Information Technology and the U.S. Workforce

Where are we and where do we go from here?

The National Academies of
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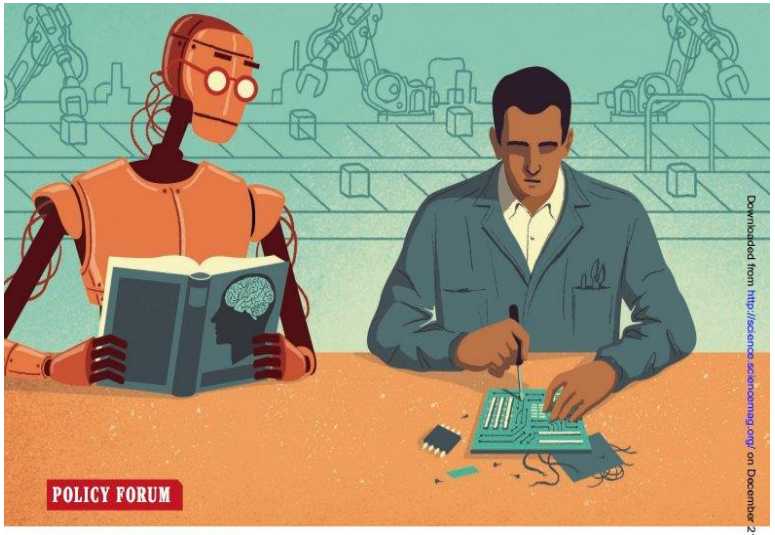
Track how technology is transforming work

Without data on how artificial intelligence is affecting jobs, policymakers will fly blind into the next industrial revolution, warn Tom Mitchell and Erik Brynjolfsson.

Science



POLICY FORUM

TECHNOLOGY AND THE ECONOMY

What can machine learning do? Workforce implications

Profound change is coming, but roles for humans remain

By **Erik Brynjolfsson**[1,2] *and* **Tom Mitchell**[3]

Digital computers have transformed work in almost every sector of the economy over the past several decades (*1*). We are now at the beginning of an even larger and more rapid transformation due to recent advances in machine learning (ML), which is capable of accelerating the pace of automation itself. However, although it is clear that ML is a "general purpose technology," like the steam engine and electricity, which spawns a plethora of additional innovations and capabilities (*2*), there is no widely shared agreement on the tasks where ML systems excel, and thus little agreement on the specific expected impacts on the workforce and on the economy more broadly. We discuss what we see to be key implications for the workforce, drawing on our rubric of what the current generation of ML systems can and cannot do [see the supplementary materials (SM)]. Although parts of many jobs may be "suitable for ML" (SML), other tasks within these same jobs do not fit the criteria for ML well; hence, effects on employment are more complex than the simple replacement and substitution story emphasized by some. Although economic effects of ML are relatively limited today, and we are not facing the imminent "end of work" as is sometimes proclaimed, the implications for the economy and the workforce going forward are profound.

Any discussion of what ML can and cannot do, and how this might affect the economy, should first recognize two broad, underlying considerations. We remain very far from artificial general intelligence (*3*). Machines cannot do the full range of tasks that humans can do (*4*). In addition, although innovations

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ILLUSTRATION: DAVID BONAZZI/STEALINGMARKET

Committee's Charge

A National Research Council study will consider the possible impacts of automation and other applications of information technology on the U.S. workforce.

Consider current knowledge and open questions about

- drivers of increased automation;
- types and scale of jobs that might be affected;
- societal implications
- the timeframe for impact;
- implications for education, training, and workforce development.

The committee's report will set forth a research agenda and describe types and sources of data and analysis that would enhance understanding of the workforce impacts of IT and automation and inform future policymaking.

Committee Membership

ERIK BRYNJOLFSSON, Massachusetts Institute of Technology, *Co-Chair*
TOM M. MITCHELL, NAE, Carnegie Mellon University, *Co-Chair*
DARON ACEMOGLU, NAS, Massachusetts Institute of Technology
STEPHEN R. BARLEY, University of California, Santa Barbara
BARRETT S. CALDWELL, Purdue University
MELISSA CEFKIN, Nissan Research Center
HENRIK I. CHRISTENSEN, Georgia Institute of Technology
JOHN C. HALTIWANGER, University of Maryland, College Park
ERIC HORVITZ, NAE, Microsoft Research
RUTH M. MILKMAN, City University of New York
EDUARDO SALAS, Rice University
NICOLE SMITH, Georgetown University
CLAIR J. TOMLIN, University of California, Berkeley

Outline

- Technological landscape
- Impacts on productivity, employment, incomes
- Changes in the nature of work
- Data sources and methods
- Findings
- Research themes

The Technological Landscape

- Technology creation, then diffusion
- Digitization of everything
- Internet growth, computational speedups
- Widespread adoption of enterprise software
- Educational tools and platforms
- Peer-to-peer exchanges
- Cloud computing
- Internet of things
- Rapid advances in AI, fueled by machine learning

Internet Growth, Speedups

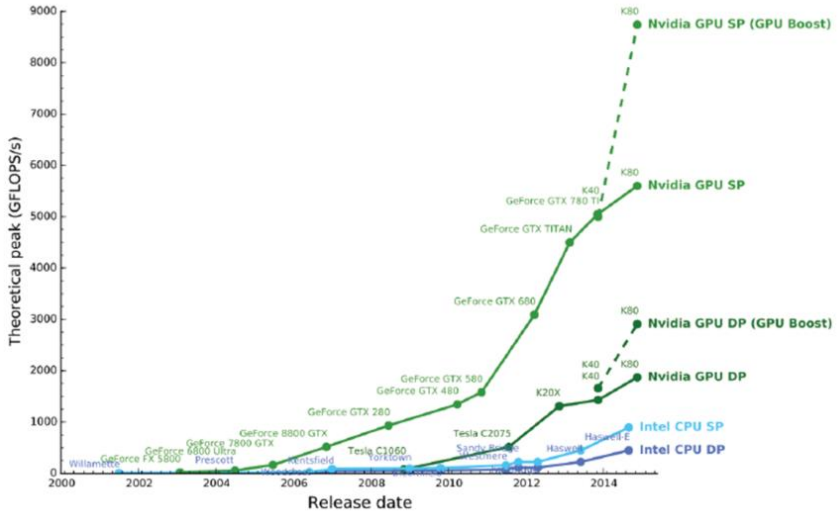


FIGURE 2.1 Illustration of approximate peak computing capacity of commercial processor lines since 2000. Vertical axis indicates the estimated theoretical peak performance of each processor model indicated in gigaflops (billions of floating point operations) per second. SOURCE: M. Galloy, 2013, "GPU vs. CPU Performance Data," *MichaelGalloy.com*, http://michaelgalloy.com/2013/06/11/cpu-vs-gpu-performance.html.

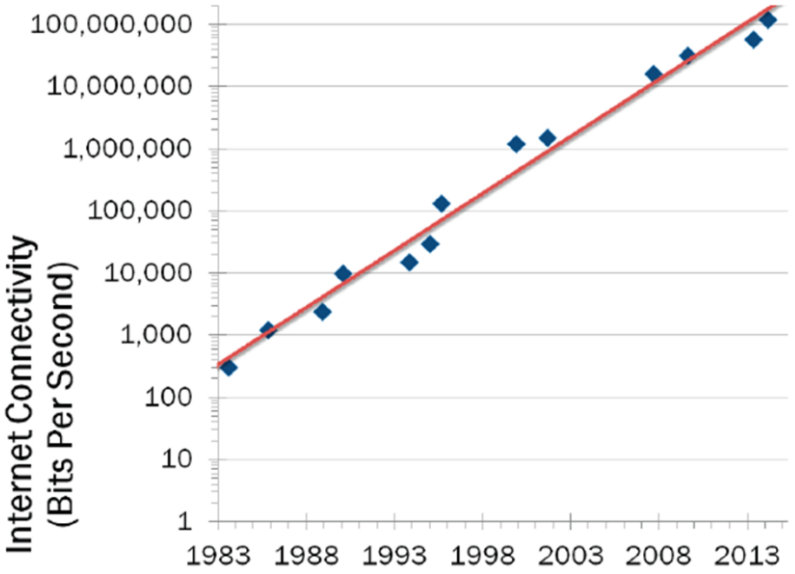
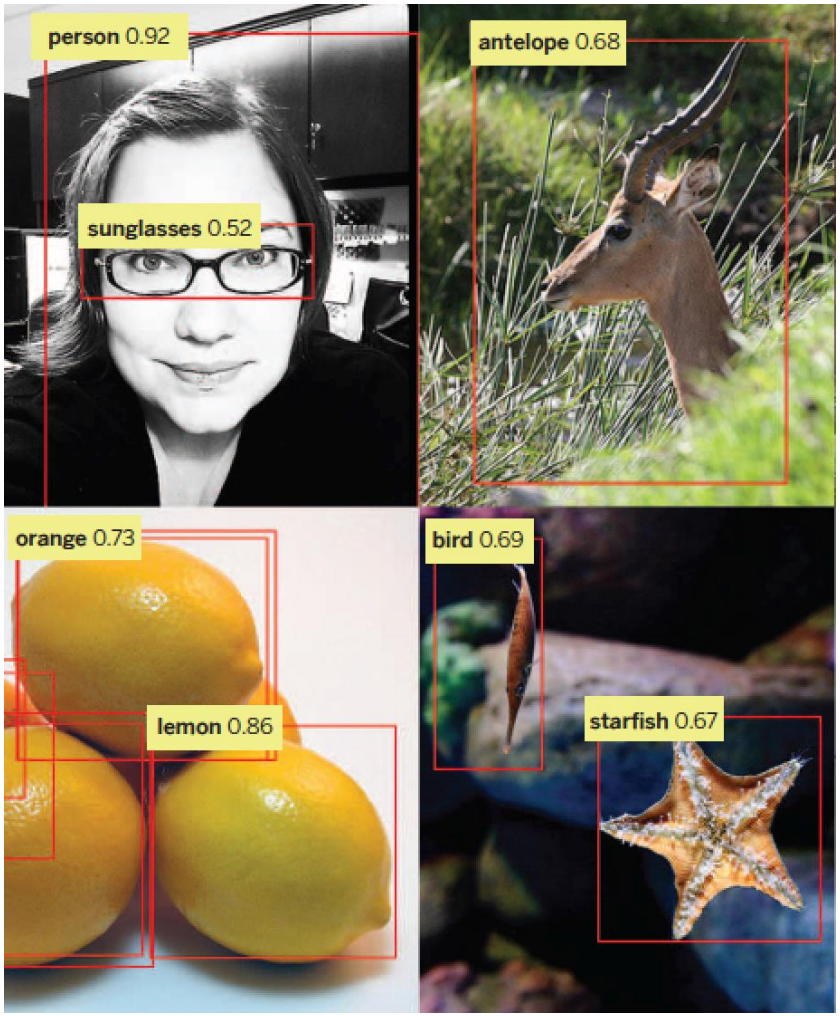


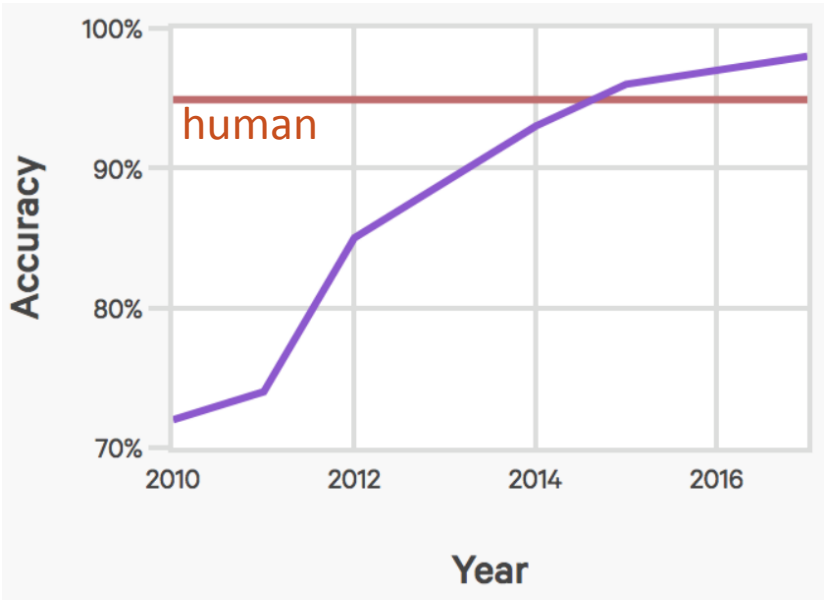
FIGURE 2.2 Internet bandwidth over time. Internet connection speeds in bits per second, as recorded and reported by Jakob Nielson, 1983-2014. SOURCE: J. Nielsen, 1998, "Nielsen's Law of Internet Bandwidth," Nielsen Norman Group, last modified 2014, https://www.nngroup.com/articles/law-of-bandwidth/.

Computer Vision



Imagenet Visual Recognition Challenge

Accuracy of AI system

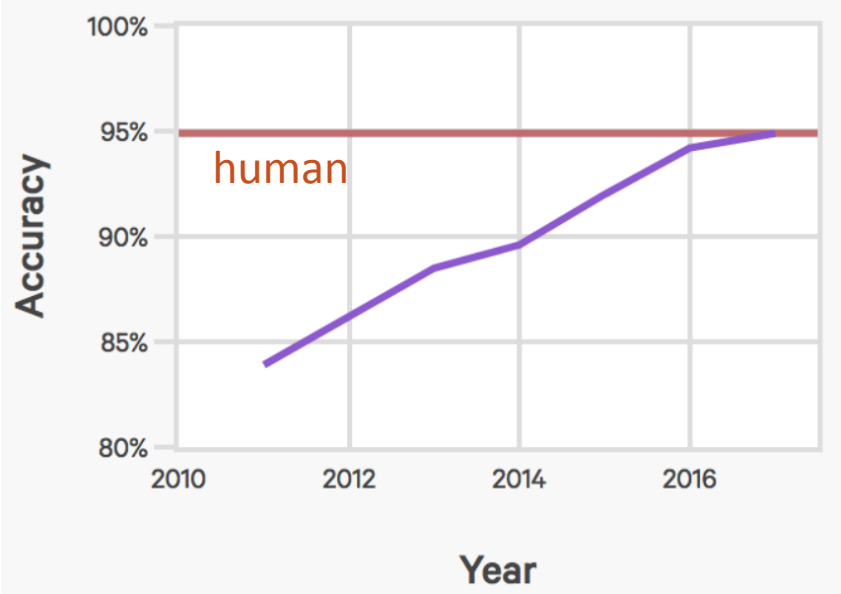


Speech Recognition

Recognize speech from phone call audio

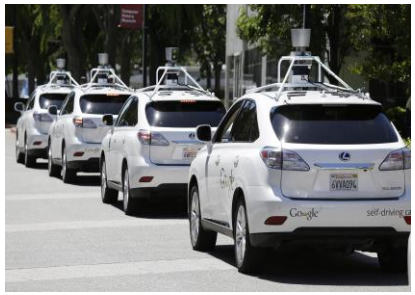
Switchboard HUB5’00 dataset

Accuracy of AI system



Robots

Factories, Land, Air, Sea, Mines, Homes



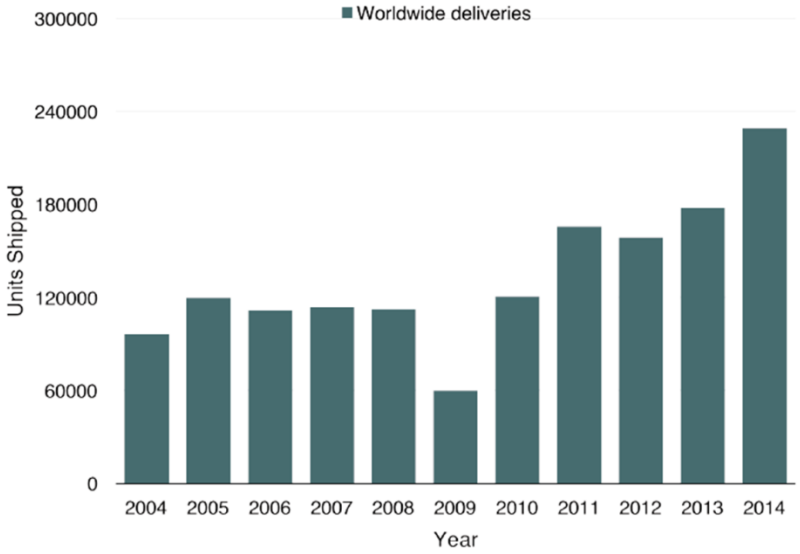


FIGURE 2.4 Worldwide shipping of robots over time. SOURCE: International Federation of Robotics, 2015.

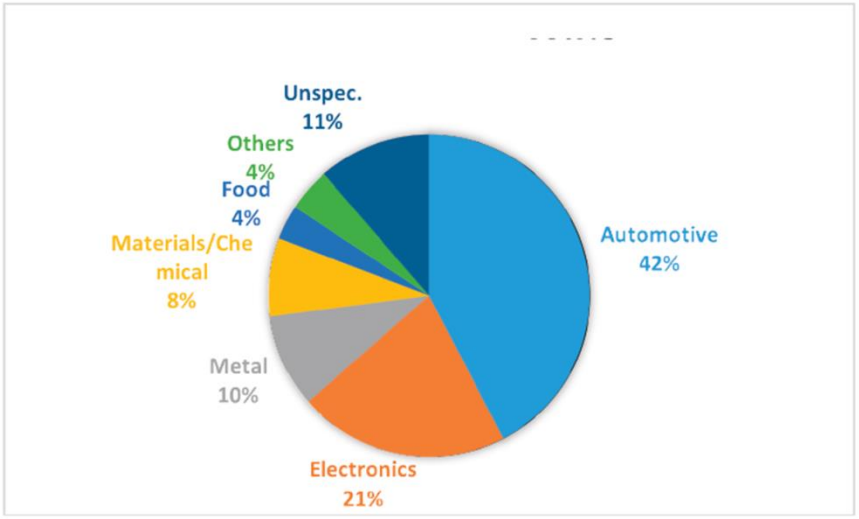
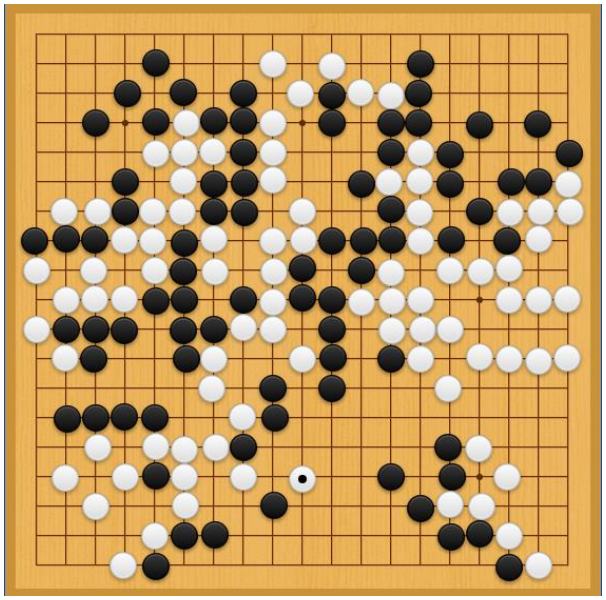


FIGURE 2.5 Robot application areas in 2015. SOURCE: Data from International Federation of Robotics, 2015.

Games and reasoning

Chess



Go

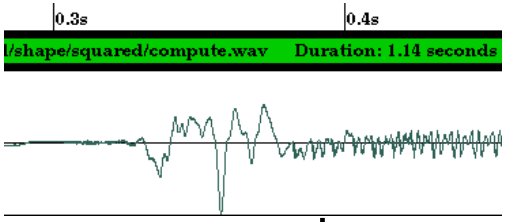
Jeopardy

Poker

The key: Machine Learning

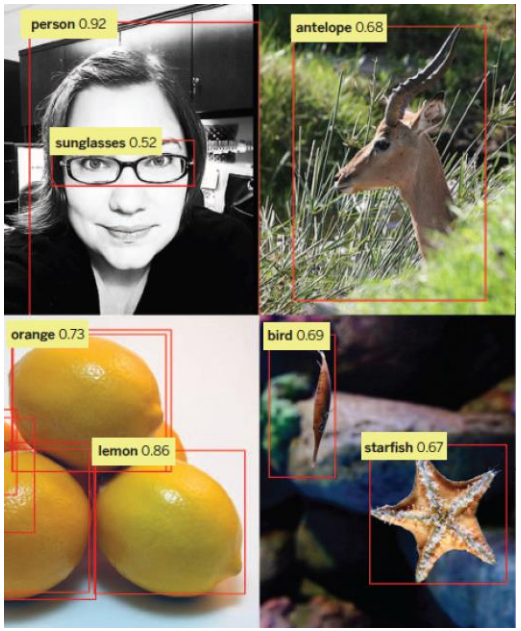
Peter H. van Oppen , **Chairman of the Board & Chief Executive Officer**
Mr. van Oppen has served as chairman of the board and chief executive officer of ADIC since its acquisition by Interpoint in 1994 and a director of ADIC since 1986. Until its acquisition by Crane Co. in October 1996, Mr. van Oppen served as chairman of the board of directors, president and chief executive officer of Interpoint . Prior to 1985, Mr. van Oppen worked as a consulting manager at Price Waterhouse LLP and at Bain & Company in Boston and London. He has additional experience in medical electronics and venture capital. Mr. van Oppen also serves as a director of Seattle FilmWorks Inc. and Spacelabs Medical, Inc.. He holds a B.A. from Whitman College and an M.B.A. from Harvard Business School, where he was a Baker Scholar.

text



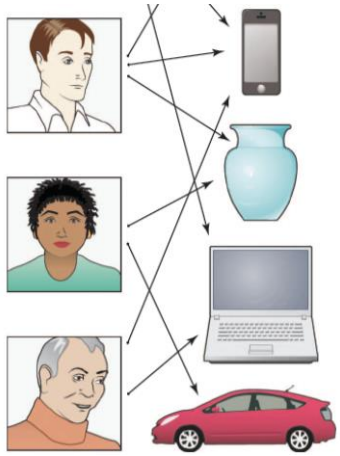
speech

fraud detection



vision

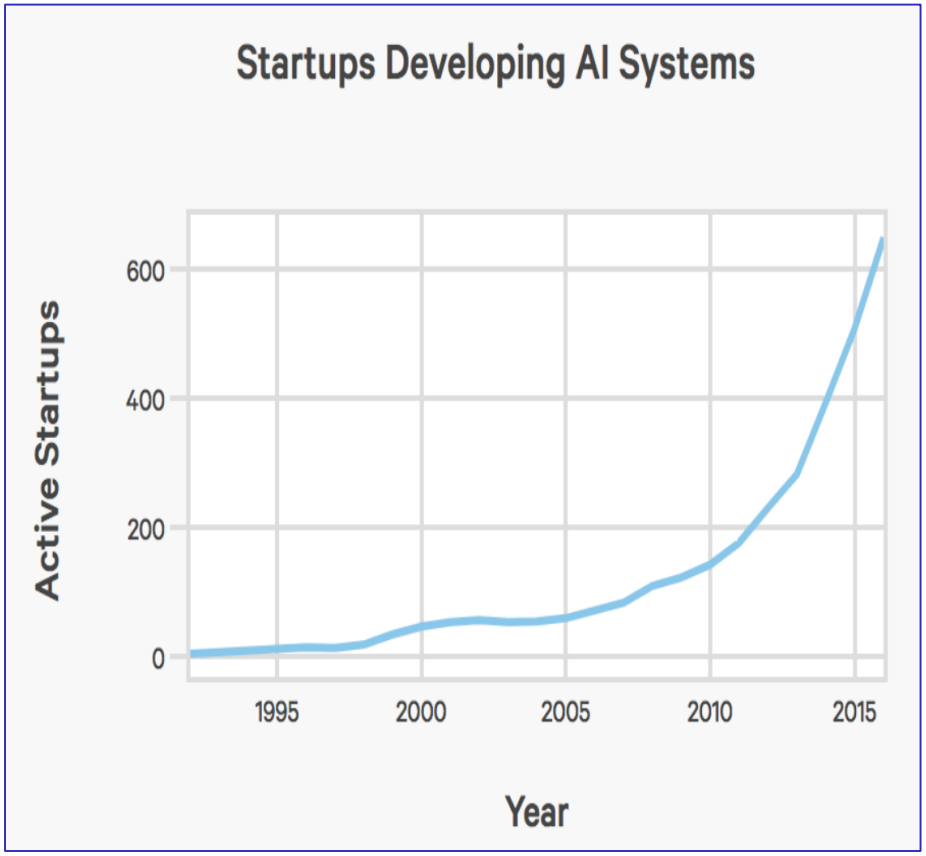
translation

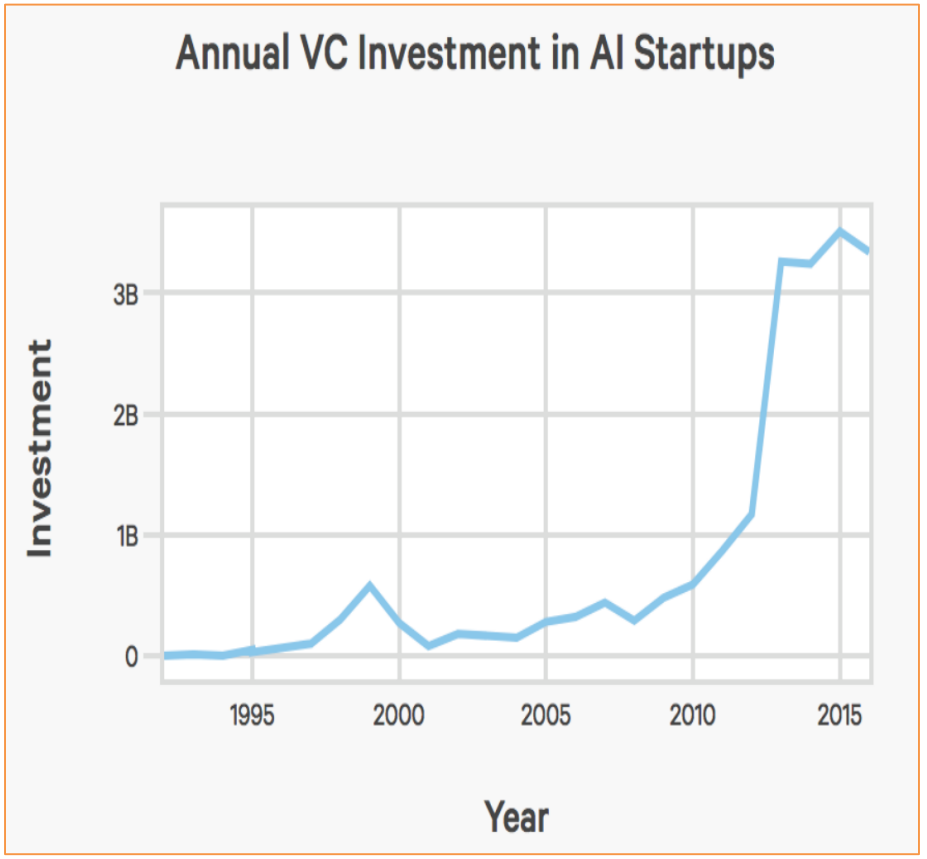


recommendations

self driving

AI Startups and Venture Funding (US)





source: http://aiindex.org/2017-report.pdf

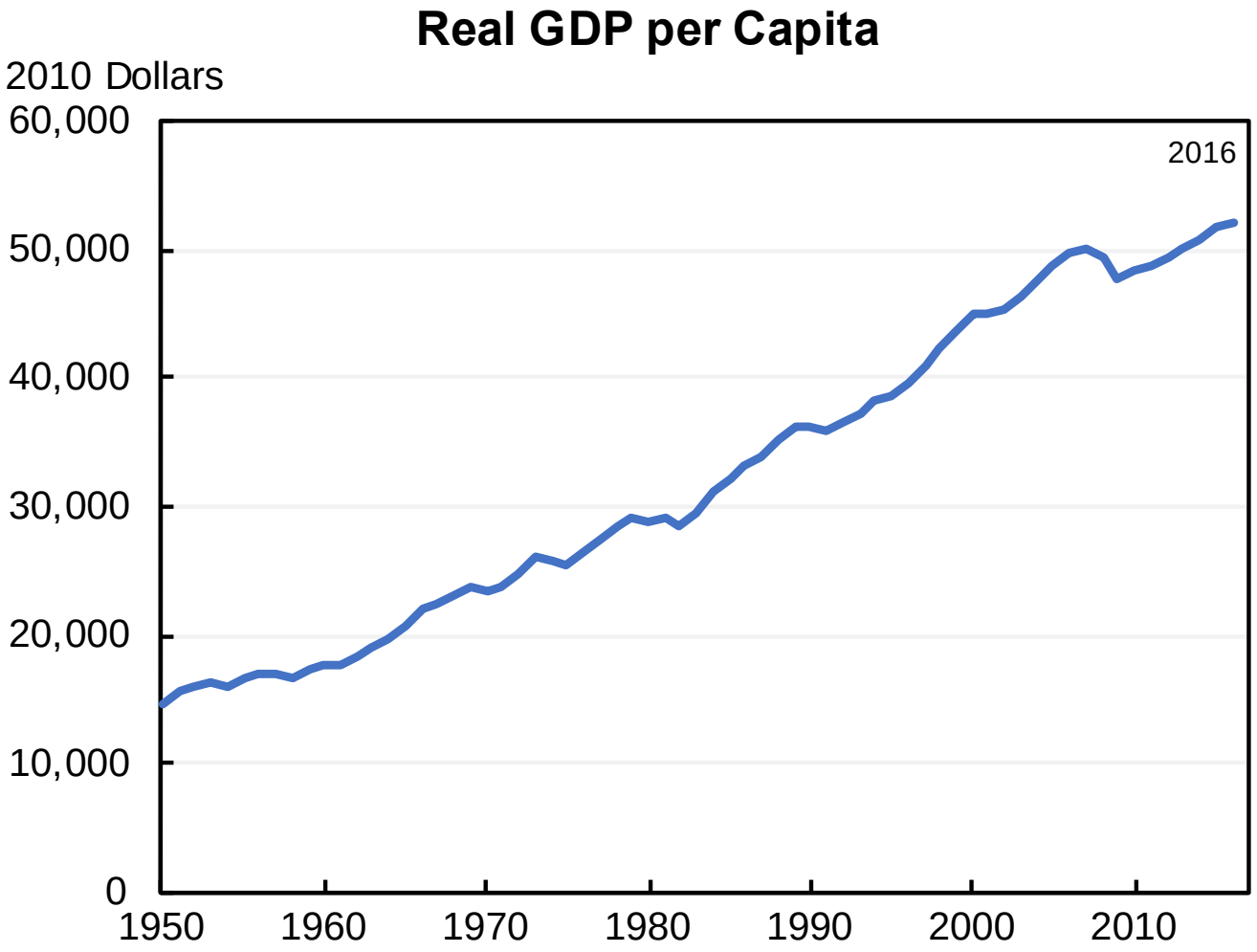
Next Decade?

- Continued growth of online data, machine learning
- Human-machine collaboration, conversational
- Self-driving vehicles
- Growth and diversity in automated assembly
- High-competence computer vision, hearing, …
- High-reliability, real-time language translation
- Automation of routine work-flows

- Possible game changers: Privacy breakthrough? Instructable machines? Machine reading?

Effects of IT on Productivity, Employment, and Incomes

We Have Become Richer in Material Goods



Source: Bureau of Economic Analysis, National Income and Product Accounts; Haver Analytics.

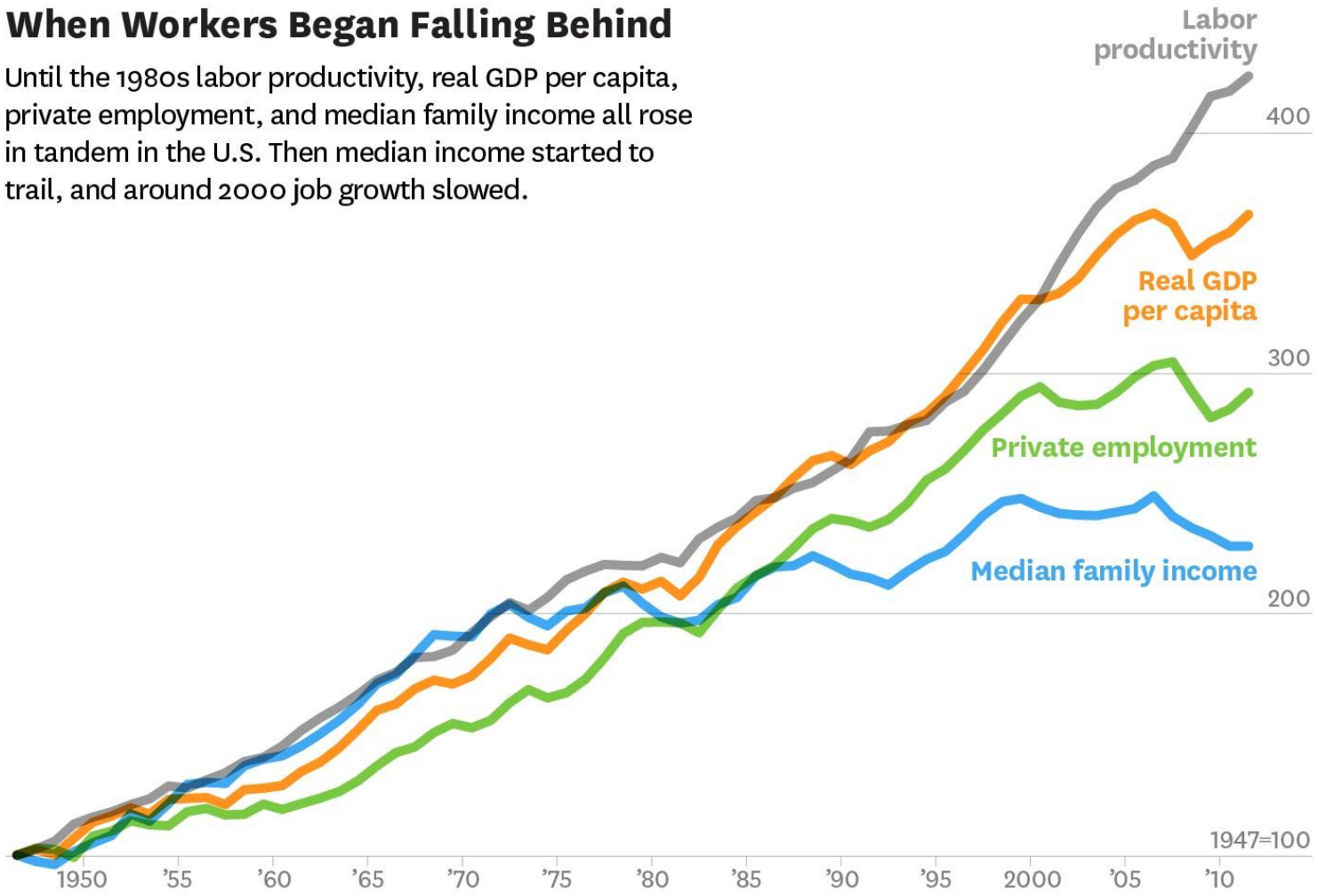


FIGURE 3.2 The decoupling of productivity from GDP per person, employment, and median income. SOURCE: E. Brynjolfsson, and A. McAfee, "Why the Middle Class is Shrinking," *Harvard Business Review,* November 5, 2015, https://hbr.org/video/4598665579001/why-the-middle-class-is-shrinking, accessed April 2016.

“The adoption of computers substitutes for… workers performing routine tasks—such as bookkeeping, clerical work, and repetitive production and monitoring activities—which are readily computerized because they follow precise, well-defined procedures.”

- Autor and Dorn, 2013

http://dspace.mit.edu/openaccess-disseminate/1721.1/82614

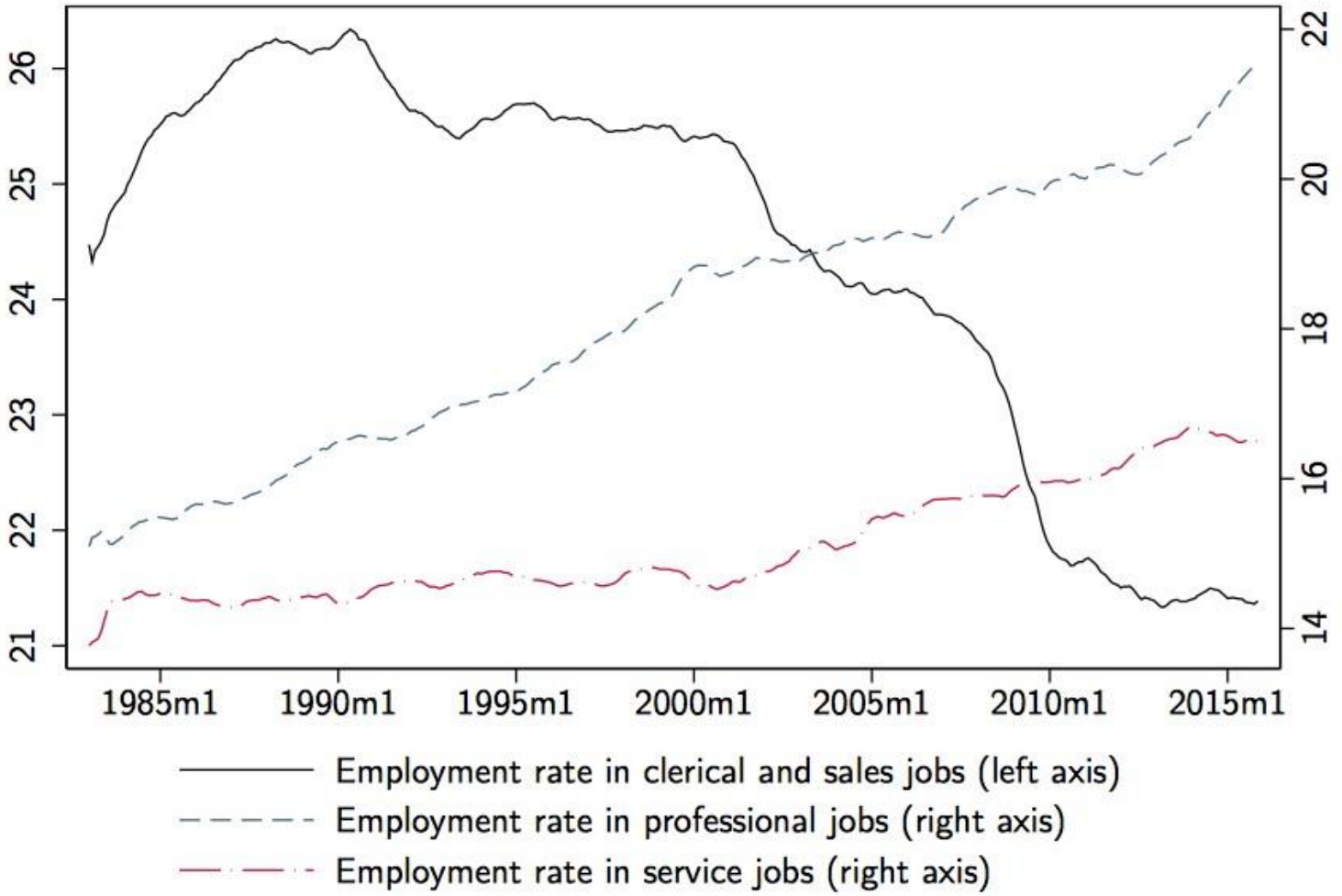


FIGURE 3.1 U.S. employment rates for different occupational categories.
SOURCE: P. Restrepo, 2015, "Skill Mismatch and Structural Unemployment," Massachusetts Institute of Technology, http://pascual.scripts.mit.edu/research/01/PR_jmp.pdf.

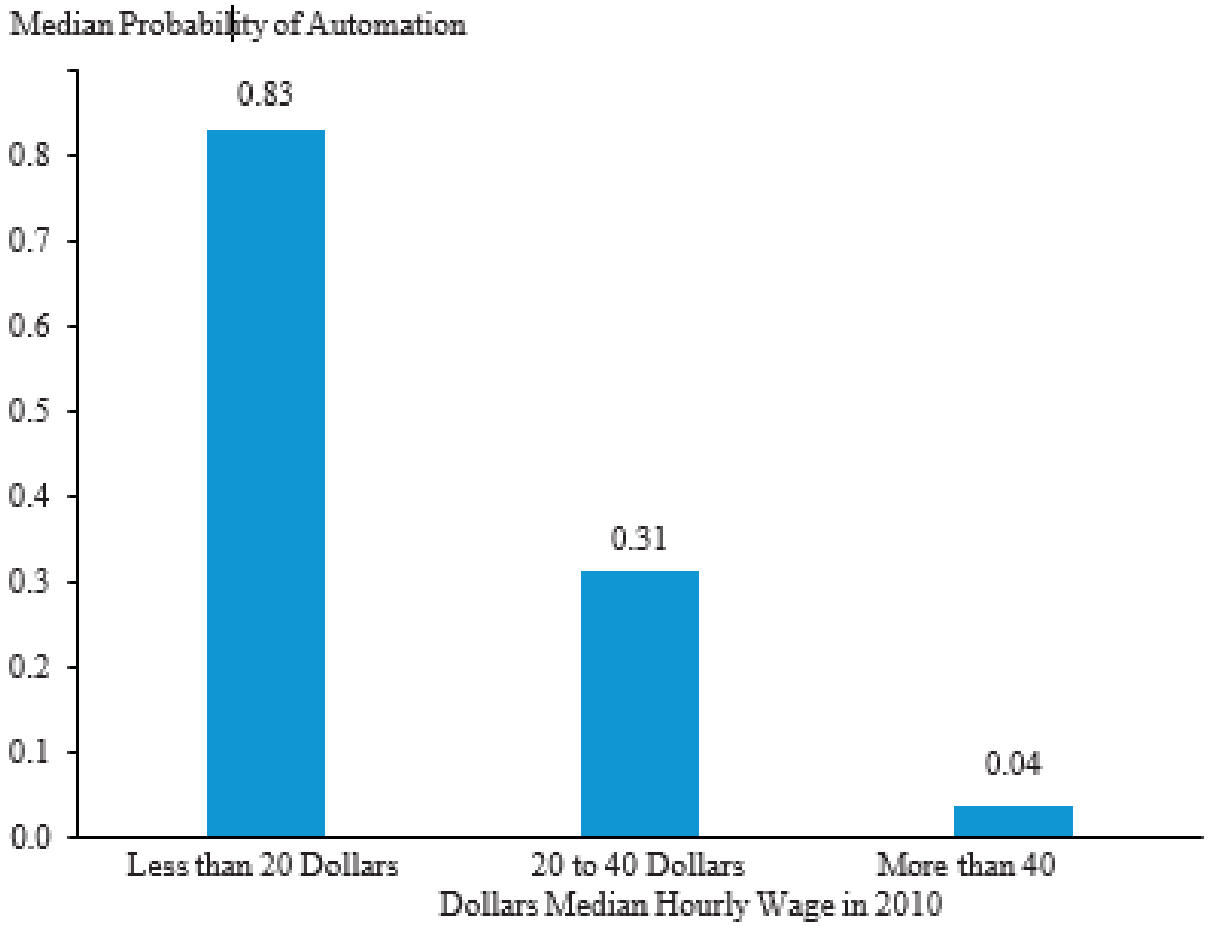


FIGURE 5.1 Probability of automation by an occupation's median hourly wage. SOURCE: Council of Economic Advisors, 2016, *Economic Report of the President*, p. 249, https://www.whitehouse.gov/sites/default/files/docs/ERP_2016_Book_Complete%20JA.pdf.

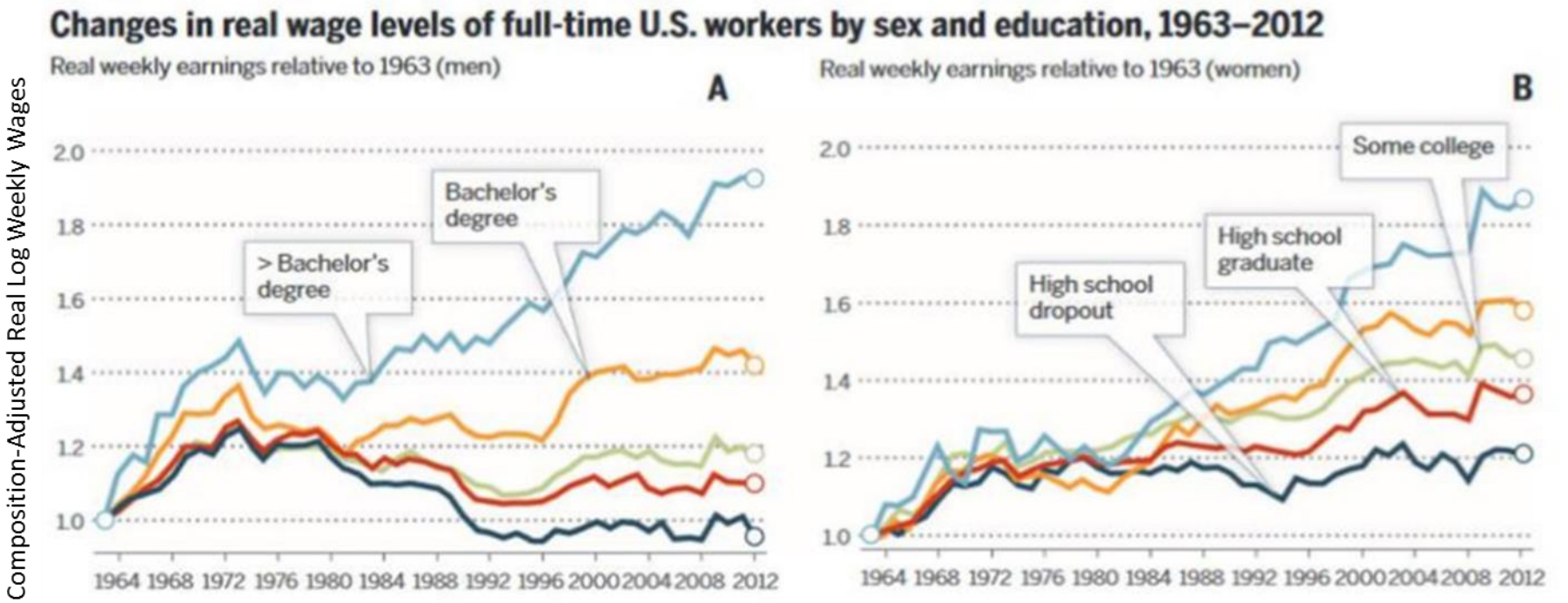


FIGURE 3.3 Changes in wage levels of full-time U.S. workers by sex and education, 1963-2012.
SOURCE: Autor, D. H., 2014, "Skills, Education, and the Rise of Earnings Inequality Among the 'Other 99 Percent.'" *Science* 344 (6186):843-851, http://science.sciencemag.org/content/sci/344/6186/843.full.pdf.

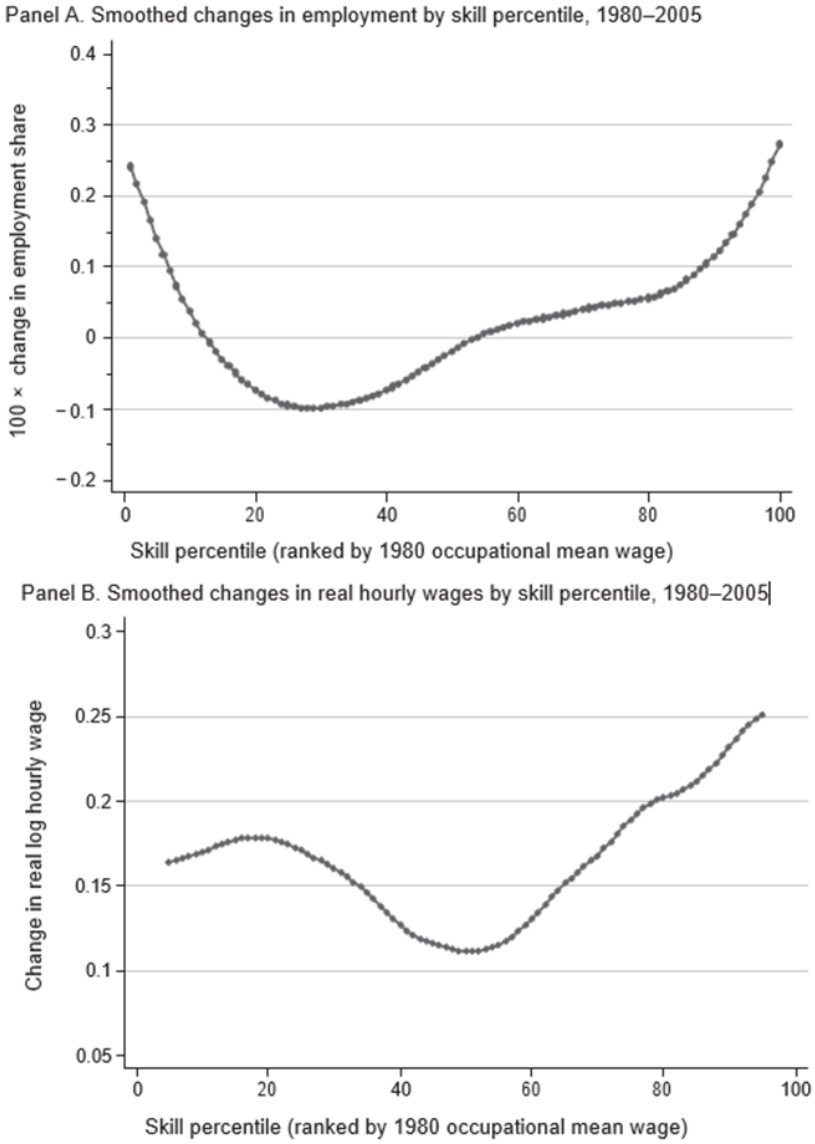


FIGURE 3.4 A and B Workers in the middle of the skill distribution have had lower employment growth and wages growth than workers at the top and bottom.
SOURCE: (A) D.H. Autor and D. Dorn, 2013, The Growth of low-skill ser- vice jobs and polarization of the US labor market, *American Economic Review* 103(5):1553-1597.

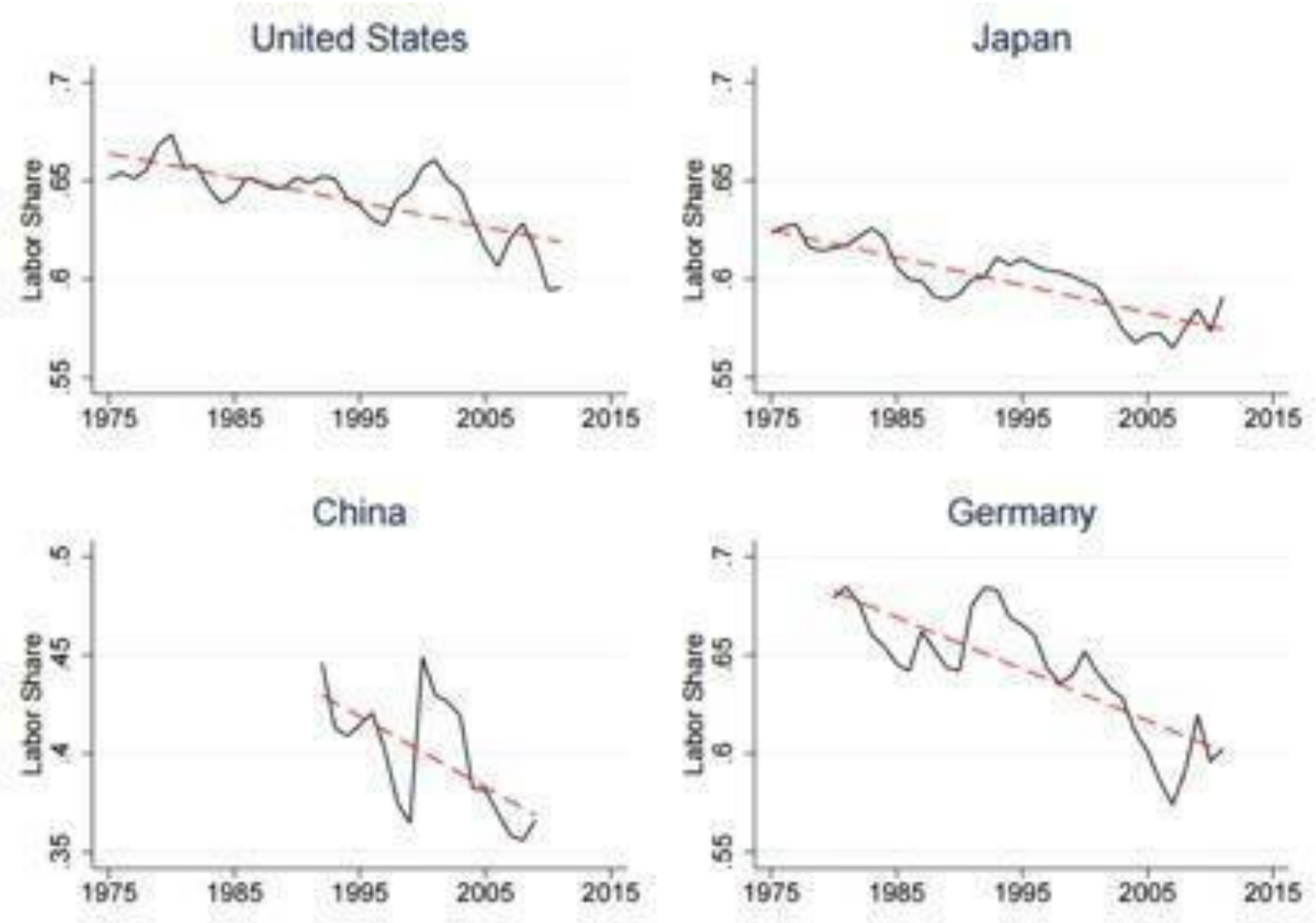


FIGURE 3.5 Declining labor share of income for the largest economies in the world, with linear trend lines.

SOURCE: L. Karabarbounis and B. Neiman, 2014, The Global Decline of the Labor Share, *Quarterly Journal of Economics* 129(1):61-103.

Evaluating Susceptibility to Automation

- Frey and Osborn (2013)
  - Classified job susceptibility to automation, based upon feasibility of automating associated tasks
  - Estimated that 47% of jobs have a ≥ 70% probability of being automated
- Elliot (2014)
  - Comparing leading-edge technological capabilities to level of human skills required for job tasks
  - Estimated that current SoA technologies could be capable of performing the functions required in ~81% of current US jobs
- McKinsey Global Institute (2015)
  - Evaluated 2000 occupational activities
  - Estimated ~45% of work activities are currently automatable; would be 58% if NLP reached reliably human-level performance

More Recent Research

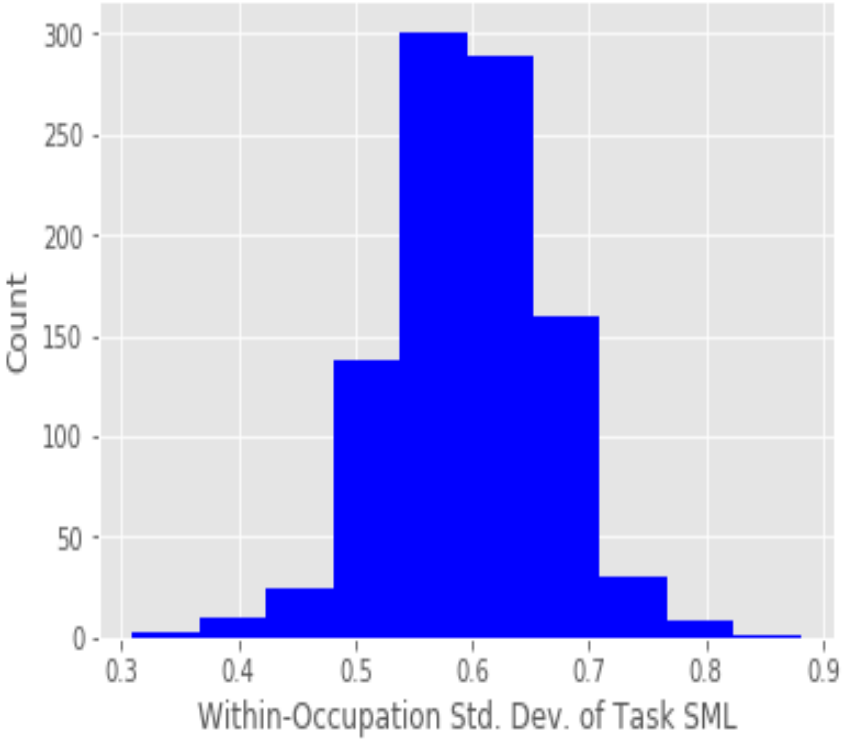
- Acemoglu and Restrepo (2017a, 2017b)
  - Developed framework of task substitution and task creation as tech advances
  - Found that robots could account for significant decrease in demand for labor
- Brynjolfsson, Rock and Syverson (2017)
  - AI Paradox: Remarkable AI capabilities yet dismal productivity growth
  - Four plausible explanations
  - Lags and restructuring key: AI is a "general purpose technology": take decades to have full impact
- Brynjolfsson and Mitchell (2017)
  - ML has has breakthroughs but we are far from artificial general intelligence (AGI)
  - 21-question rubric to identify tasks Susceptible to Machine Learning (SML)
  - Identified 6 economic factors which determine demand for labor
    1. Substitution
    2. Demand Elasticity
    3. Complementarities
    4. Income Elasticity
    5. Supply Elasticity
    6. Reengineering
  - Follow on work by Brynjolfsson, Mitchell and Rock (2018) applies rubric to ~18,000 tasks from O*Net and find few most jobs have at least some SML tasks

SML Rankings – Top and Bottom 15 Occupations

Rank	Lowest SML Ranked Occupations	SML	Highest SML Ranked Occupations	SML
1	Massage Therapists	2.78	Concierges	3.90
2	Animal Scientists	3.09	Mechanical Drafters	3.90
3	Archeologists	3.11	Morticians, Undertakers, and Funeral Directors	3.89
4	Public Address System and Other Announcers	3.13	Credit Authorizers	3.78
5	Plasterers and Stucco Masons	3.14	Brokerage Clerks	3.78
6	Dancers	3.15	Gaming Cage Workers	3.77
7	Slaughterers and Meat Packers	3.15	Gem and Diamond Workers	3.75
8	Logging Equipment Operators	3.15	Office Machine Operators, Except Computer	3.74
9	Stonemasons	3.18	Multimedia Artists and Animators	3.74
10	Hoist and Winch Operators	3.18	Ushers, Lobby Attendants, and Ticket Takers	3.74
11	Brickmasons and Blockmasons	3.19	Insurance Claims Clerks	3.74
12	Physical Therapist Assistants	3.20	File Clerks	3.73
13	Animal Trainers	3.20	Fiberglass Laminators and Fabricators	3.72
14	Segmental Pavers	3.21	Bookkeeping, Accounting, and Auditing Clerks	3.72
15	Athletes and Sports Competitors	3.21	Document Management Specialists	3.72

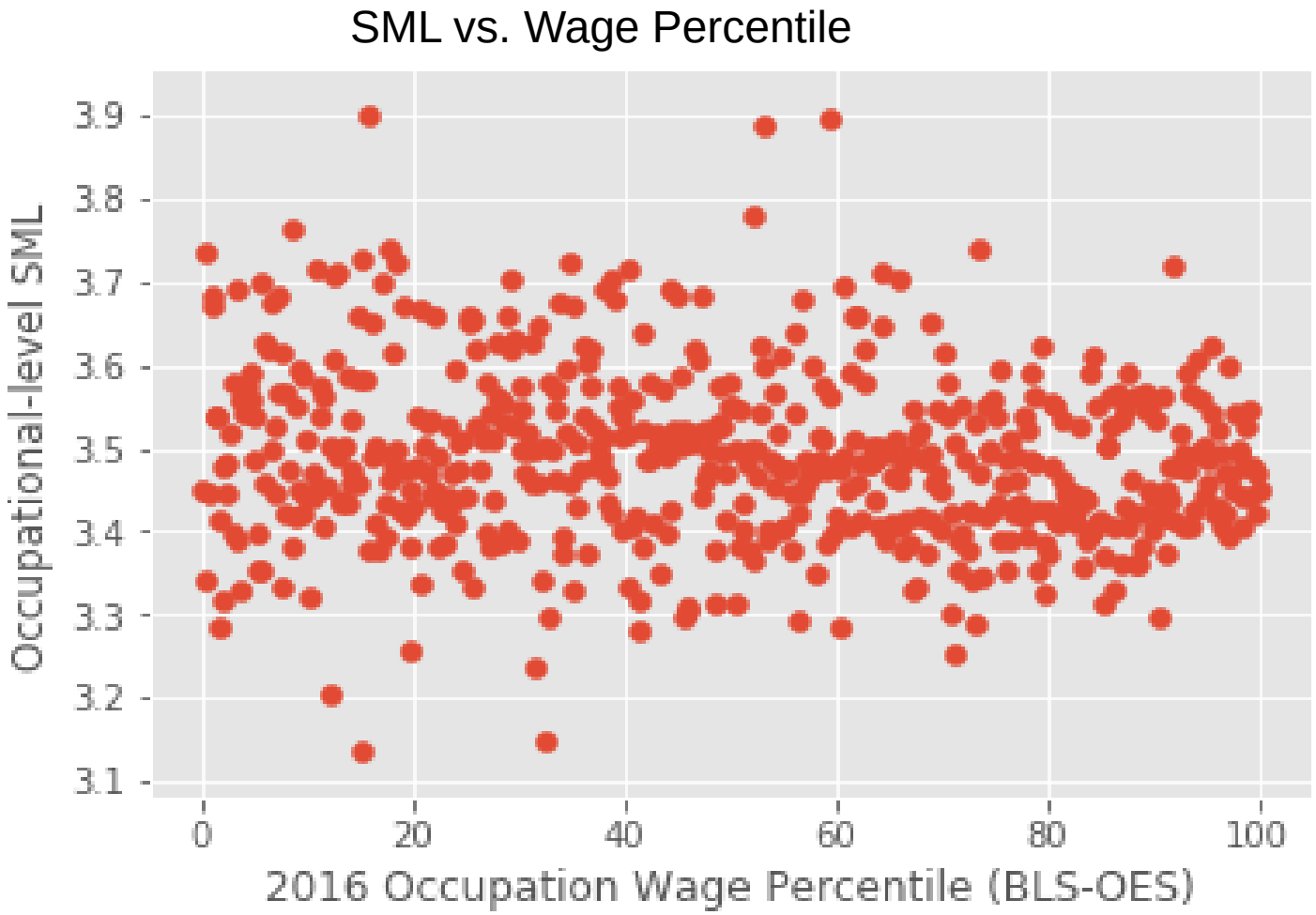
SML and Std Dev of SML vary considerably within jobs

Distribution of Counts of SML Scores



Distribution of Counts of SML Reorganization Scores

SML is not correlated with wages



Changes in the Nature of Work and its Organization

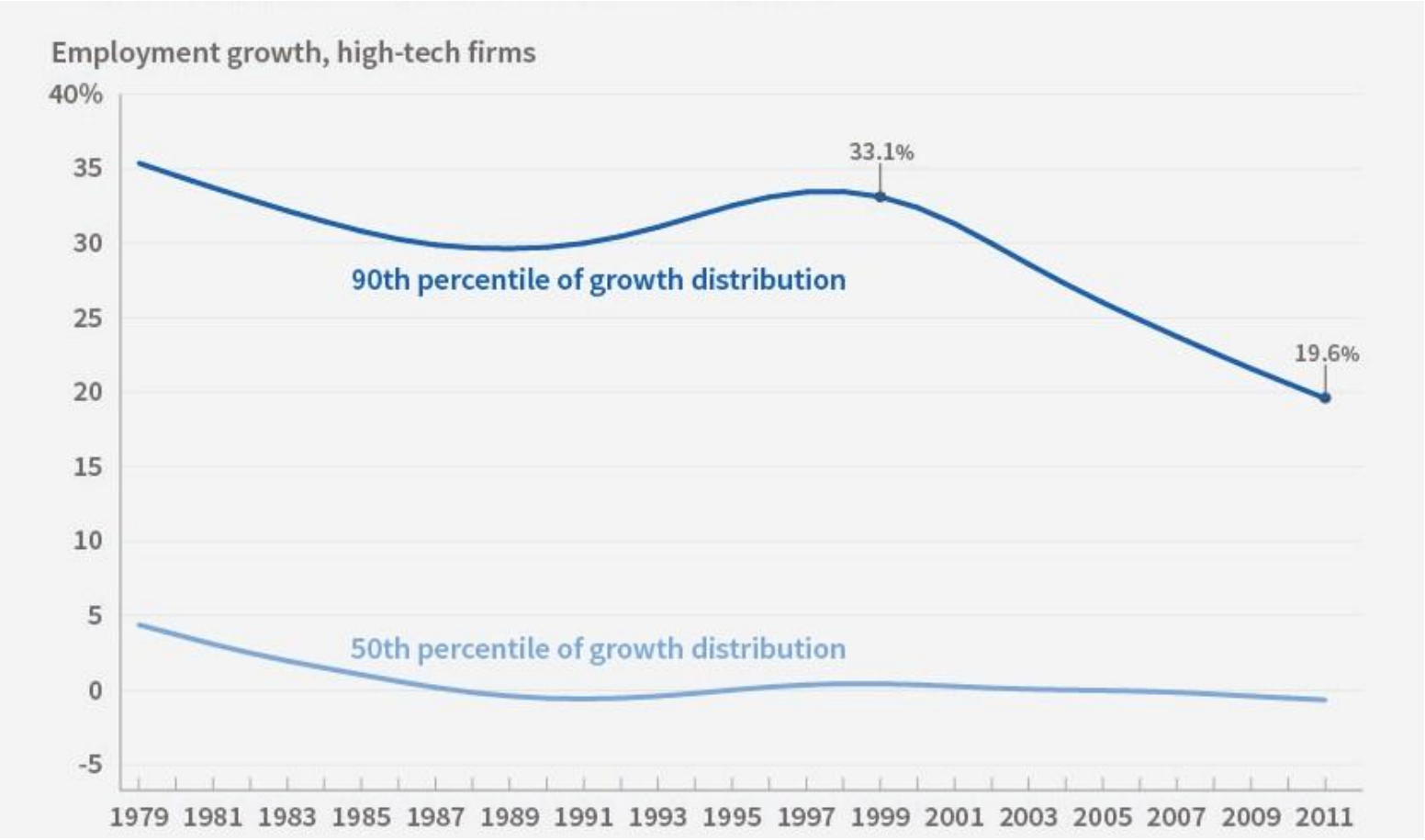


FIGURE 4.2 High-tech firm employment growth, 1979-2011.
SOURCE: J. Fitzger- ald, 2016, "The Number of High-Growth, Job-Creating Young Firms is Declining," http://www.nber.org/digest/feb16/w21776.html, accessed April 15, 2016.

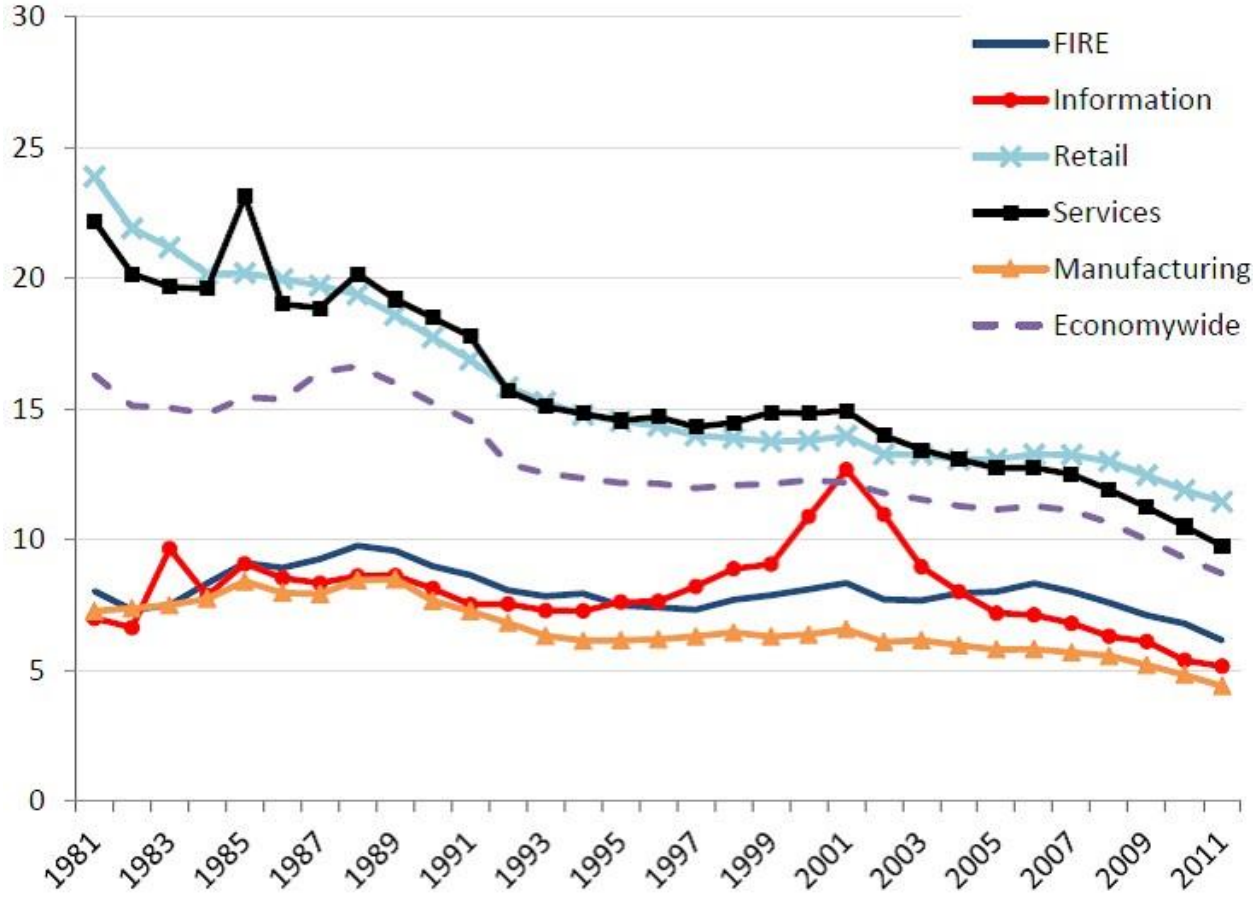
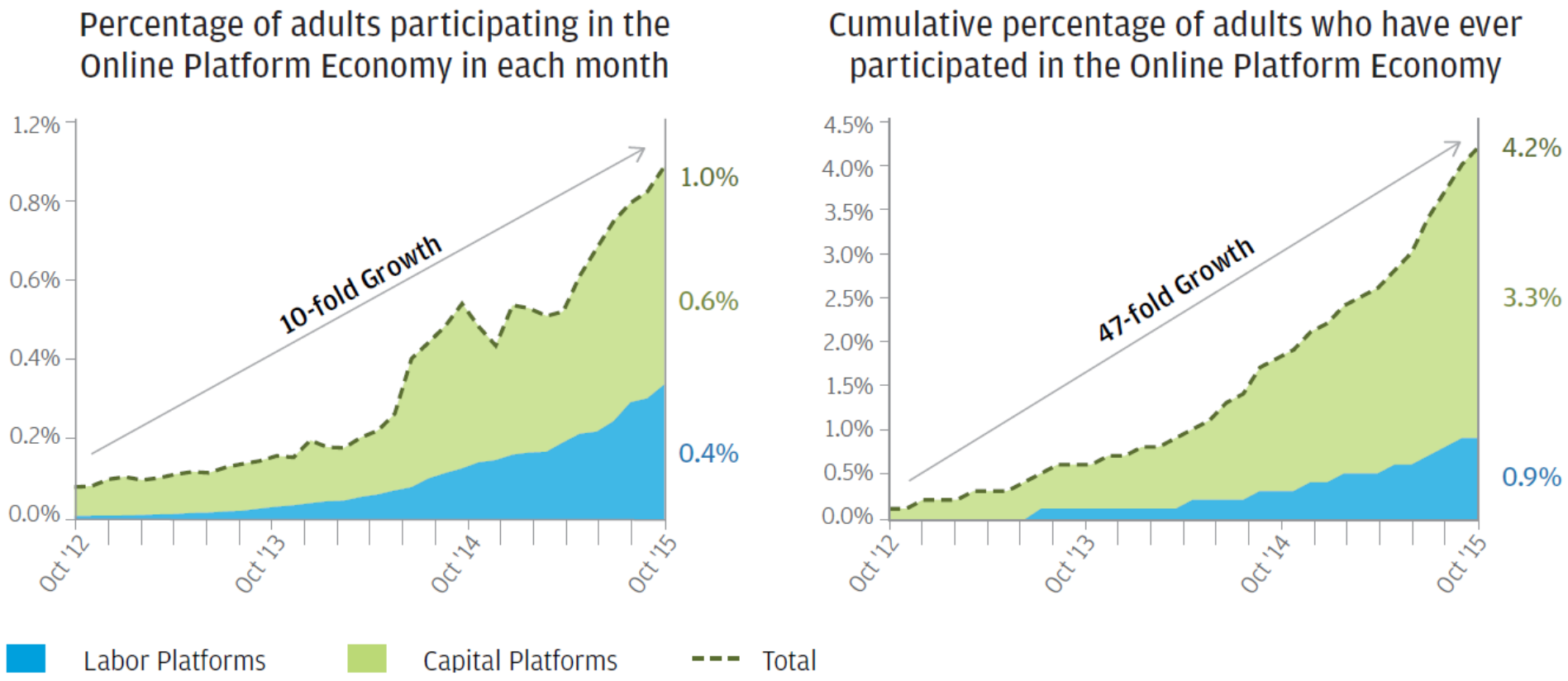


FIGURE 4.3 Share of employment accounted for by young firms (less than 5 years old) for selected industries. Tabulations from Longitudinal Business Database.
SOURCE: R.A. Decker, J. Haltiwanger, R.S. Jarmin, and J. Miranda, 2016, Where has all the skewness gone? The decline in high-growth (young) firms in the United States, *European Economic Review* 86:4-23.

Share of Workers Participating in Online Platform Labor Market is Still Small (<1%)



Source: Diana Farrell and Fiona Greig, JPMorgan Chase & Co. Institute, "Paychecks, Paydays and the Online Platform Economy," Feb. 2016.

Note: Based on monthly deposits of 30 large online work platforms.

Data Sources and Methods

- Data from Federal Statistical Agencies
  - Current Establishment Survey; Quarterly Census of Employment and Wages
  - Current Population Survey; Decennial Census, American Community Survey
  - JOLTS, BED, BDS, QWI
  - Business R&D Innovation Survey
  - Dictionary of Occupational Titles
  - Occupational Information Network (O*NET)

Data Sources and Methods

- Web-based and private-sector data
  - Individual worker profiles
  - Job listings
- Social Science Methods
  - Microdata
  - Qualitative methods (e.g. ethnography)

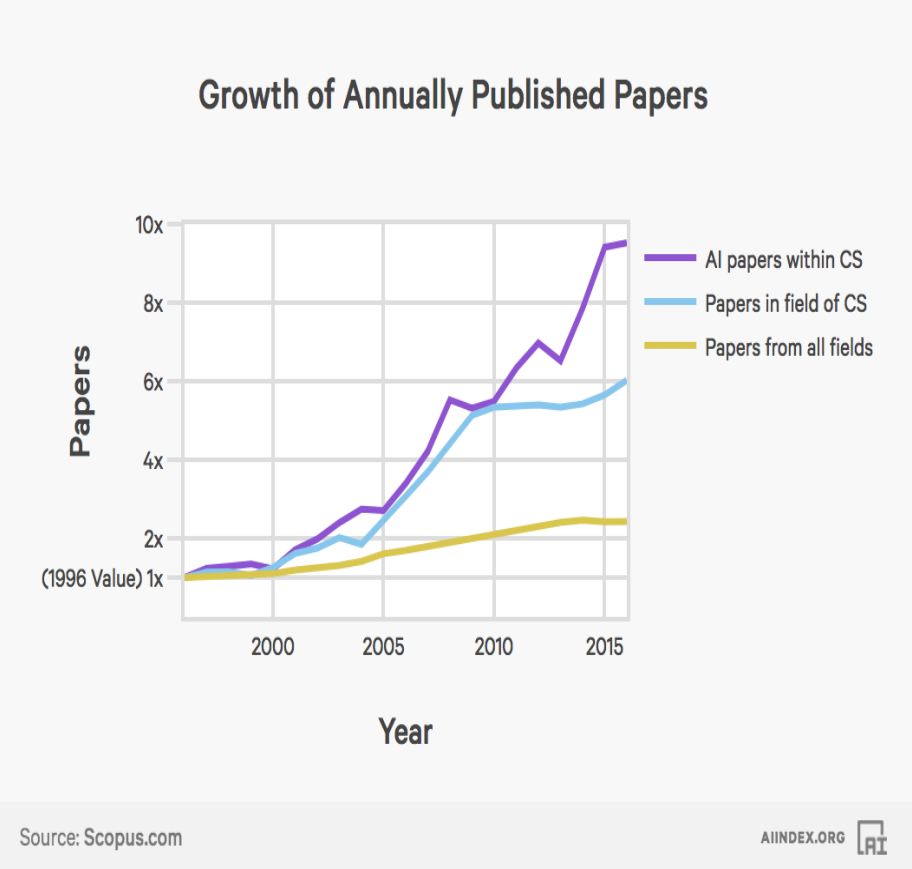
Recent Data Gathering

- AI Index

artificial
intelligence
index

https://aiindex.org/

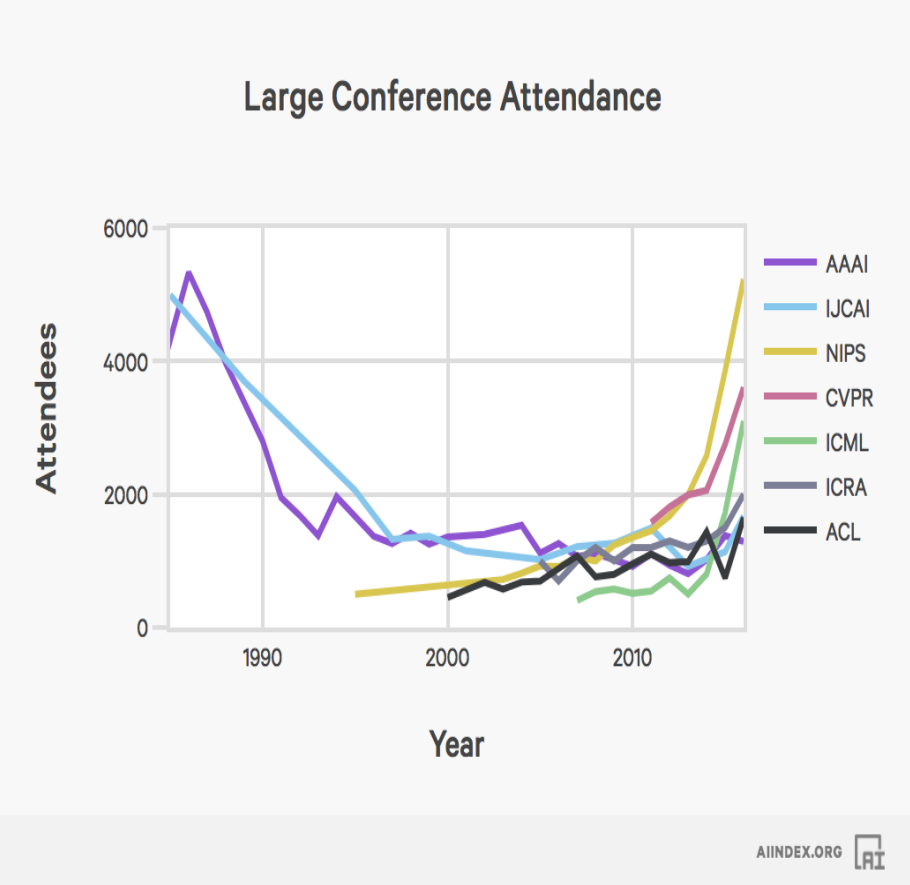
Volume of Activity - Academia



9x

The number of AI papers produced each year has increased by more than 9x since 1996.

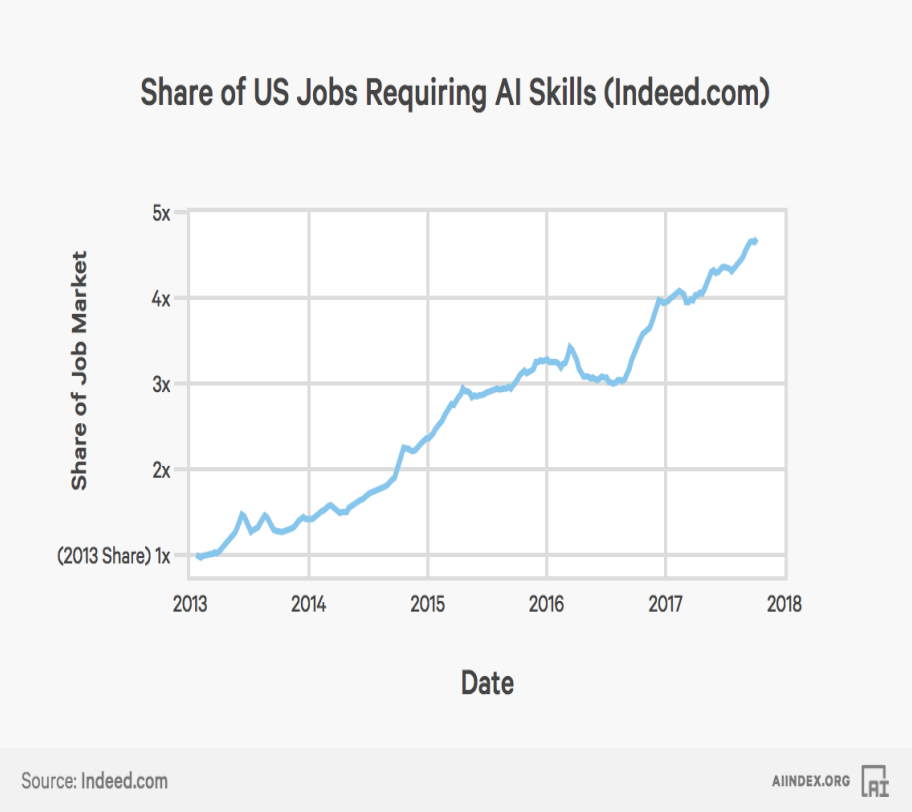
Volume of Activity - Academia



Shifting Focus

These numbers show focus shifting [from symbolic reasoning to machine learning and deep learning](#).

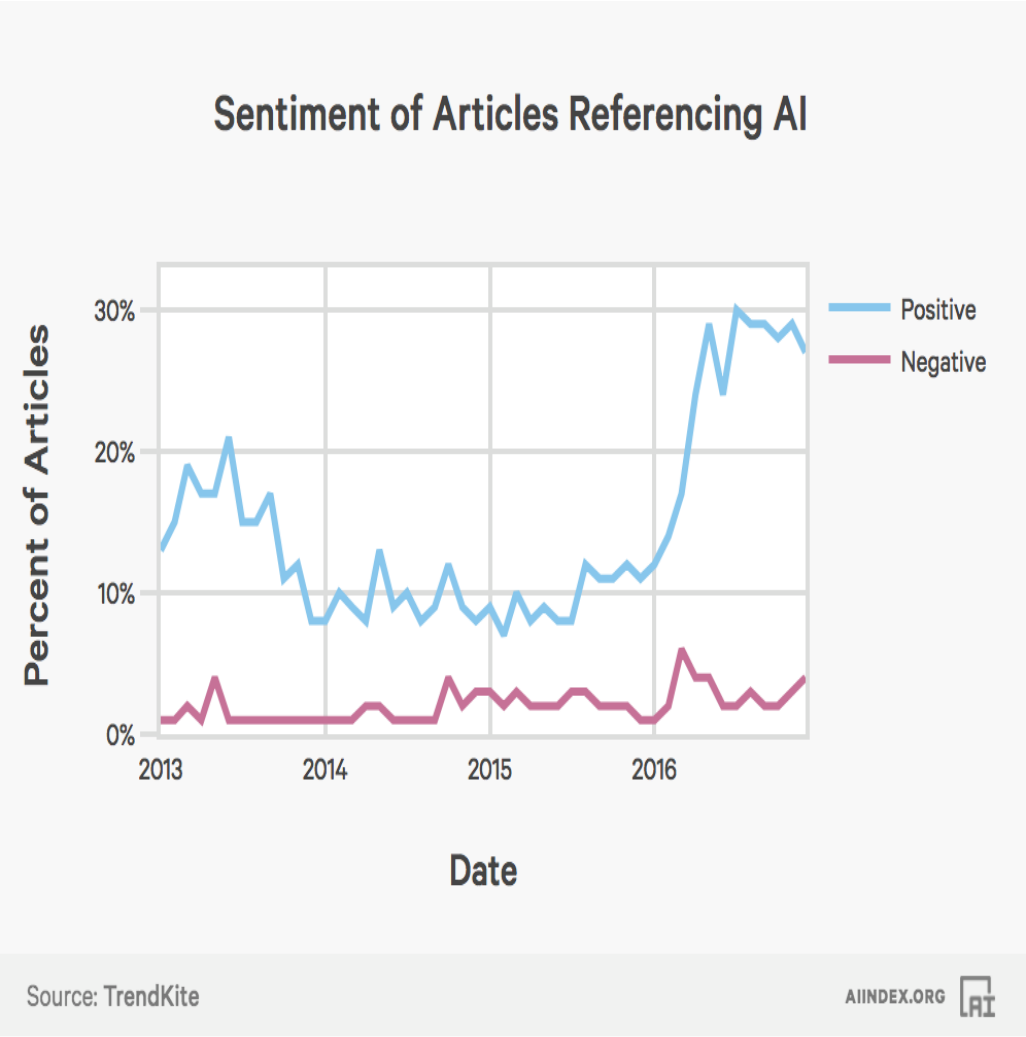
Volume of Activity - Industry



4.5x

The share of jobs requiring AI skills in the US has grown 4.5x since 2013.

Volume of Activity - Public Interest



Findings

Finding 1

Advances in IT are far from over, and some of the biggest improvements in areas like AI are likely still to come. We expect improvements in many areas and entirely new capabilities in others.

Finding 2

Advances in technology will result in

- automation of some jobs,
- augmentation of workers' abilities to perform others
- creation of still others.

The ultimate effects of technology are not preordained; they depend on decisions of policy makers, organizations, and individuals.

Finding 3

The recent increase in income inequality in the United States is due to multiple forces, including advances in IT and its diffusion.

Finding 4

IT is making new work relationships possible, including new forms of on-demand employment. While current digital platforms for on-demand work directly involve less than 1 percent of the workforce, such platforms are likely to evolve and grow.

Finding 5

New educational strategies will be necessary to build a successful future workforce, with decreased emphasis on routine information processing and increased focus on creativity, adaptability, and interpersonal skills.

Recent technological advances make possible new, potentially democratizing ways to access education.

Finding 6

Policy makers and researchers would benefit significantly from a better understanding of our technology options and their implications. In particular,

(1) a sustained, integrated, multidisciplinary research program and

(2) ongoing monitoring of workforce and technology developments

would provide a more rigorous basis for informing our public policies, organizational choices, and education and training strategies for the workforce.

Recommended Research Themes

Theme 1: Evaluating and Tracking Progress in IT

- Develop strategies for classifying technological capabilities in terms of the human skills and tasks they can or could replace.
- Identify key indicators that could signal disruptive change in a given technological field.
- Develop new mechanisms to track and forecast technological and economic changes of particular relevance to the future of the workforce.
- Develop indexes, analogous to the Consumer Price Index, to assess
  (1) the current state of technologies
  (2) the degree of diffusion of technologies into firms and organizations
  (3) the technological capabilities and diffusion of AI and robotics

Theme 2: Technology Adoption and Impact Within Organizations

- Research how different industries use technology to organize operations, allocate tasks, and perform specific functions, including whether technology is used to replace, augment or re-organize workers

- Conduct this research at both the micro- and macro-level scales to provide a firm- and industry-level window into the impacts of technology on employees.

Theme 3: Impacts of Policy Choices

Identify and evaluate

- policies, resources, and practices that would ease transitions for workers forced to change occupational fields due to technological change
- opportunities for actively guiding the future impacts of technology development and deployment before they occur.

Theme 4: Working with Emerging Technologies

As emerging technologies diffuse into different industries, individuals and teams must learn how to interact with these technologies to successfully complete tasks, which can affect the nature of decision making, teamwork, and organization.

Technology used in multiple ways:

- For connecting, communicating, convening,
- For data-driven decision making and other aspects of human intelligence
- To create new kinds of collective intelligence.

Research is needed to understand technology-augmented organizations, teams, and individuals and the conditions under which they are most effective.

Theme 5: Societal Acceptance of Automation Technologies

Many factors influence the decision of whether and how to deploy available technologies.

In some contexts, people (either workers or customers) may prefer to interact with a human over a machine (or vice versa).

Consumer behaviors and worker preferences and bargaining power will drive markets; understanding the behavioral economics of automation will be important for understanding its adoption patterns. Additional human factors and the social, philosophical, and psychological dynamics of automation should be explored.

Theme 6: Changing Labor and Skill Demands and Implications for Education and Training

Research in this area should aim to assess:

- *Education needs*: what new educational and training needs exist due to evolving technology and its influence on needed job skills?

- *Education delivery*: how can technology be used to improve education, to better prepare, train, and retrain the future workforce?

- *Education access and incentives*: How can we extend the benefits of education to *all* segments of society, including students who do not attend four-year colleges?

- *Education policies*: What lessons can be learned from experience in other countries with different policies, such as France's policy of providing 20 hours of paid time for continuing education each year?

Theme 7: The On-Demand Economy and Emerging Ways of Organizing Work

We have insufficient data to understand the state and dynamics of the on-demand economy. Research is needed:

- to understand what economic and labor statistics should be collected to study the impact and dynamics of the on-demand economy
- on the rights, protections, and autonomies of on-demand workers and how on-demand jobs fit into workers' lives and careers.
- on the potential for technology-mediated on-demand jobs to positively impact unemployed or low-income workers.
- into the roles of technology in shifting where and how work is conducted, including changes in access to employment in geographically remote or isolated locations.

Theme 8: New Data Sources, Methods, and Infrastructures

All of the preceding themes would benefit from new data sources, methods, and infrastructures to enable the collection, aggregation, and distribution of a diverse range of data.

The committee sees opportunities in the following areas:

1. Updating and augmenting authoritative data sources
2. Development of new data sources and methods
3. Combination of micro- and macro-level data and methods
4. New infrastructure and public-private partnerships for aggregation, sharing, and collaboration

Conclusions

1. The digital, networked economy will become increasingly important.
2. Advances in IT will boost America's overall income and wealth, improve healthcare, shorten the workweek, develop new goods and services, and increase product safety and reliability.
3. These same advances could also lead to growing inequality, decreased job stability, increasing demands on workers to change jobs, and changes in business organization.
4. There are also important implications for other aspects of society, both intended and unintended, including potentially profound changes in education, privacy , security, social relationships and even democracy.
5. The ultimate effects of these technologies are not pre-determined.
6. Investing in extensive and effective data gathering, a robust infrastructure for analyzing these data, and multidisciplinary research will enable a deeper understanding of emerging changes in technology and the workforce.
7. The results of this research will inform the adoption of policies that will help maximize the resilience and prosperity of the institutions, organizations, and individuals in our society.

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