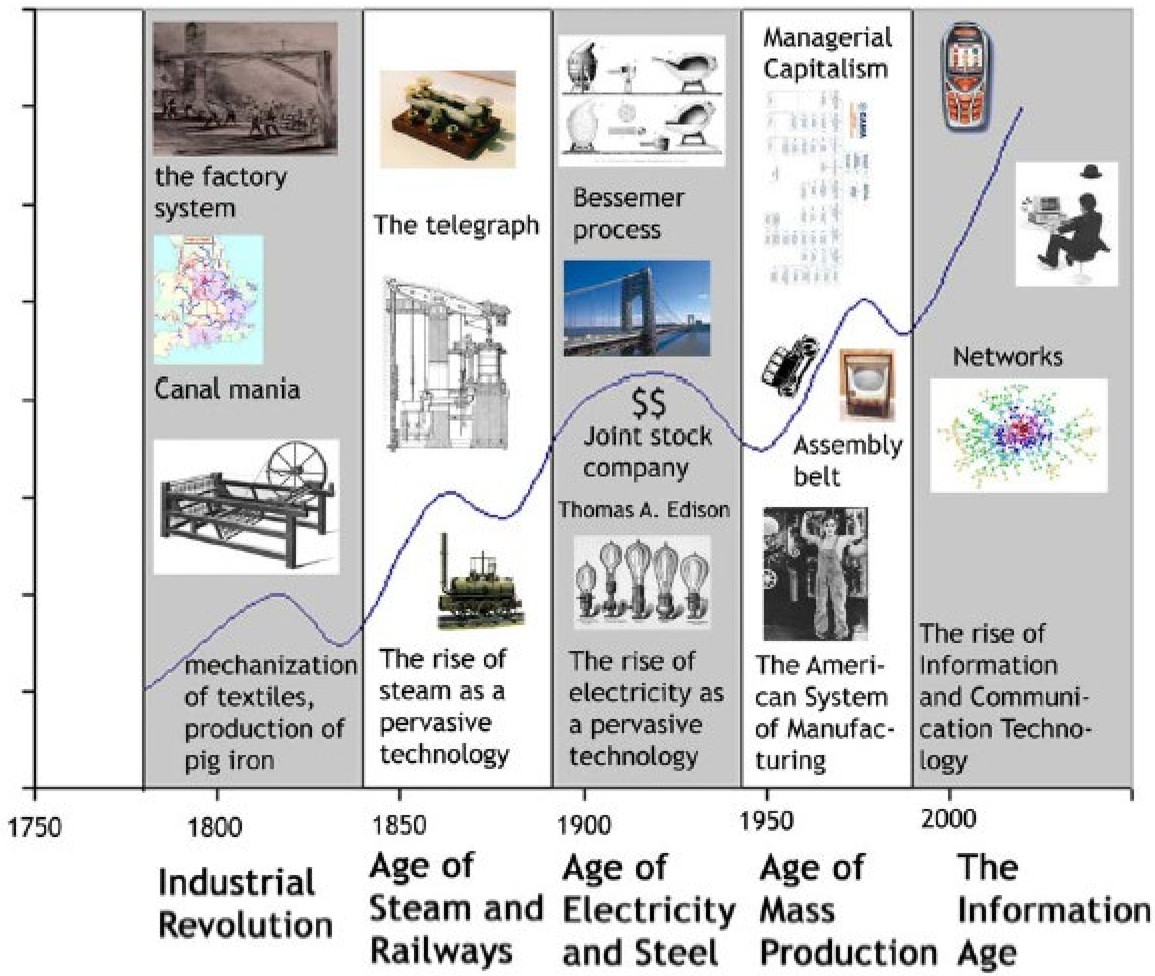
Required Readings for today

- Perez, C. (2010). Technological revolutions and techno-economic paradigms. Cambridge journal of economics, 34(1), 185-202.
- Arora, A., Belenzon, S., & Patacconi, A. (2015). Killing the golden goose? The decline of science in corporate R&D (No. w20902). National Bureau of Economic Research.
- Arora, A., Belenzon, S., & Sheer, L. (2017). Back to Basics: Why do Firms Invest in Research? (No. w23187). National Bureau of Economic Research. (page 1-9 only)

Suggested Readings for today

- Freeman, C., & Louça, F. (2001). As time goes by: the information revolution and the industrial revolutions in historical perspective. Oxford University Press. Pp. 139-151 and Chapter 6.
- OECD (2002). Proposed Standard Practice for Surveys on Research and Experimental Development. *The Measurement of Scientific and Technological Activities Series. Paris*.

Technology and long term growth



Source: Verspagen (2006) adapted from Freeman and Soete (1997)

Technological and organizational trajectories

Technological trajectories	Organizational trajectories
The quest for time saving innovation in the cotton industry *Flexibility through mechanization*	Factory work (1° and 2° waves) to control time and pace *Wedgwood's pottery (& early steps of marketing practices)*
The quest for flexible energy *Steam power (larger, more efficient)*	
The quest for large scale production (chemicals, steel) *Scale economies, high pressure reactions, flow production, catalysis*	Cost accounting (3° wave) *Andrew Carnegie and US Steel* Time & Motion studies (3° to 4° waves) *FW Taylor and Scientific Management*
The quest for cheap mobility *Internal combustion engine (small, reliable, efficient)*	Moving assembly line (4° wave) *Henry Ford and mass production/consumption*
The quest for cheap computational power *Semiconductors (smaller, faster)* *Software, now AI …*	Networks (5° wave) *Big Tech and internet enabled organizational forms (platforms?)*

Teaching case: a closer look at “the quest for computational power”

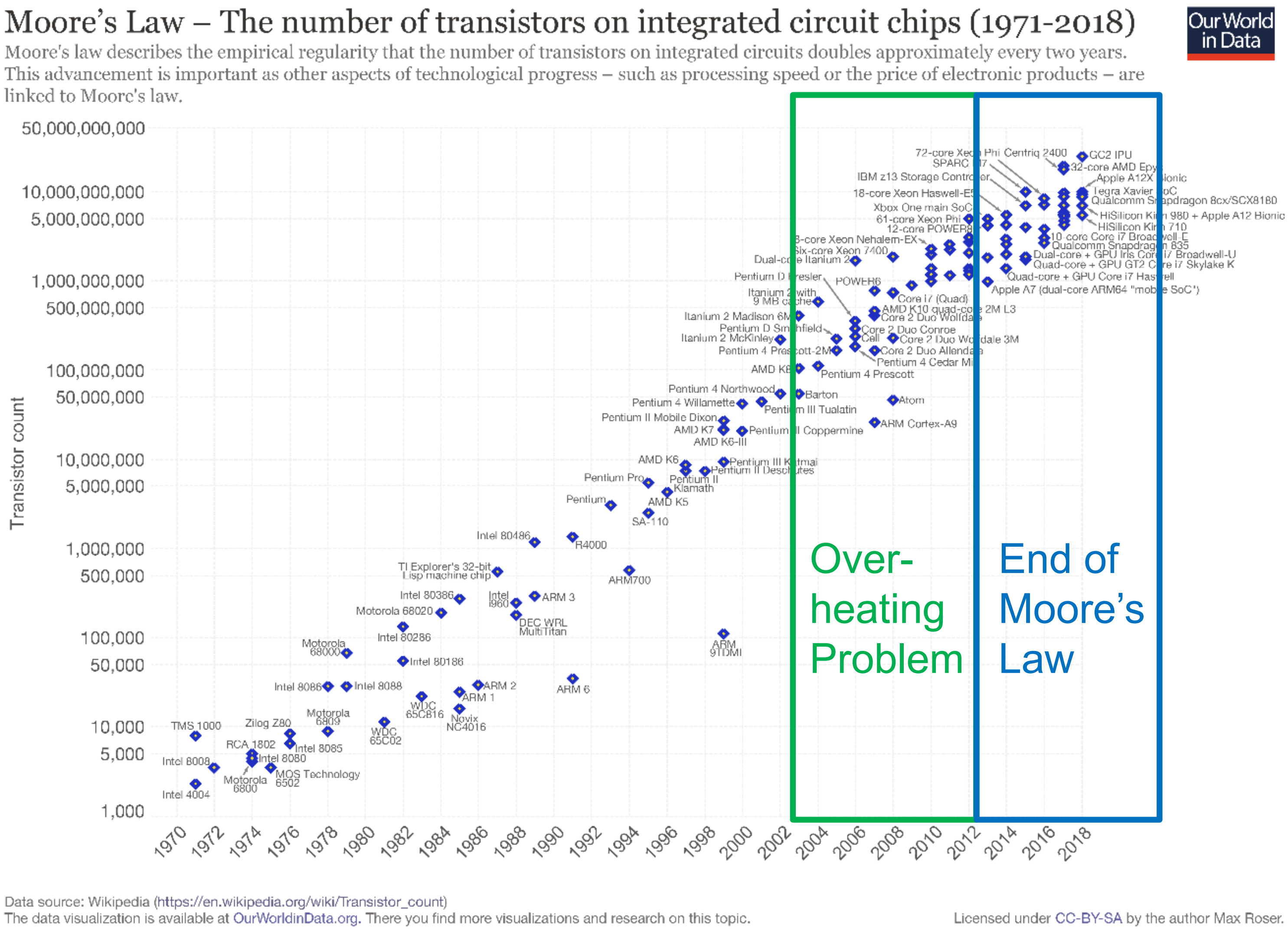
The quest for cheap computational power

Semiconductors (smaller, faster)

Software, now AI …

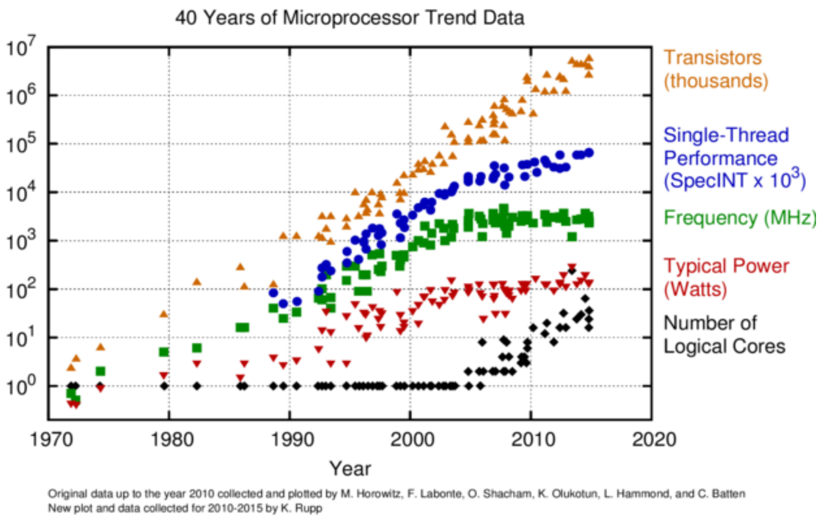
Given trajectories, predictions are easy. Right?

Case study: Stability and change in the semiconductor industry

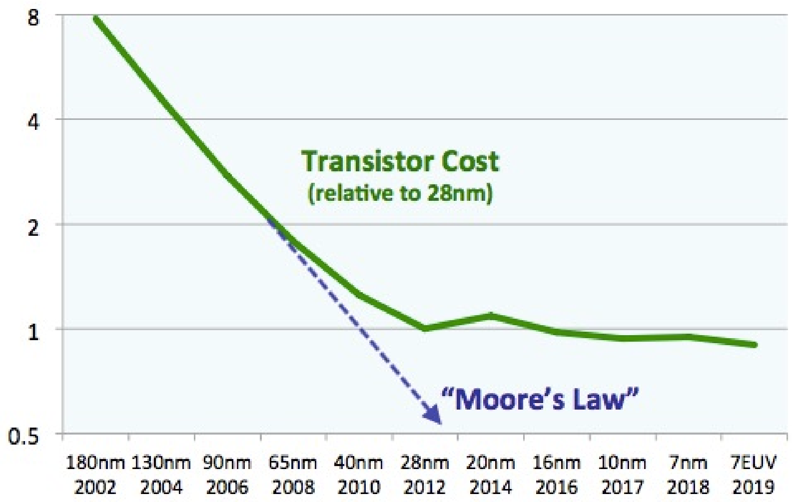


Technological challenges

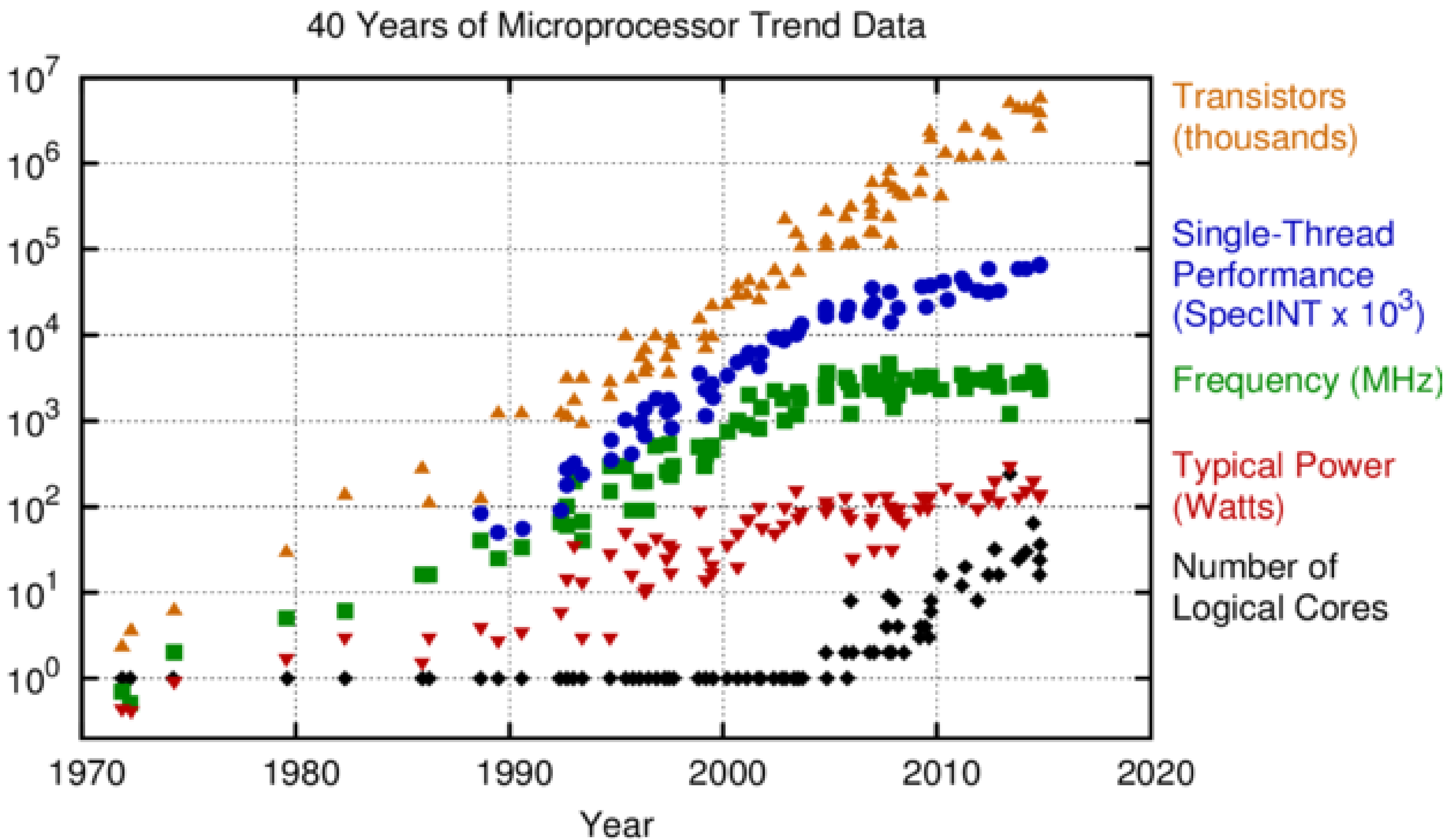
2004: Overheating problem



2012: End of Moore's law



Q1: How would you track technological progress in this industry?



Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2015 by K. Rupp

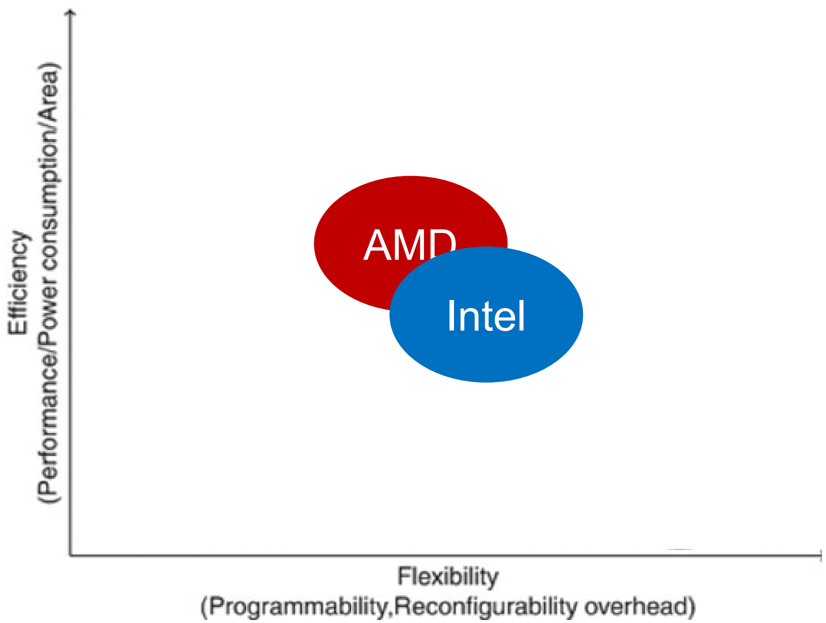
Q2: How do the technology trajectories of Intel and AMD differ?

- Before 2004
  - Small differences
  - Intel was ahead in fabrication
  - AMD was ahead in processor architecture
- After 2004
  - Intel faced overheating first in April 2004
  - AMD had one year to plan and introduced its dual-core processor in May 2005
  - AMD’s market share grew in between 2004-2006
  - Intel introduced its dual-core processor in 2006 and took back AMD’s market share growth

Q2: How do the technology trajectories of Intel and AMD differ?

- Between 2004 and 2012
  - AMD acquired ATI to improve their processor architecture
  - AMD spun off its fabrication side
  - Intel increased its focus on the server market
  - Intel refused Apple's request to make its iPhone's chips

- After 2012
  - Intel kept investing in fabrication and adding more functionalities to compensate higher costs
  - AMD focused on their processor architecture, i.e. graphics



Larger repercussions

Between 2004 and 2015

arm

XILINX

Qualcomm

After 2015

Google

TESLA

Alibaba Group 阿里巴巴集团

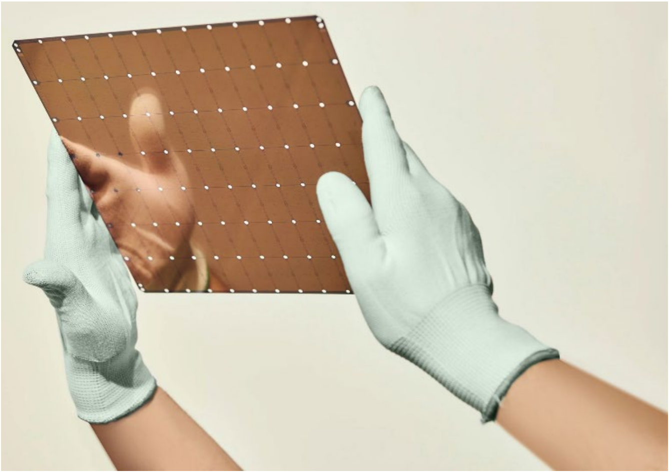
facebook

Future of the industry?

August 2019:

Cerebras announced a 1.2 Trillion transistor chip

(which was Moore's law's prediction for year 2028)



*actual size

September 2019:

TSMC announced that Moore's is "not dead, it's not slowing down, it's not even sick."

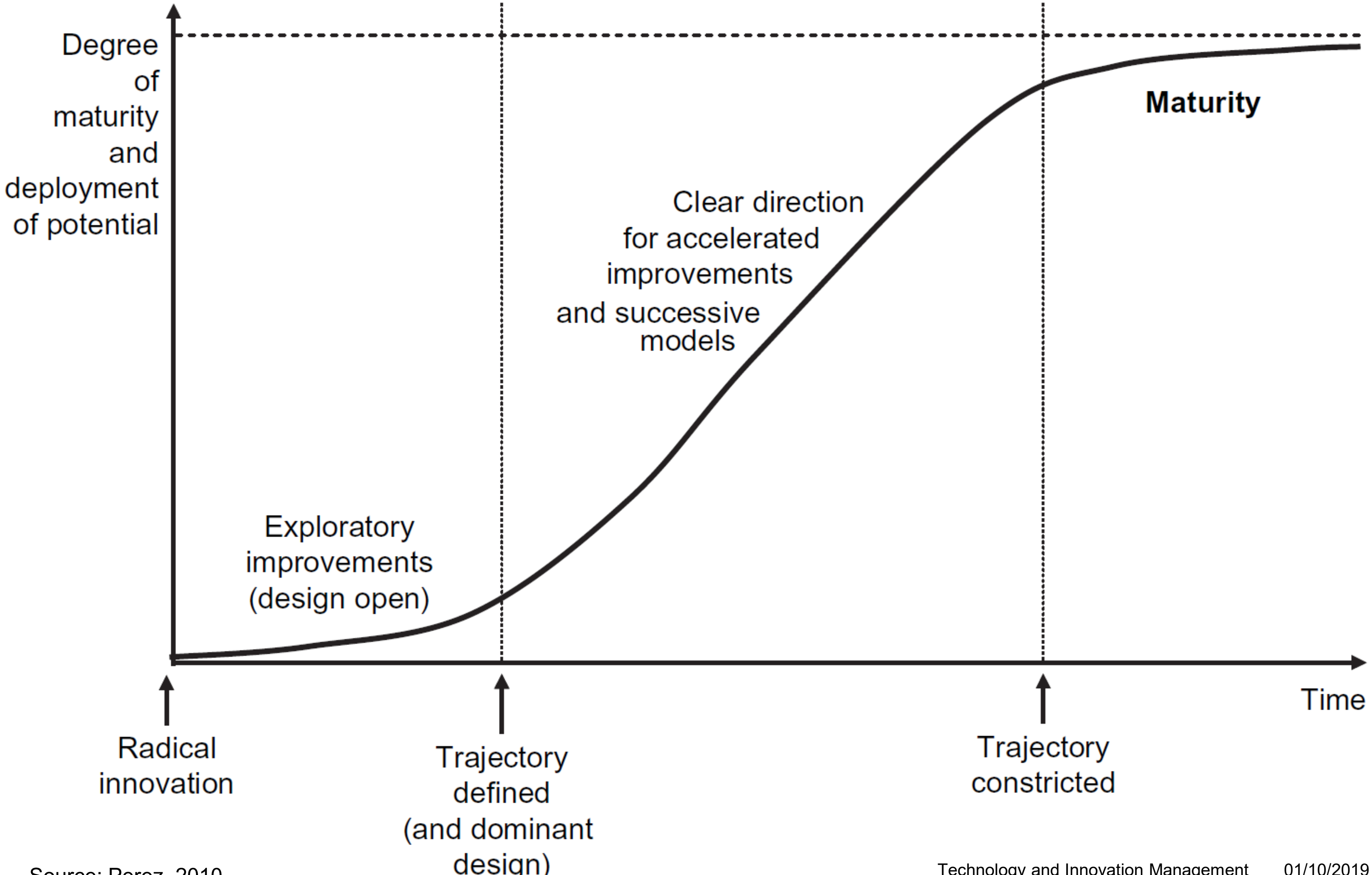
- As long as clients ask them to, they can keep Moore's law alive for the foreseeable future

https://www.tomshardware.com/news/cerebras-wafer-scale-engine-department-of-energy-supercomputer-wse,40416.html
https://www.cnet.com/news/processor-progress-is-alive-and-well-tsmc-builder-of-apple-iphone-chips-says/

Generalizing Technology Trajectories

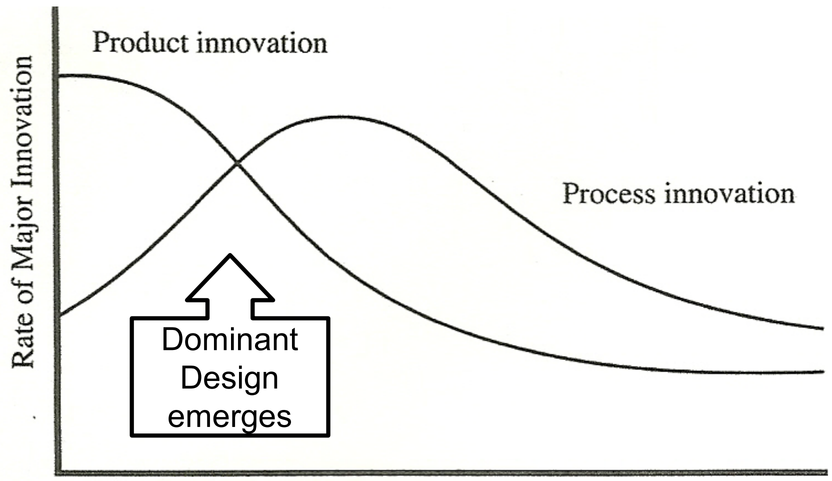
- The semiconductor industry was characterized (and guided!) by Moore's law.
  - And yet, we observe firm-level heterogeneity in strategy (e.g. AMD vs. Intel)
- Several metrics of performance doubled every two years.
  - And yet, not all dimensions of performance can be improved at the same time (e.g. flexibility vs. efficiency)
- Most industries/technologies go through a period of rapid progress, but inevitably slow down eventually
  - The eternal, pervasive S-curve!

The trajectory of individual technologies

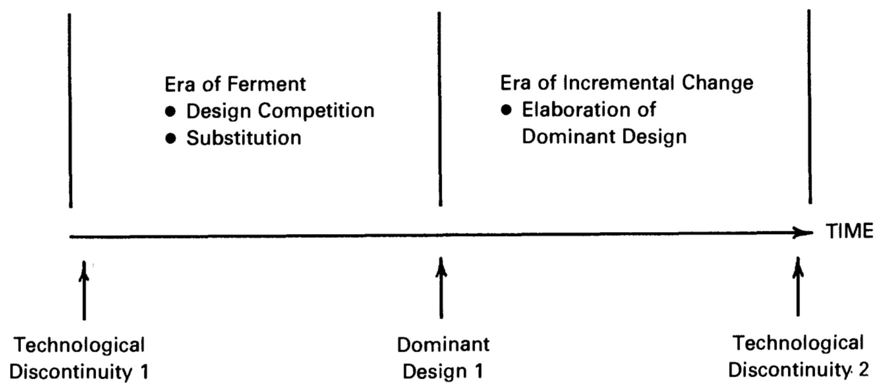


Source: Perez, 2010

Innovation and Industry development



Adapted from Utterback, 1994



Anderson & Tushman, 1990

Era of Ferment

- Trial and error in product design (competition)
- Inefficient processes (expensive, unreliable)
- Number of competitors grows

Dominant Design emerges

- Architecture-level dominant design
- Major Process improvements (production – efficient/effective)
- Number of competitors declines

Era of Incremental change

- Incremental improvements (component-level)
- Scale-driven, highly efficient (the war on cost)
- Sizable competitor structure

Adapted from HKUST Business School

Does Science lead to Technology (always)?
(technology push vs demand pull innovation)

J. D. Barnal (1954) Science in History.
Pavitt K. (1984) Sectoral patterns of technical change. *Research Policy*. 13: pp.343-73

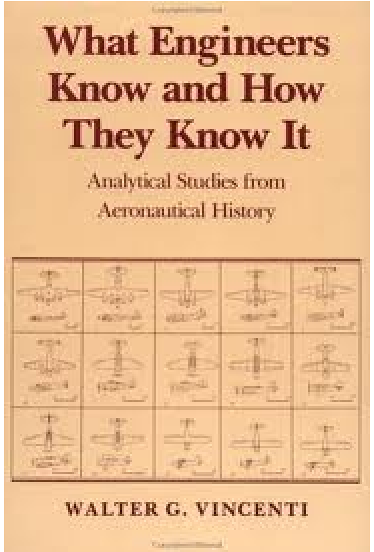
Machine building
S ------------| | ------------- T

Process engineering
S ------------ > ------------- T

Power and flying
S ------------ < ------------- T

Electrical, electronic, chemicals, pharmaceuticals

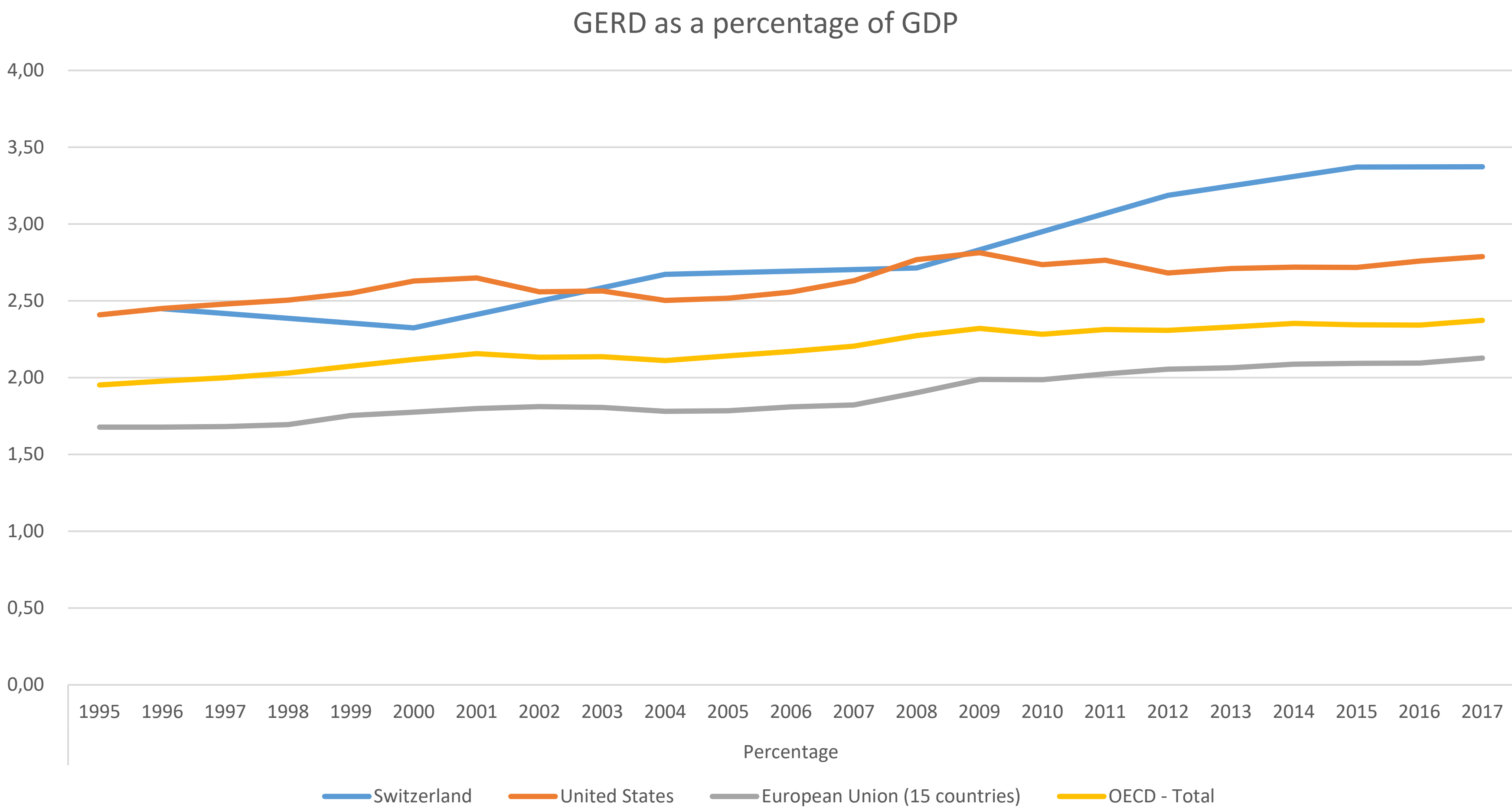
S ------------ >> ----------- T



Can we (really) separate scientific and technological developments?

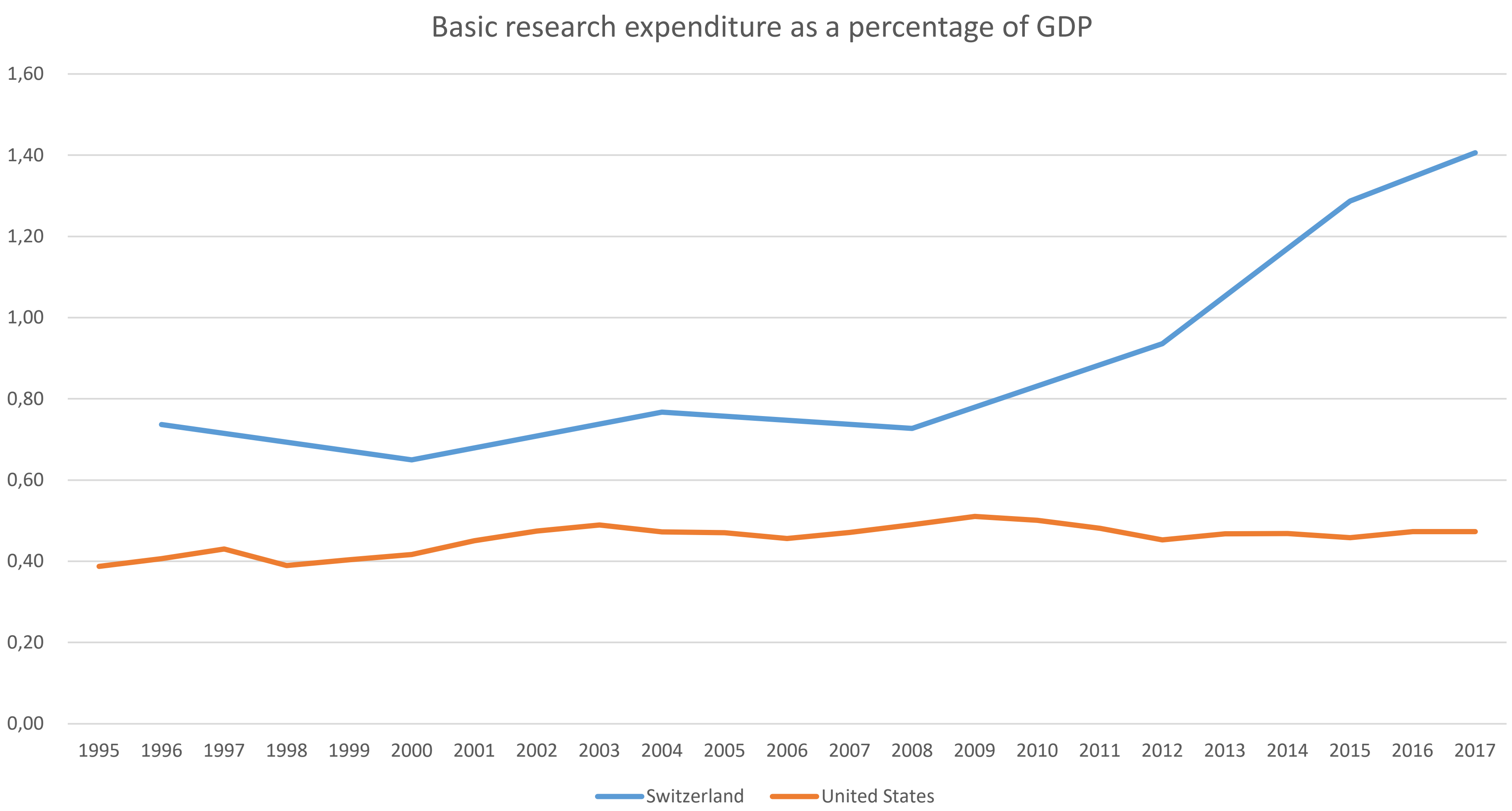
Type of activity	Purpose	Essential (tacit) skills	Discipli-nary base	Main Outputs	Location
Scientific development	**To develop and test generalizable theories** (to measure)	**To simplify to the essential to allow prediction**	**Single or few** (but note changes from 1990s onwards)	**Papers** **Skills** (techniques) (networks)	**Universities, but also large firms' R&D labs and communities**
Techno-logical development	**To develop and test specific artefacts** (to measure)	**To integrate the essential to ensure target performance**	**Several** (engineers as integrators)	**Artefacts** **Skills** (patents) (papers) (operating instructions)	**Business firms, hospitals, but also universities** (consultants)

R&D, by the numbers:



Source: OECD. GERD = **Gross** domestic **expenditure on R&D**

R&D, by the numbers:



Source: OECD

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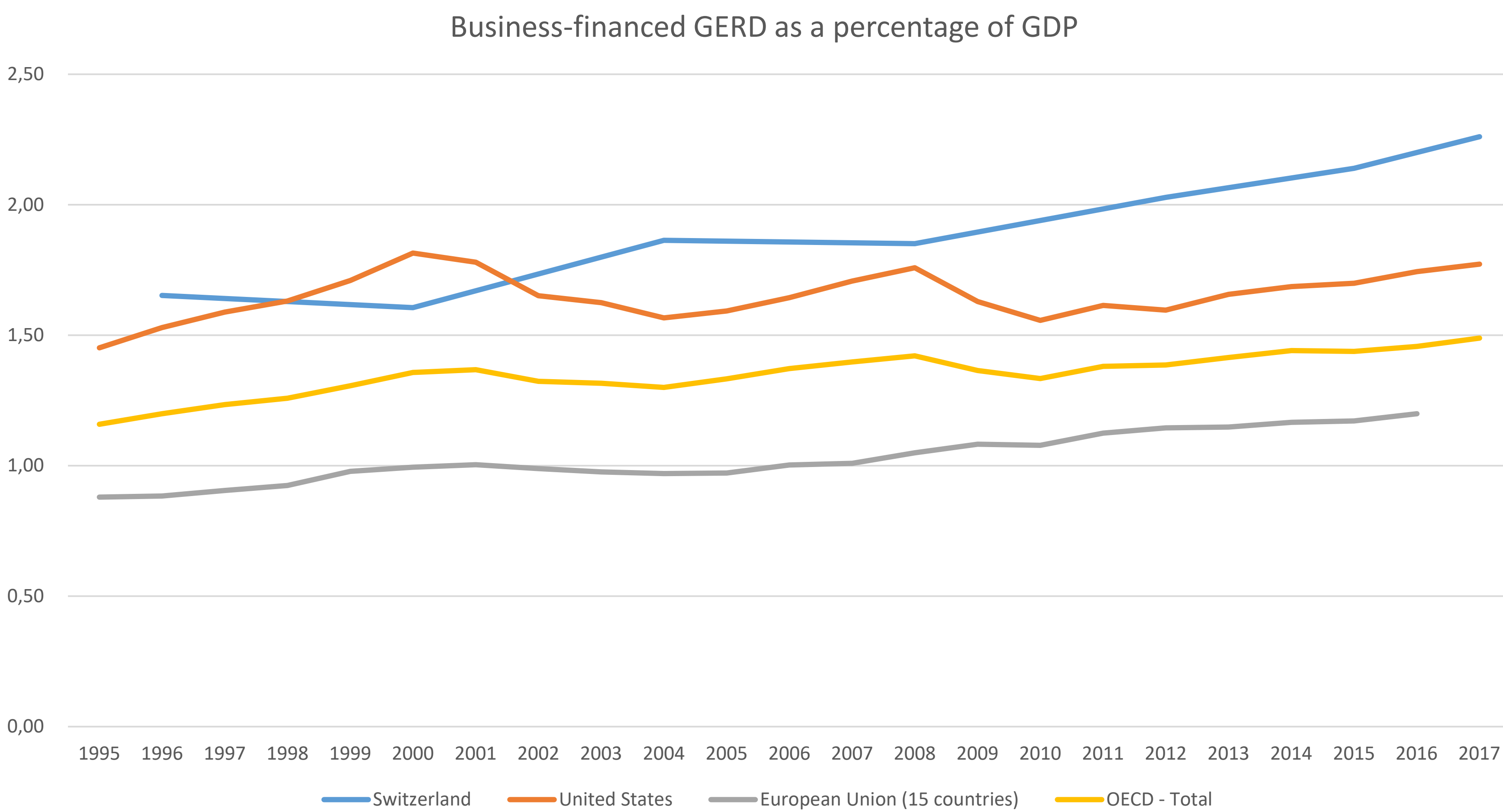

Source: OECD

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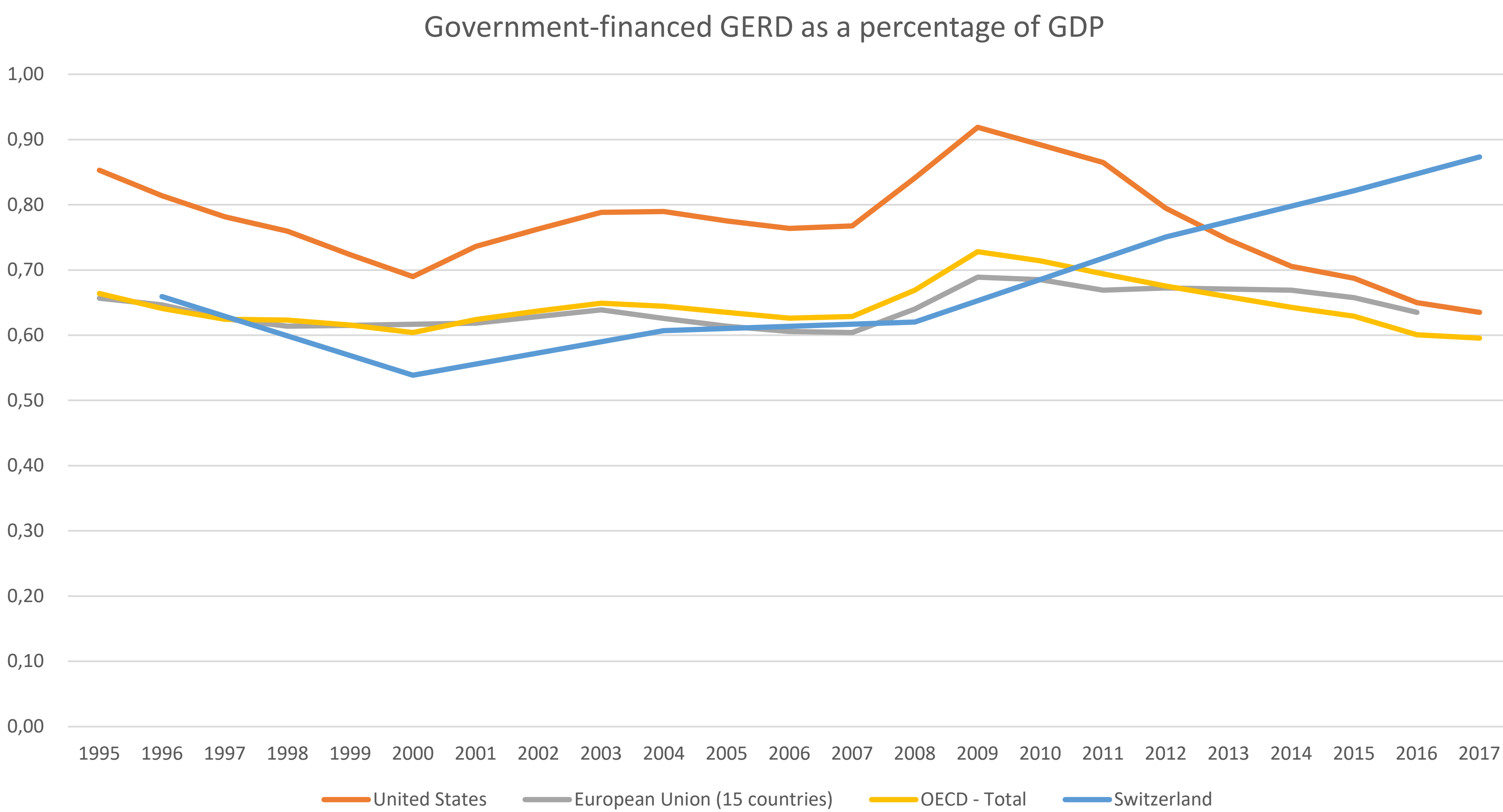


Source: OECD

Why do private firms spend money on R&D?

- **Scientific knowledge as an input into invention**
  - The linear model: basic research leads to new knowledge, from which technology development can draw
  - Scientific knowledge makes downstream inventive activity more efficient (even without direct benefits)

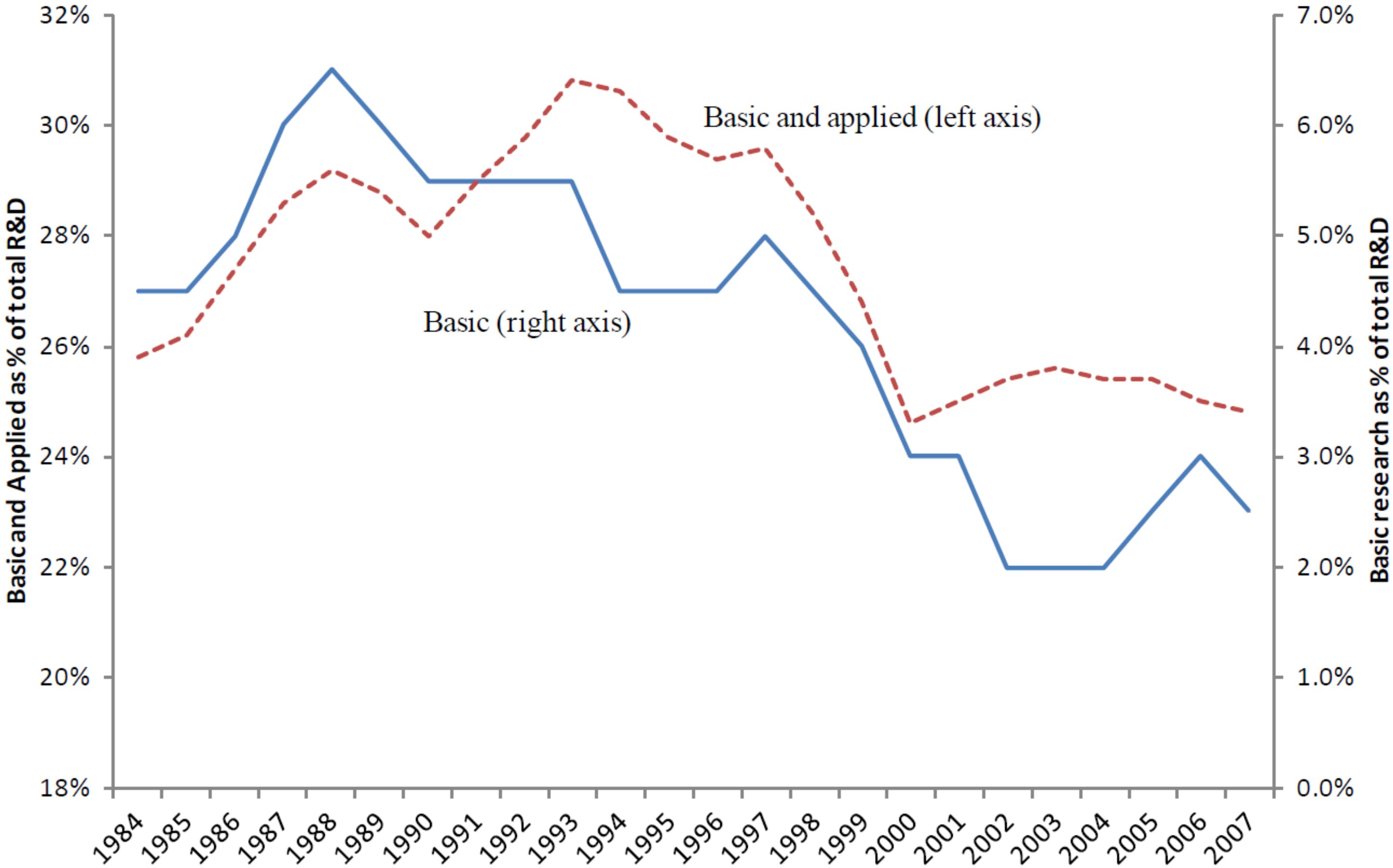
- **Absorptive capacity**
  (scientific knowledge is publicly *available*, but not necessarily *usable*)
  - Firms need their own scientific knowledge to understand others' discoveries (including their competitors)
  - Complementarities between internal and public research

- **Attracting talented inventors**
  - Staff with a "taste for science"
  - Positive relationship between intellectual challenge and innovative output

- **Signaling to consumers, investors, regulators**
  - Publications build a reputation for quality
  - Importance depends on sector (e.g. biotech) and maturity (start-ups)

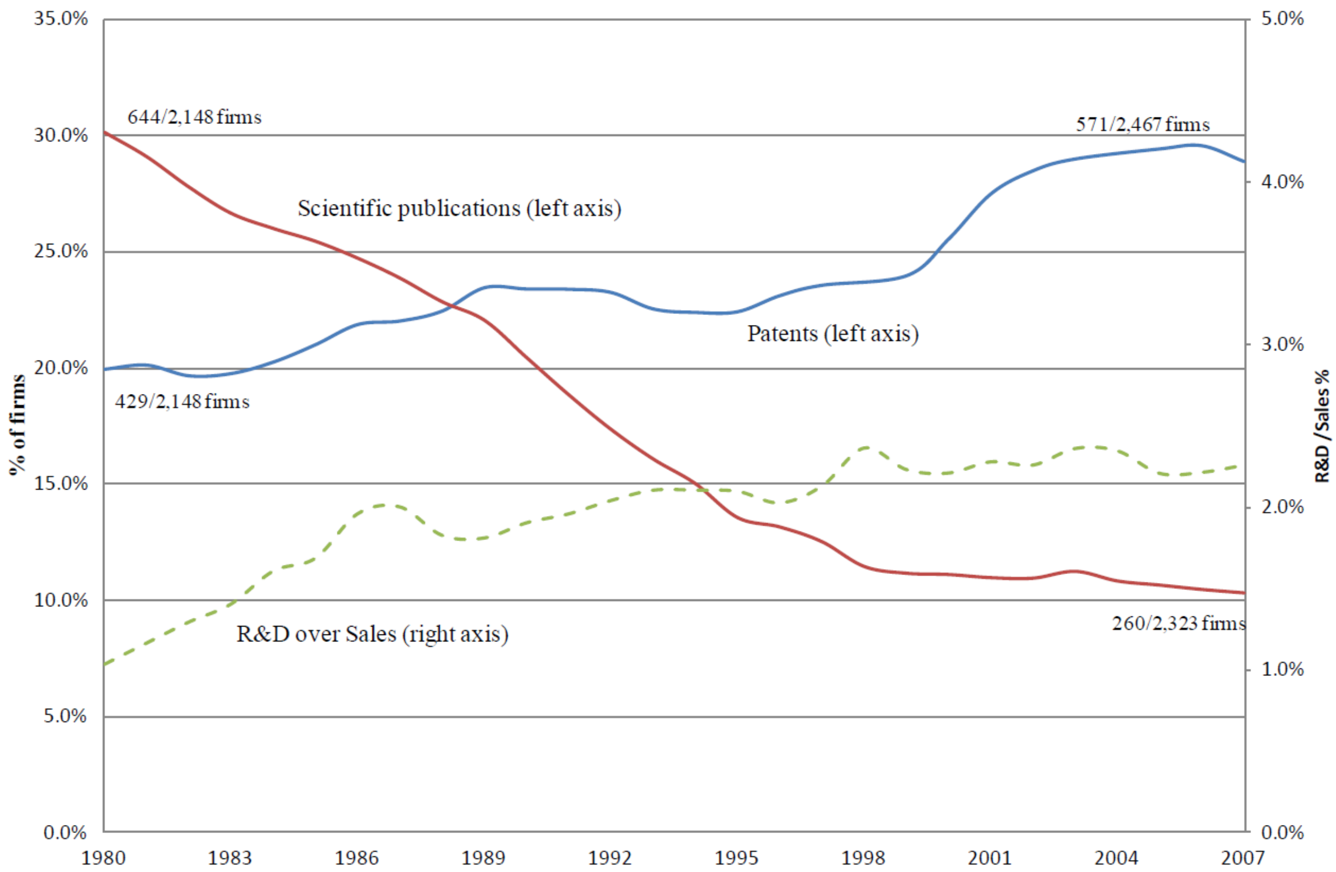
Source: Arora et al., 2017

Are we killing the golden goose? The 'R' in R&D is declining



Source: Arora, Belenzon, Patacconi (2015)

Are we killing the golden goose? Investment in technology vs. science



Source: Arora, Belenzon, Patacconi (2015)

The decline of research: what is happening?

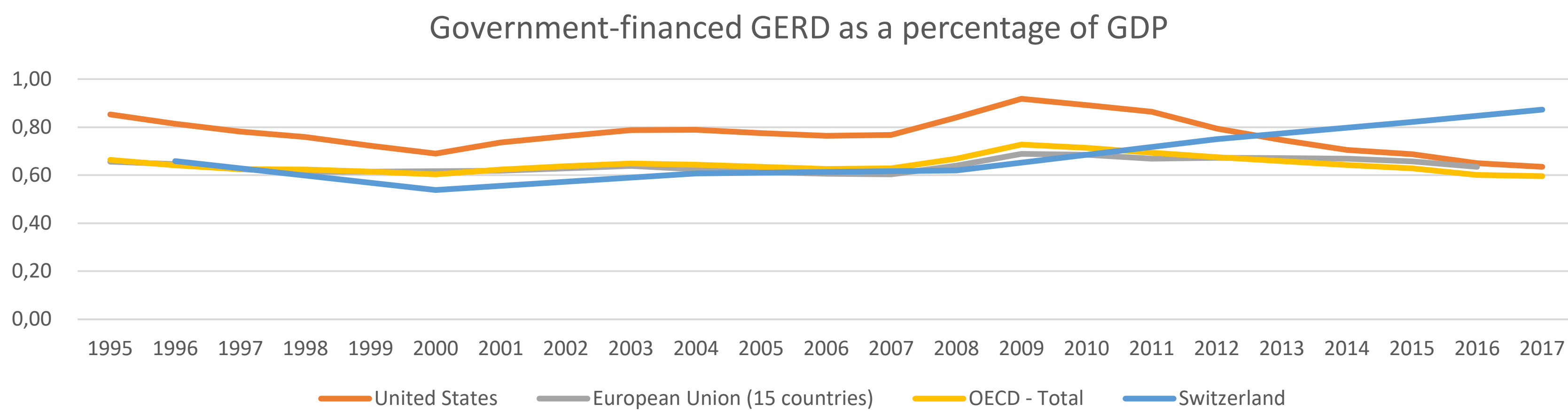
- Investments in scientific research by firms is declining
- The implied value of scientific capabilities is declining as well

    while:
- Science remains important for inventions
- Absorptive capacity is more important if science is more specialized
- Patent and copyright laws have made easier to protect scientific knowledge

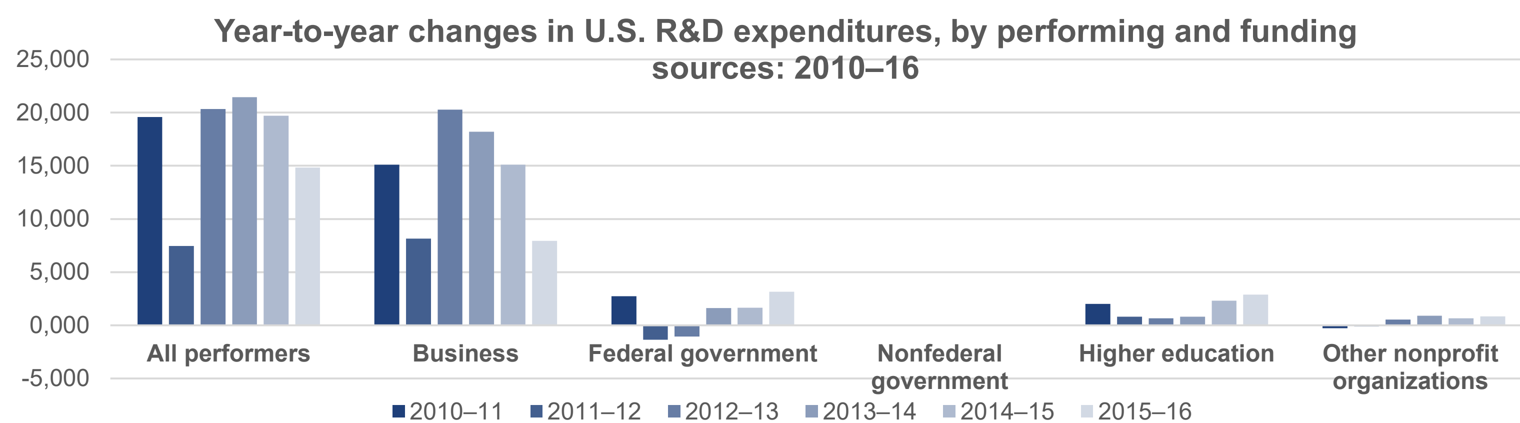
Explanations:
1. Globalizing competition
    - Driving commercial application and protection of knowledge
2. Specialization
    - In scope of activities: knowledge is less likely to be useful the less you do
    - And to different parts of the value chain (revisited later this course)
3. Focus on short-term and incremental progress

Source: Arora, Belenzon, Patacconi (2015)

Is there a compensation effect elsewhere?



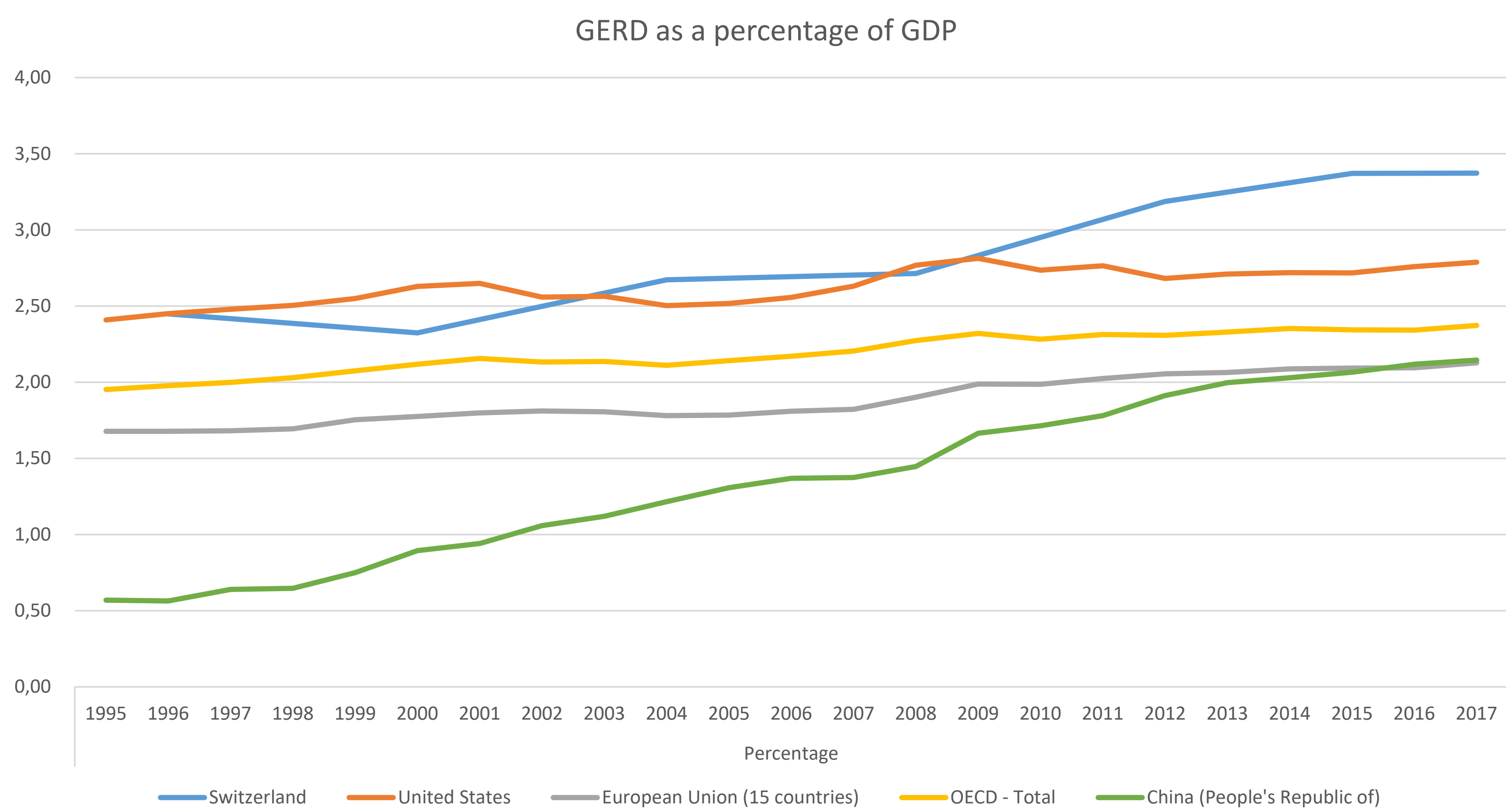
1: Public R&D funding is not filling the gap



2: Upstream institutions are not taking over the scientific inputs

Source: OECD (top), NSF (bottom); bottom: vertical axis is current $Bn

Changes in industrial leadership?



Source: OECD

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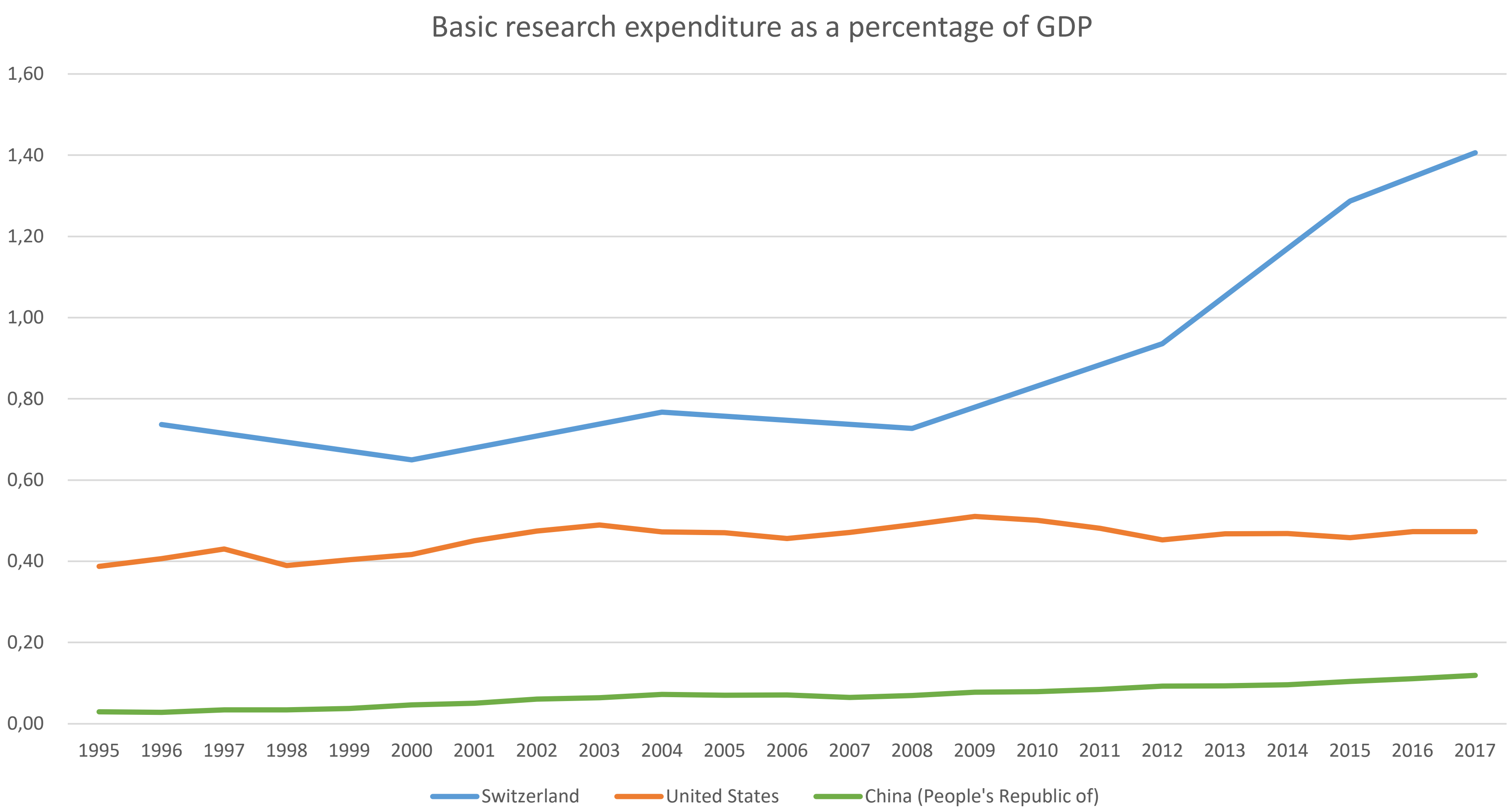

Source: OECD

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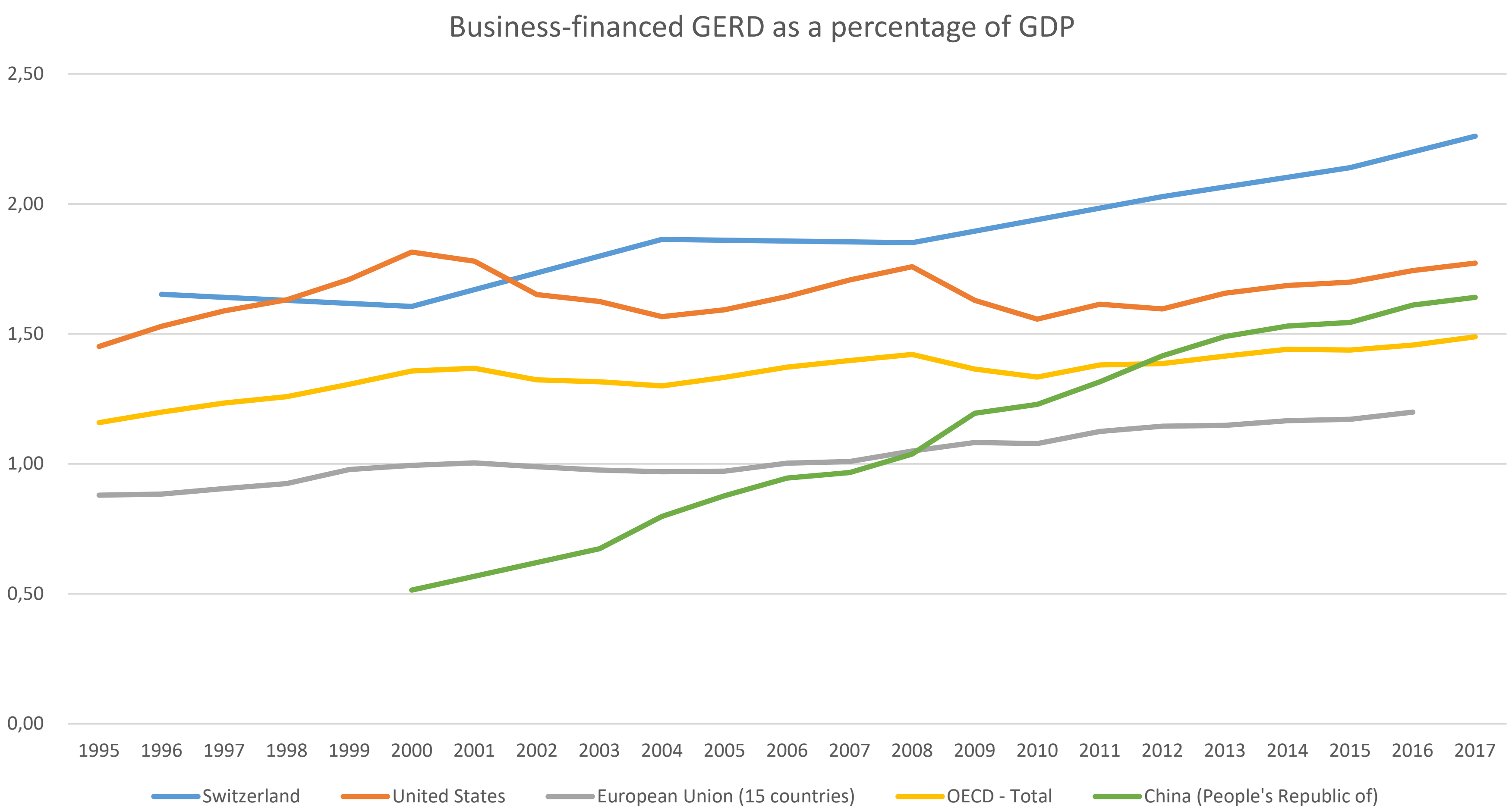

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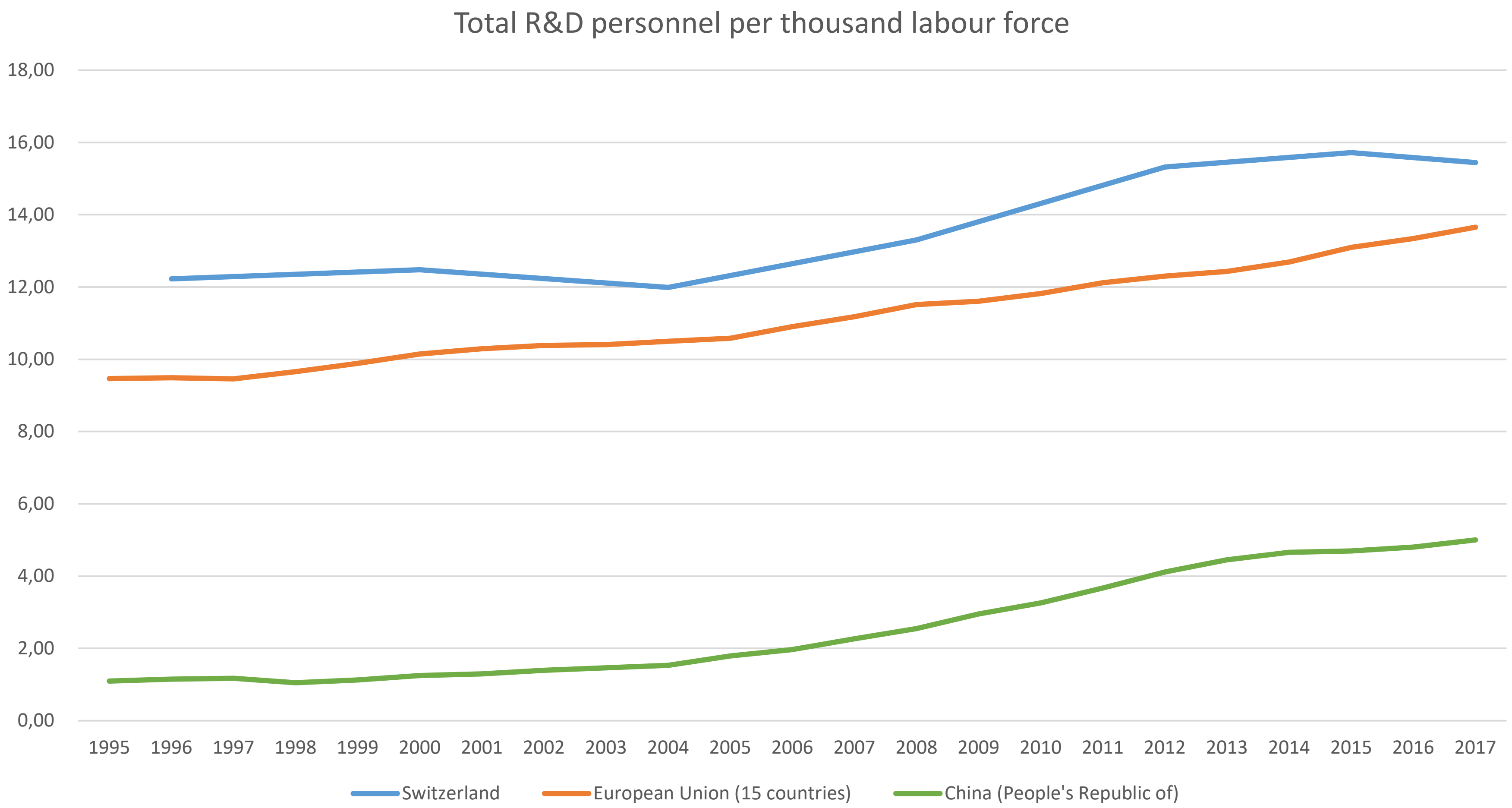

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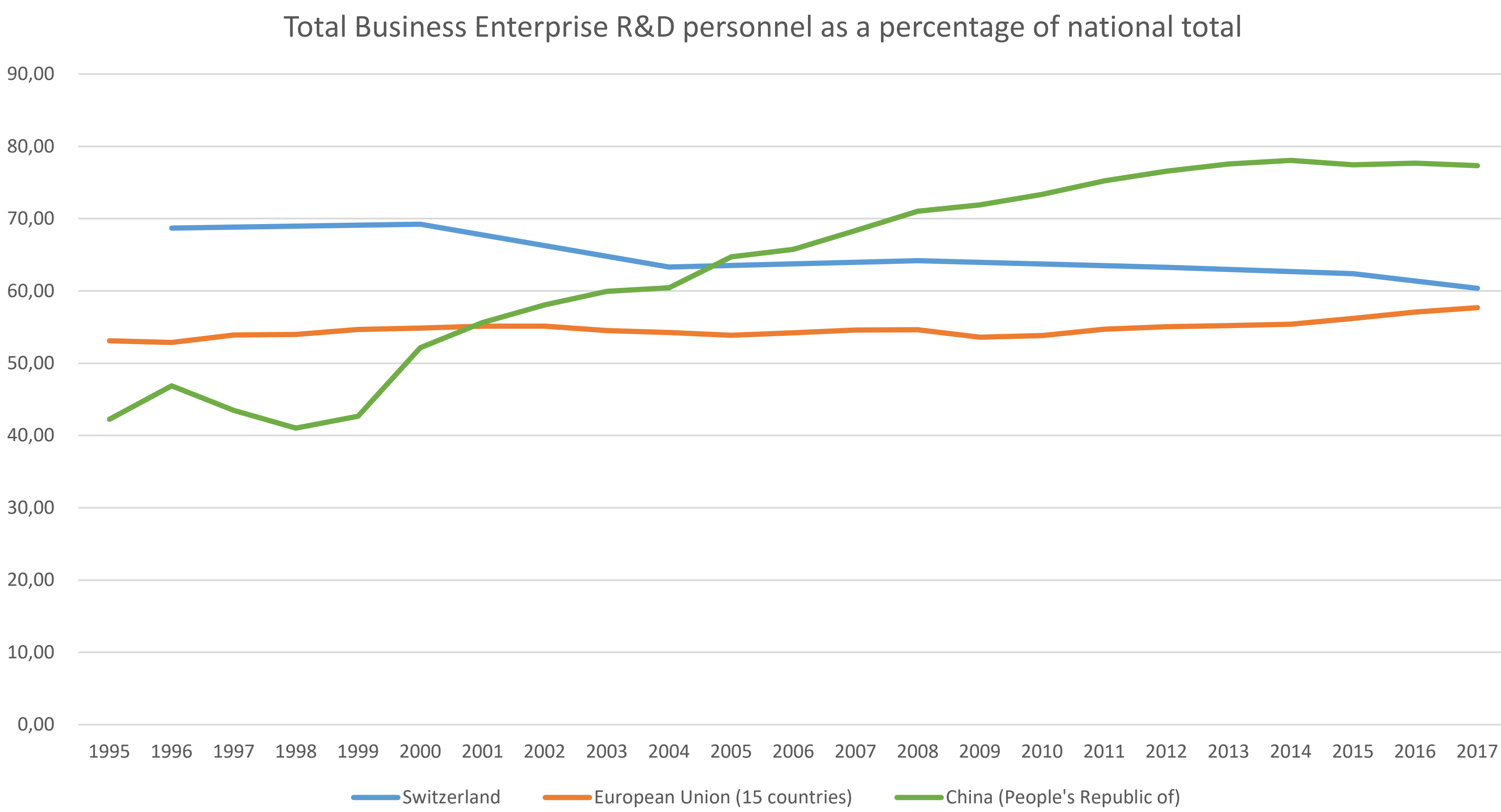

Source: OECD

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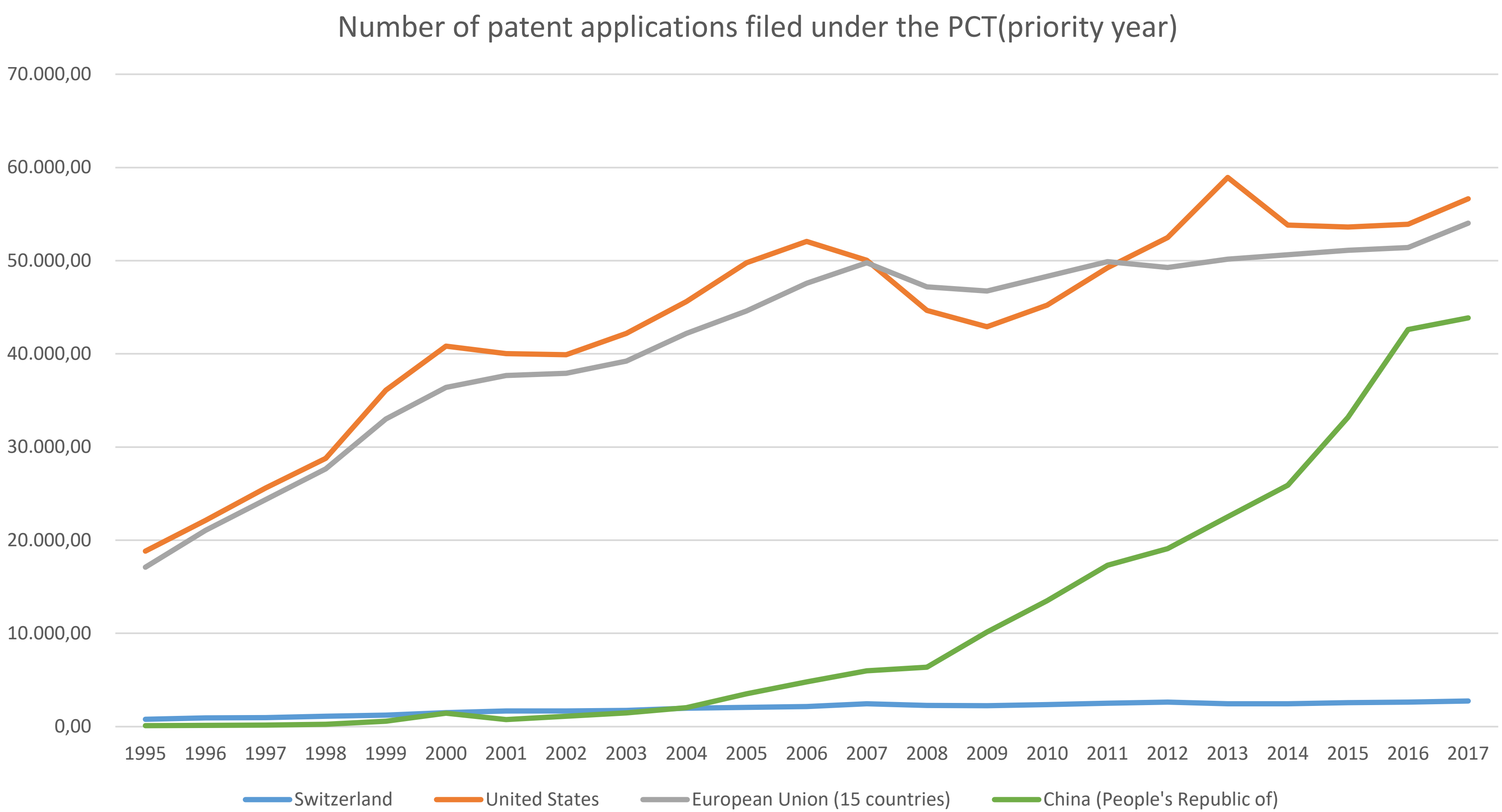

Source: OECD. PCT = Patent Cooperation Treaty, the international patent application system

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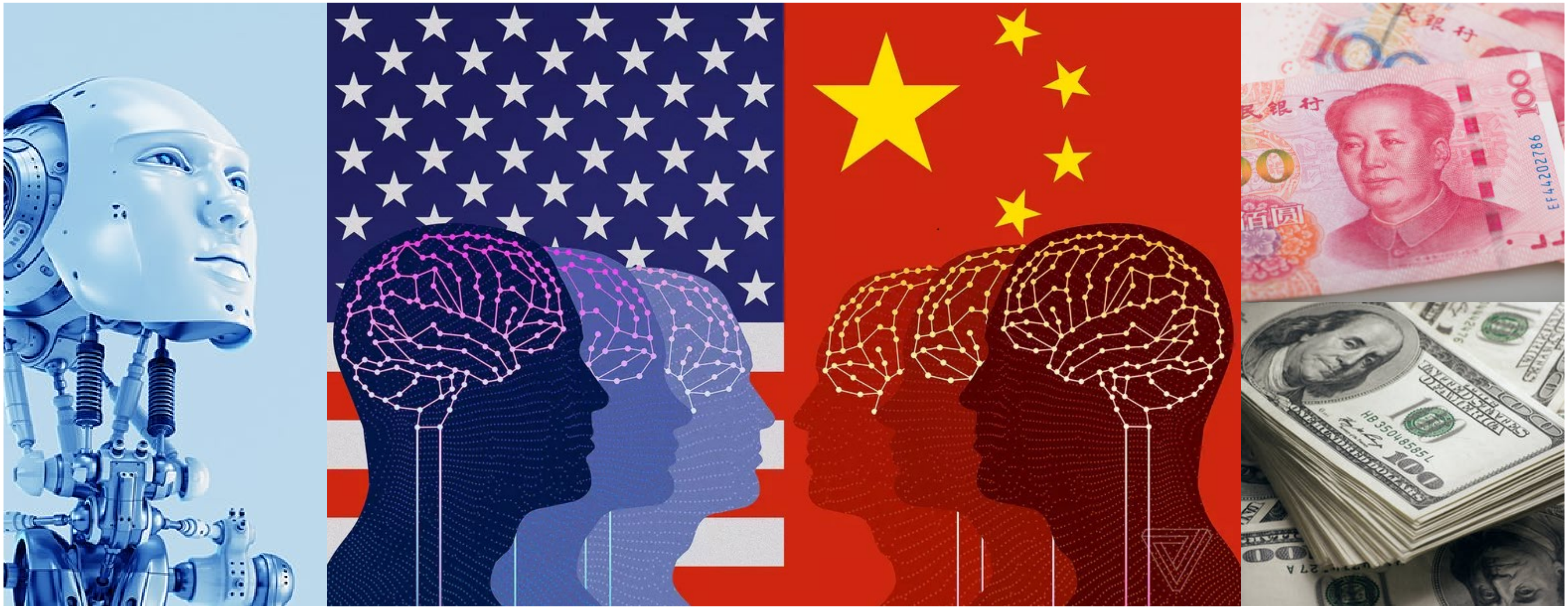

Source: Google images

Learning objectives

Key concepts

- long waves of economic development: technology and growth, crisis

The long term view: technology and growth

- Some evidence, and dynamics

Emerging issues

- Decreasing investments in R&D? Ouch.