

*AI and the Modern  
Productivity Paradox:  
A Clash of Expectations and Statistics*

**NBER WORKSHOP ON ECONOMICS OF AI  
SEPTEMBER 13, 2017**

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# The Economist

JANUARY 12TH-18TH 2013

[Economist.com](http://Economist.com)

Obama's controversial new men  
Pressure for change builds in China  
Men close the longevity gap  
The ghastly gurus of personal finance  
Microchipping your children

**Will we ever  
invent anything this  
useful again?**



The growing debate about  
dwindling innovation

# Stagnation?

**“We are passing, so to speak, over a divide which separates the great era of growth and expansion of the [last] century...”**

*- Alvin Hansen, 1938 AEA Presidential address on Secular Stagnation*

“The basic changes going on since the beginning of the century are not only important in explaining the unprecedented severity and persistence of the Great [Recession] but also in appraising the **outlook for the future.**”

The **reduced rate of growth**, with respect to both population and territory, is **likely to be permanent.** .... This is the basis on which the **stagnation** school predicts a **long-run deficiency of investing opportunity.**“

*- Seymour Harris, 1943*

**Technical advance... has not since early in the century produced anything to equal in scope the development of the railroad, the telephone, electric power or the automobile.**

*- Alvin Hansen, 1941*

# Agenda



1. The Paradox and Four Explanations
2. AI as GPT
3. Growth Accounting with Intangibles



# Optimism

“The speed of innovation has never been faster.”

- *Paul Polman, CEO Unilever*

“Innovation is moving at a scarily fast pace.”

- *Bill Gates, Founder, Microsoft*

“the beginnings of... [a] rapid acceleration in the next 10, 15, 20 years”

- *Vinod Khosla, Founder, Khosla Ventures*

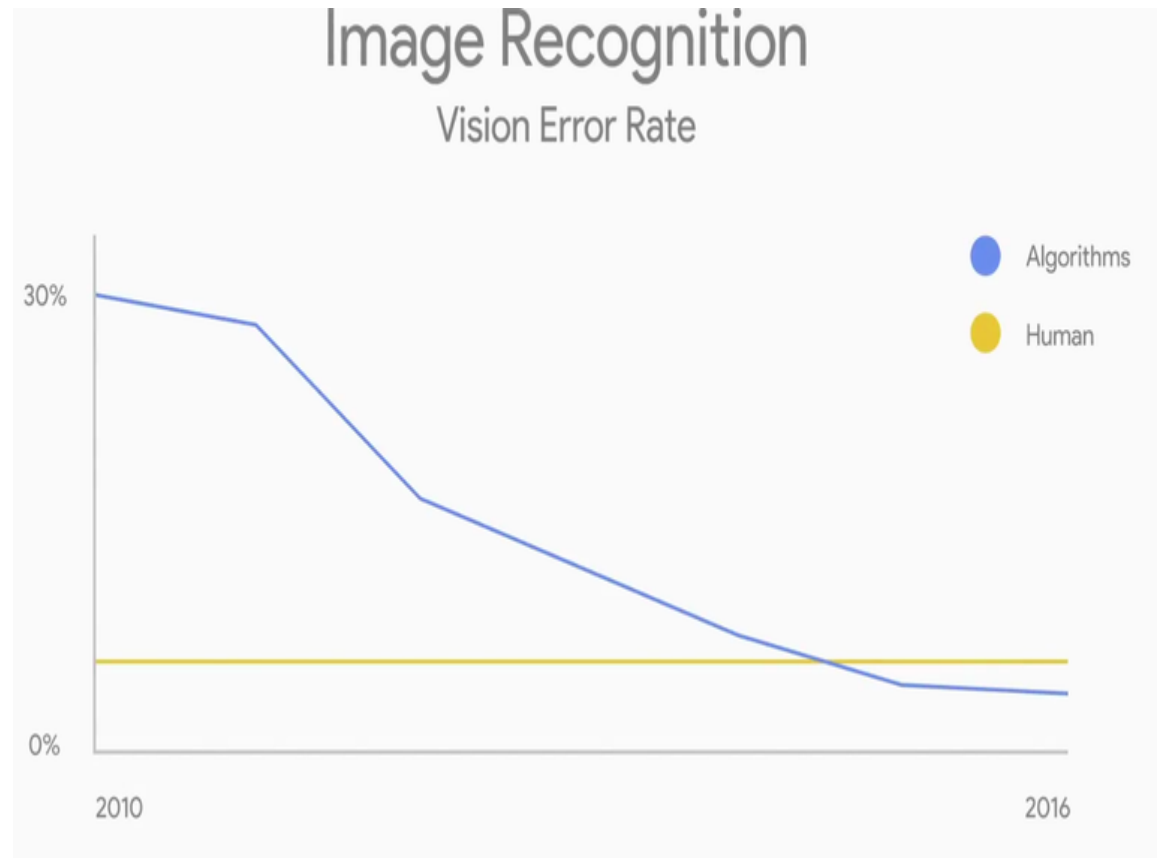
“we’re entering... the age of abundance [and] during the age of abundance, we’re going to see a new age... the age of intelligence”

- *Eric Schmidt, Chairman, Alphabet*

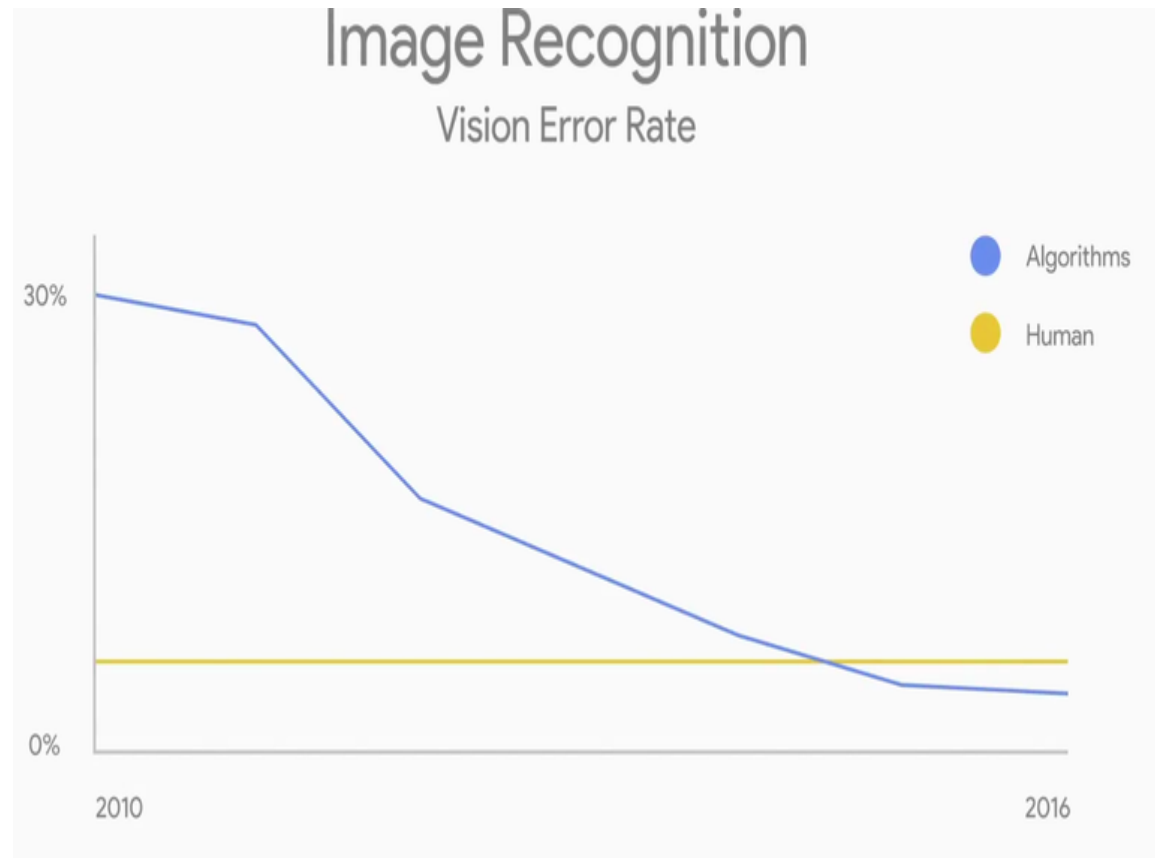
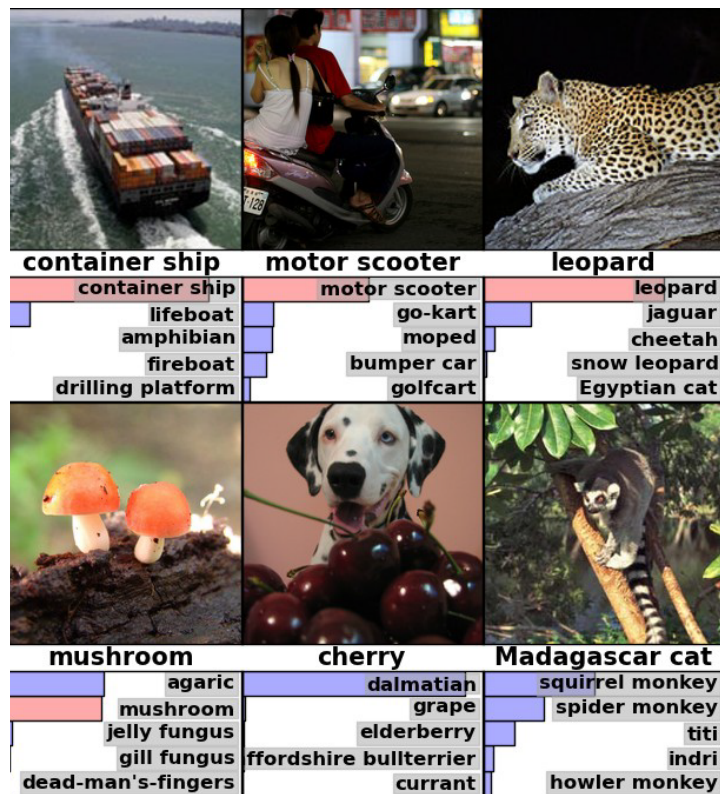
“The Singularity is Near”

- *Ray Kurzweil, National Medal of Technology Laureate*

# Machine Learning Has Crossed an Important Threshold

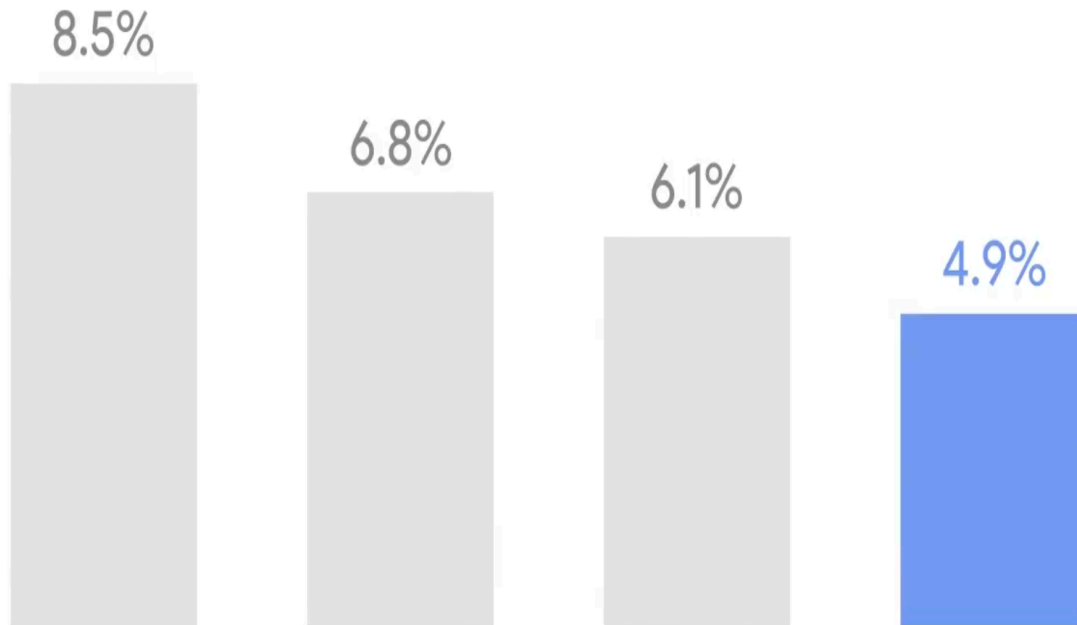


# Machine Learning Has Crossed an Important Threshold

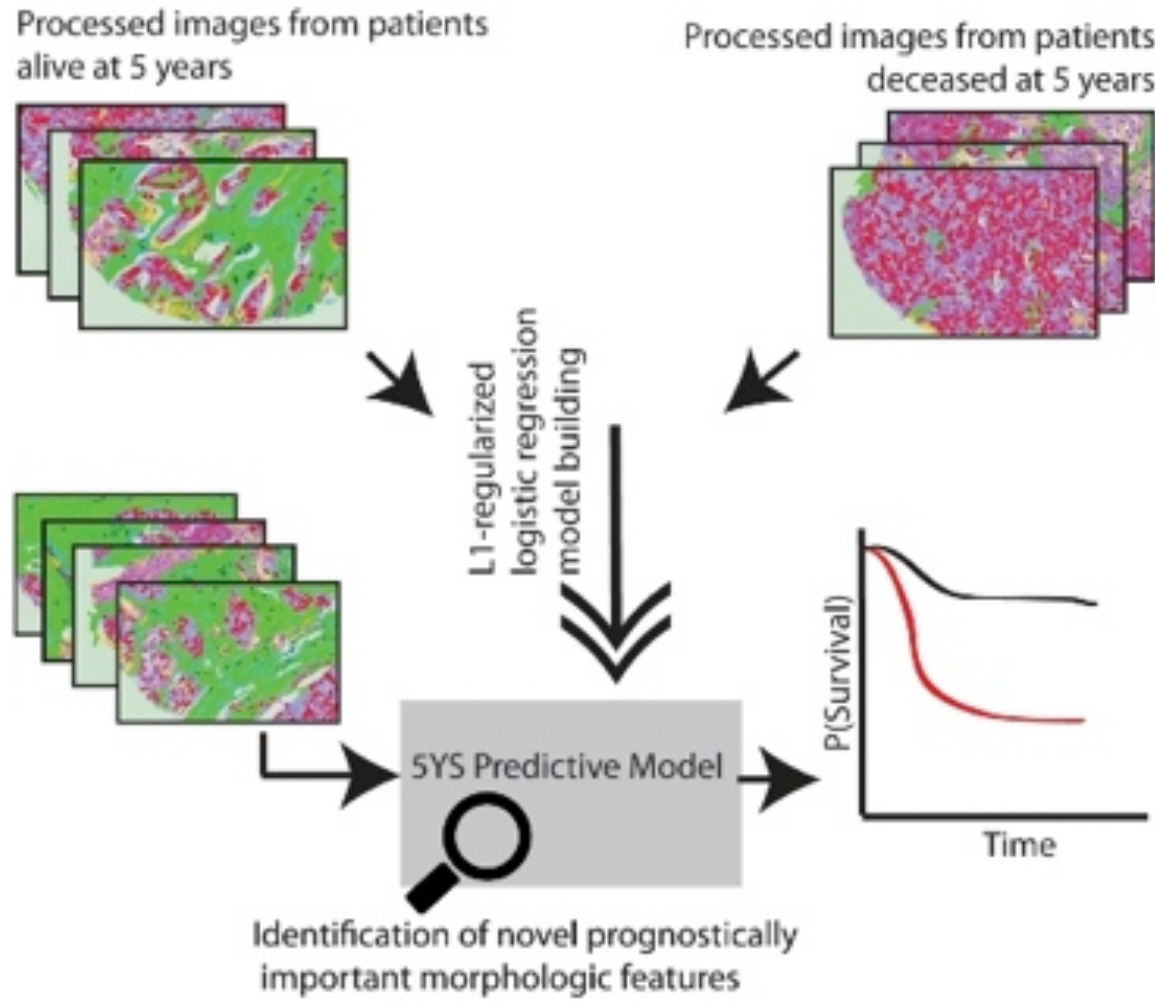


# Google Home Speech Recognition

Word Error Rate

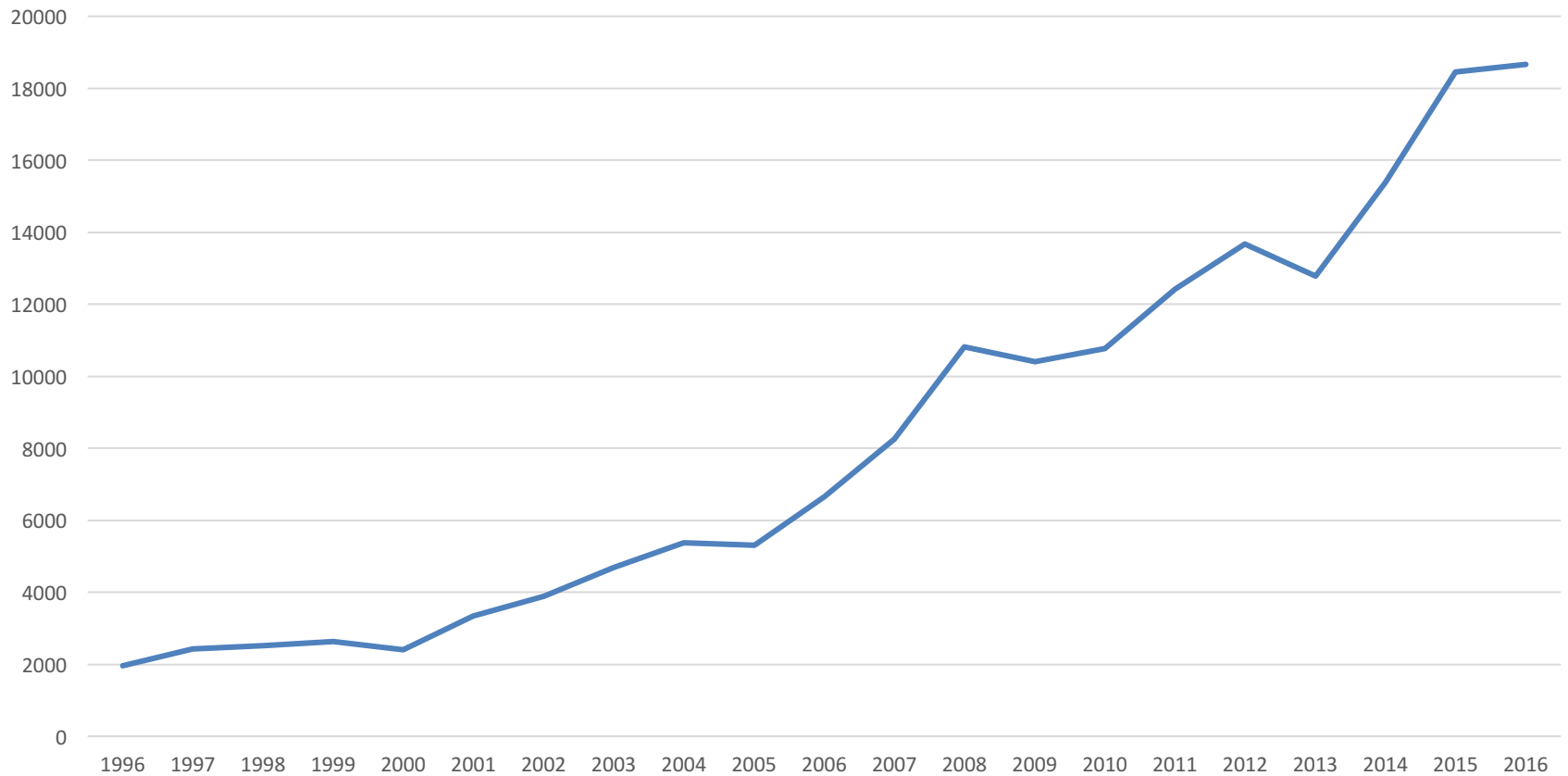


# Image Recognition for Detecting Cancer



# A Flood of Research

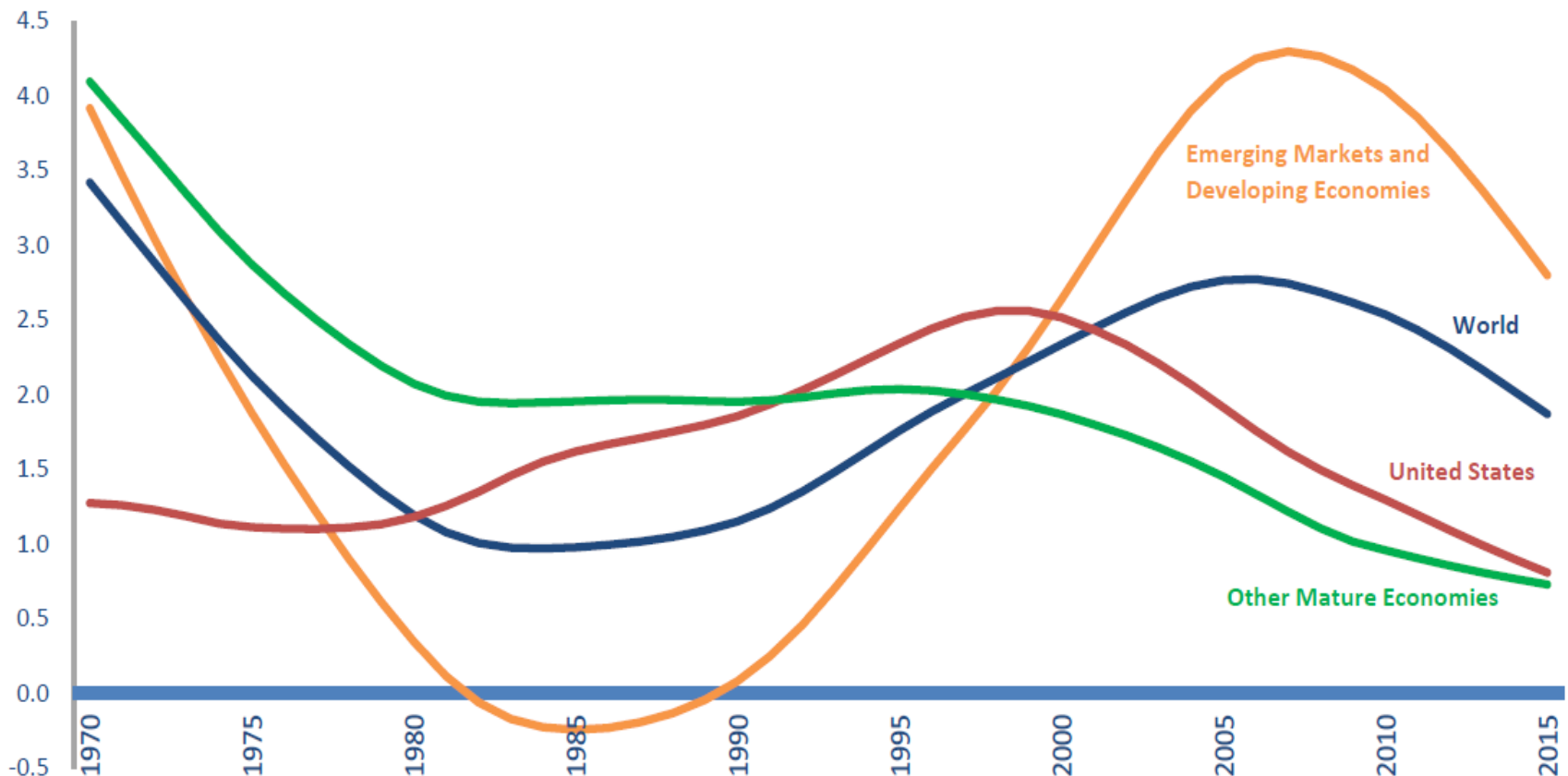
Published Papers containing "Artificial Intelligence"



# The Disappointing Recent Reality

- Productivity growth has slowed everywhere
  - We are more than one decade into a slowdown in the U.S. and OECD countries
- United States:
  - 1995-2004: 2.8% per year
  - 2005-2016: 1.3% per year
- OECD: 29 of 30 countries saw similar-sized slowdowns after 2004
- Emerging markets experienced slowdown around Great Recession (U.S. and OECD slowdowns began earlier)

# The Disappointing Recent Reality



**Source:** *The Conference Board Total Economy Database™ (Adjusted version), November 2016.*

**Notes:** Trend growth rates are obtained using HP filter, assuming a  $\lambda=100$ .



# Explanations for the Paradox

1. False hopes
  - Technological optimism unwarranted; future productivity acceleration won't come
2. Mismeasurement
  - Reality better than measured; no current slowdown
3. Distribution and dissipation
  - Technological benefits are real but concentrated; agents take large dissipative efforts to grab benefits
4. Implementation and restructuring lags
  - Technology is real, but benefits take time to emerge

# Explanations for the Paradox

1. False hopes: Certainly some past technologies have disappointed
  - But not hard to estimate large productivity gains from existing technologies
2. Mismeasurement: Reasonable prima facie case
  - But lots of recent work indicating this isn't the story
3. Distribution and dissipation: Consistent with more skewed/concentrated outcomes and links to worker pay
  - But hardly dispositive, and implies huge amounts of dissipative activity

# Explanations for the Paradox

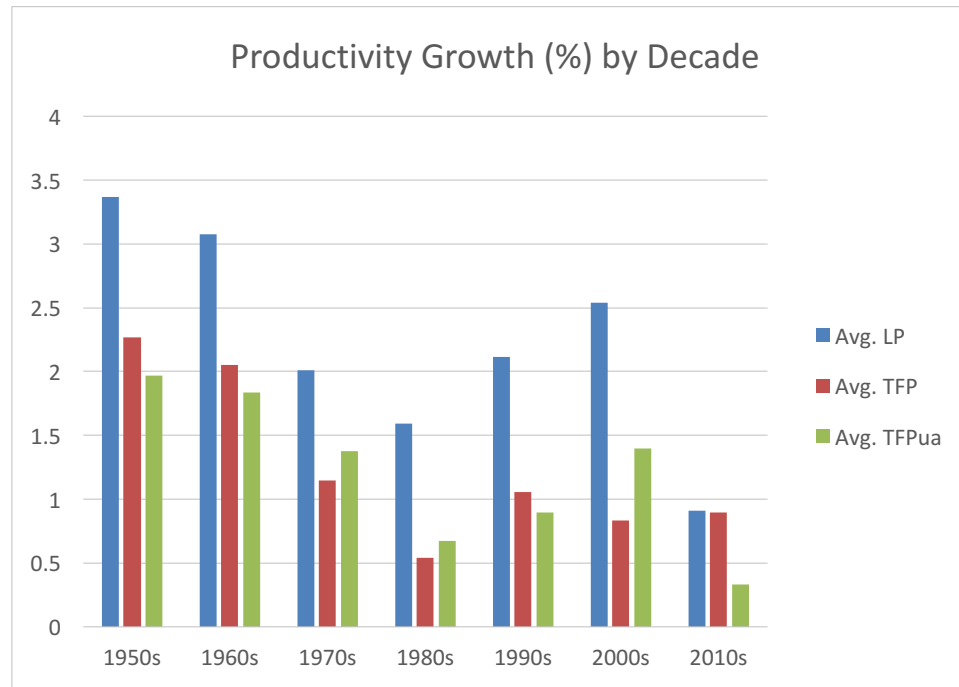
## 4. Implementation and restructuring lags

- Technology is real, but benefits take time to emerge

## AI Paradox is not a contradiction

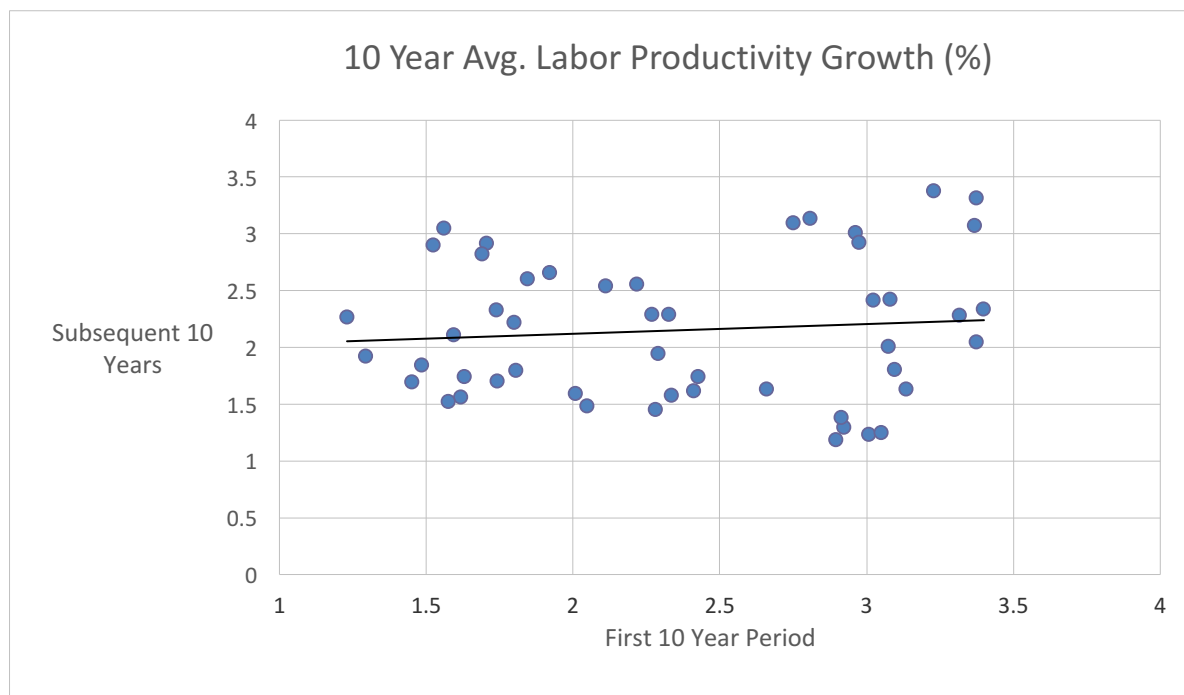
1. Optimists are extrapolating future impacts of current technologies...  
...But pessimists are extrapolating future trends from recent GDP and productivity data
2. GPTs take time to have an impact
3. GPTs may *lower* measured productivity initially
  - current slowdown tells us little about future

# Cause for concern?

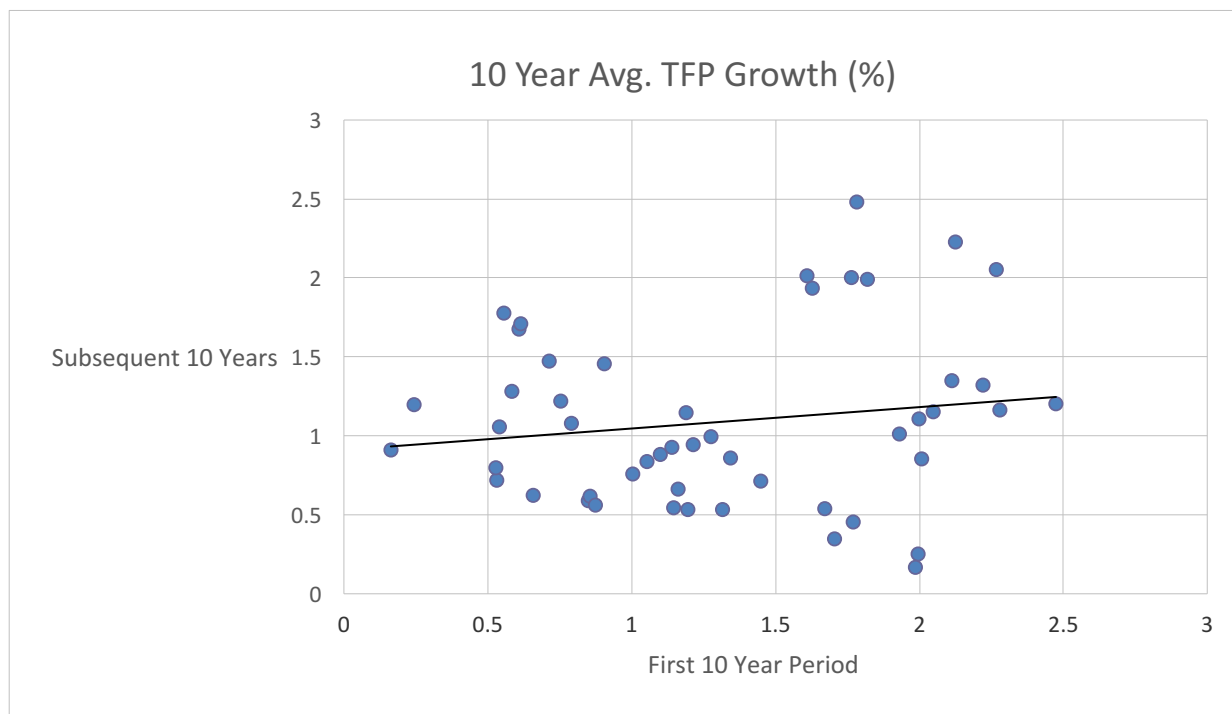


Productivity Growth by Decade

# “A Measure of our Ignorance”

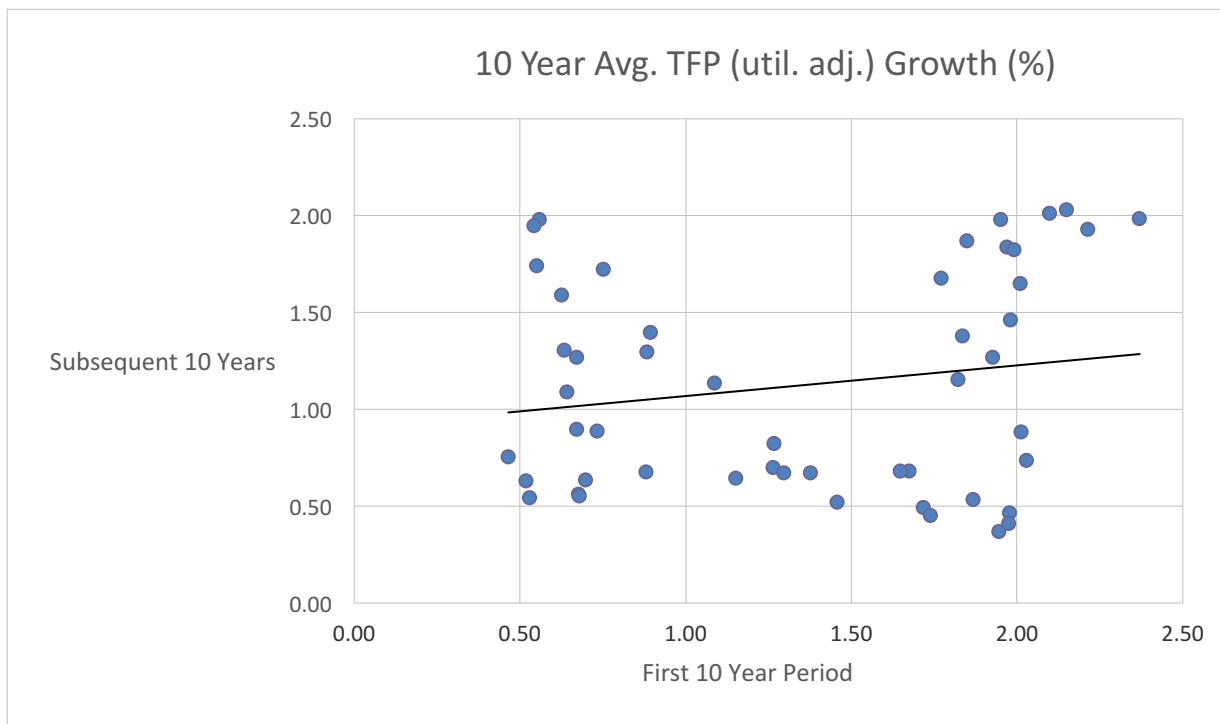


# “A Measure of our Ignorance”

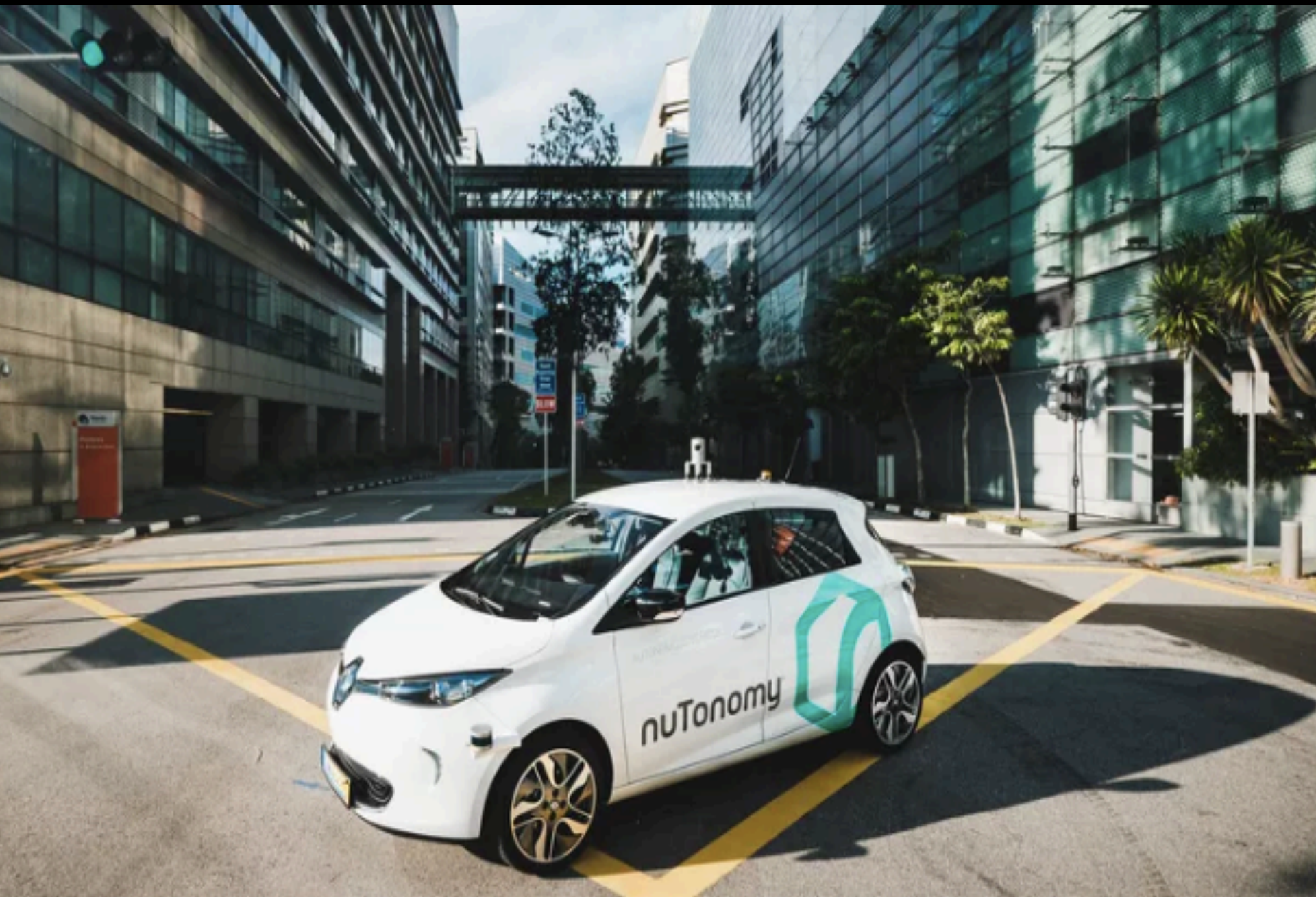


Total Factor Productivity

# “A Measure of our Ignorance”



Total Factor Productivity (Util. Adj.)







# Productivity Scenarios

- Call Centers:
  - 2.2 million employed in large call centers
  - Suppose reduced to 1 million
  - Private employment is 122 million
    - => ~ 1% increase in productivity
    - => Over 10 years, perhaps an additional 0.1%/yr
- Self-driving cars:
  - BLS reports 3.5 million “motor vehicle operators”
  - Suppose autonomous cars reduced that to 1.5 million
    - => ~ 1.7% increase in productivity
    - => Over 10-15 years, perhaps an additional 0.11-0.17%/yr

*Also, healthcare, retailing, security, insurance, legal, banking, warehouses, factories, education, etc.*

# Google uses DeepMind AI to cut data center energy bills

*The AI successfully reduced power consumption by 15 percent overall*

By **James Vincent** on July 21, 2016 04:02 am [@jjvincent](#)



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The amount of energy consumed by big data centers has always been a headache for tech companies. Keeping the servers cool as they crunch numbers is such a challenge that Facebook even built one of its facilities on [the edge of the Arctic Circle](#). Well, Google has a different solution to this problem: putting its DeepMind artificial

THE  
LATEST

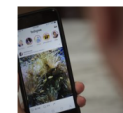
## HEADLINES



Windows 10 Mobile's Anniversary Update to arrive on August 9th



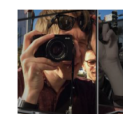
Berlin is getting an electric scooter-sharing program



Instagram's anti-abuse comment filter is rolling out now



US government poised to approve first private mission to the Moon

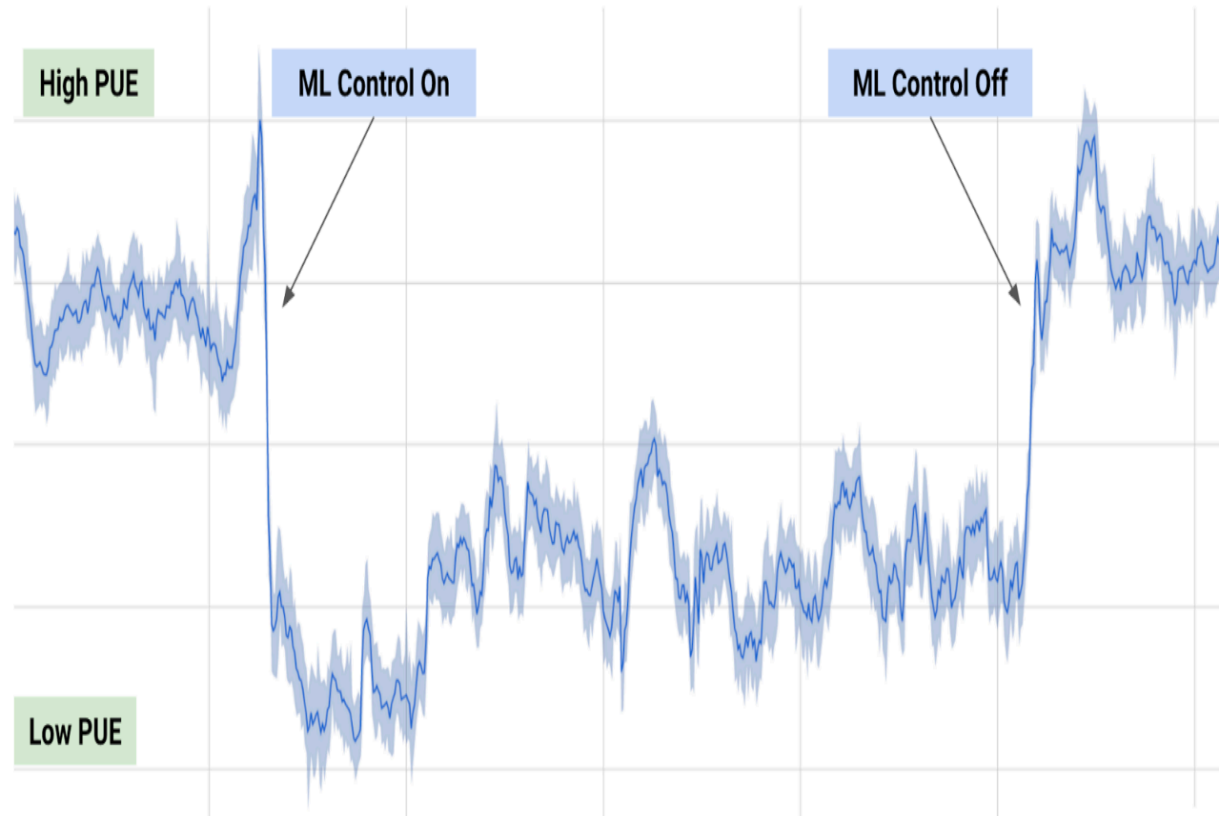


The Xbox One S heats up the HDR format war

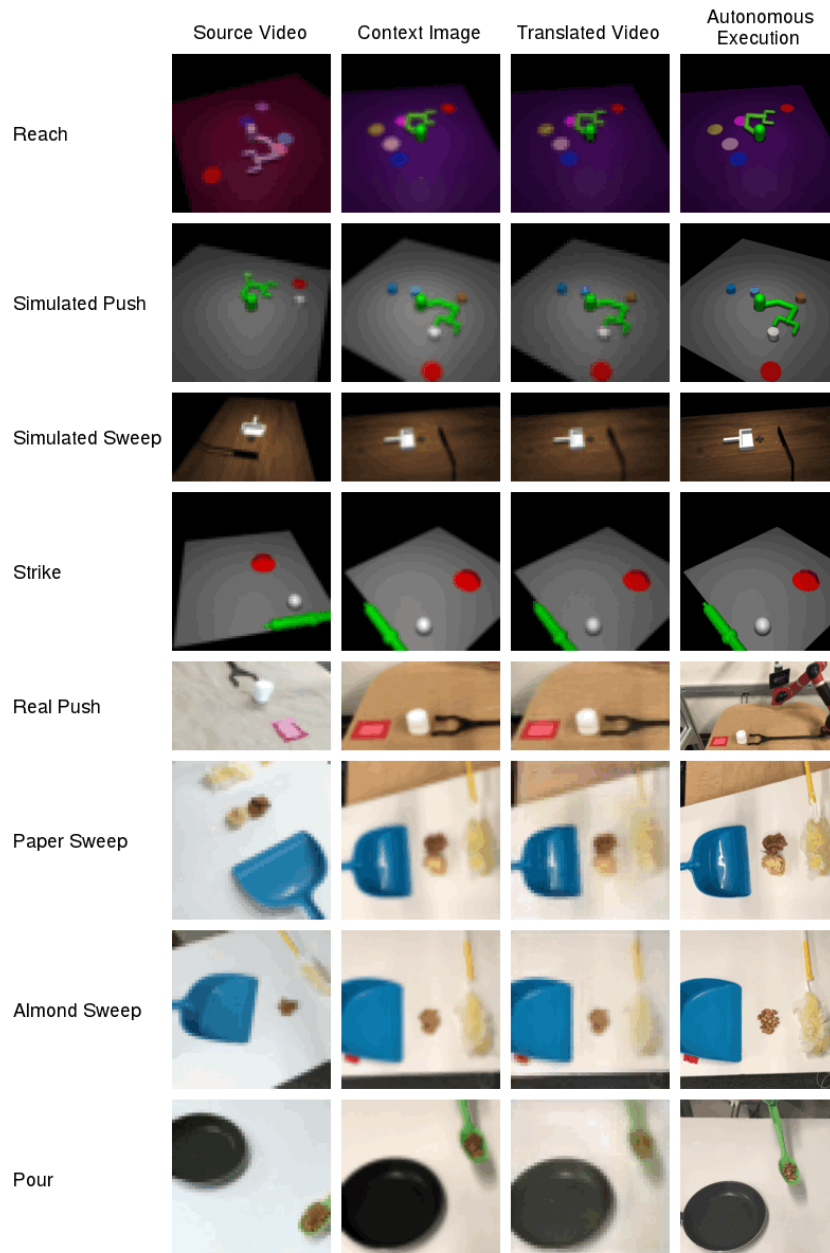


Bitcoin exchange hit with \$61 million theft

We tested our model by deploying on a live data centre. The graph below shows a typical day of testing, including when we turned the machine learning recommendations on, and when we turned them off.



Our machine learning system was able to consistently achieve a 40 percent reduction in the amount of energy used for cooling, which equates to a 15 percent reduction in overall PUE overhead after accounting for electrical losses and other non-cooling inefficiencies. It also produced the lowest PUE the site had ever seen.



- Techniques like Deep Reinforcement Learning are nascent, but have great potential
- Learning from imitation, for instance (Liu et al. 2017) can be applied to myriad tasks
- But have barely diffused yet

# More importantly, AI is a GPT

- GPTs (Bresnahan & Trajtenberg, 1996)
  1. Pervasive
  2. Able to be improved on over time
  3. Able to spawn complementary innovations

# More importantly, AI is a GPT

- GPTs (Bresnahan & Trajtenberg, 1996)
  1. Pervasive
    - “Prediction” (Agrawal, Gans & Goldfarb, 2017) including diagnosis, classification, and labeling is core to broad range of tasks, occupations and industries
  2. Able to be improved on over time
    - Essence of machine learning is improving over time (Brynjolfsson & Mitchell, 2017) and overcoming “Polanyi’s Paradox”
  3. Able to spawn complementary innovations
    - Perception (esp. vision, voice recognition) and cognition (problem solving) are building blocks that drive combinatorial innovation
    - Learning to learn

# The most G of all GPTs

“Our goal is to solve intelligence, and then use that to solve the other problems in the world”

- *Demis Hassabis,*

*Co-founder of Google DeepMind*



# If AI Is So Great, Why a Slowdown?

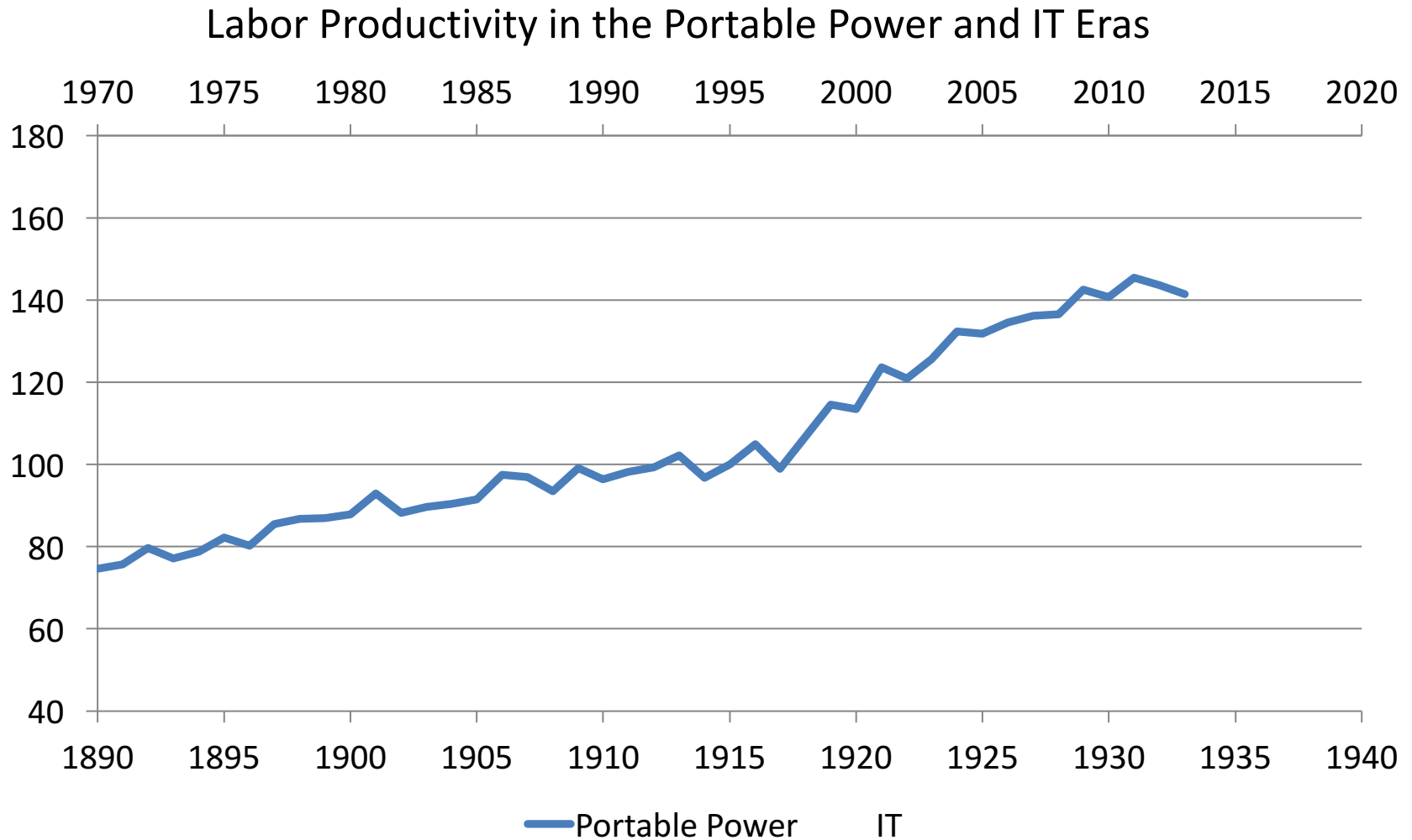
1. Stock must be accumulated enough to affect aggregates
2. Complementary assets need to be invented and installed

*This can take years or decades*

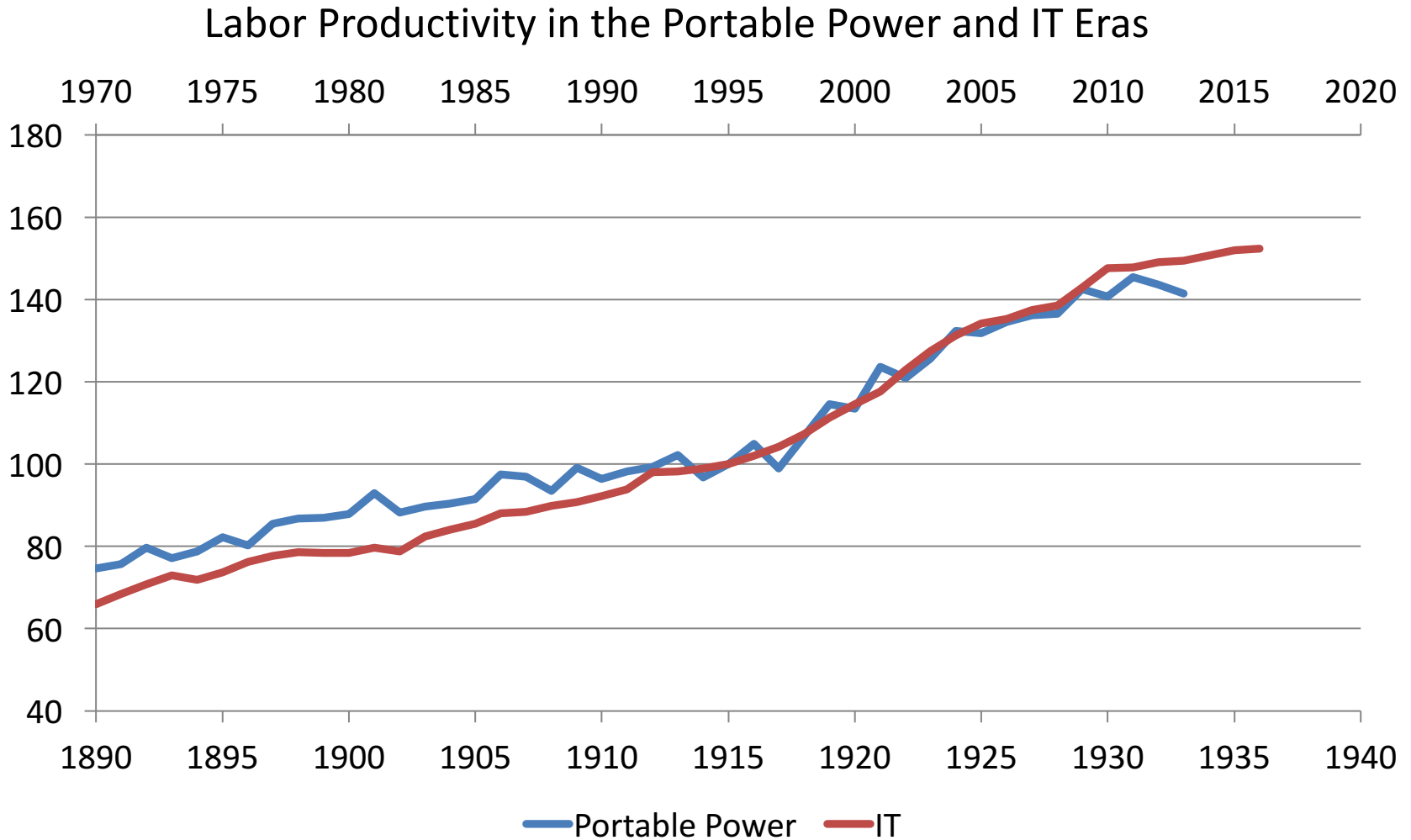
# If AI Is So Great, Why a Slowdown?

- It can take a long time for enough GPT stock to be accumulated to show up in aggregates
  - Computer capital in U.S. topped off at about 5% of total nonresidential equipment capital by late 1980s
    - 25+ years after invention of integrated circuit
    - Only half that level 10 years earlier
  - Over half of U.S. manufacturing establishments unelectrified in 1919
    - 30 years after alternating current systems standardized

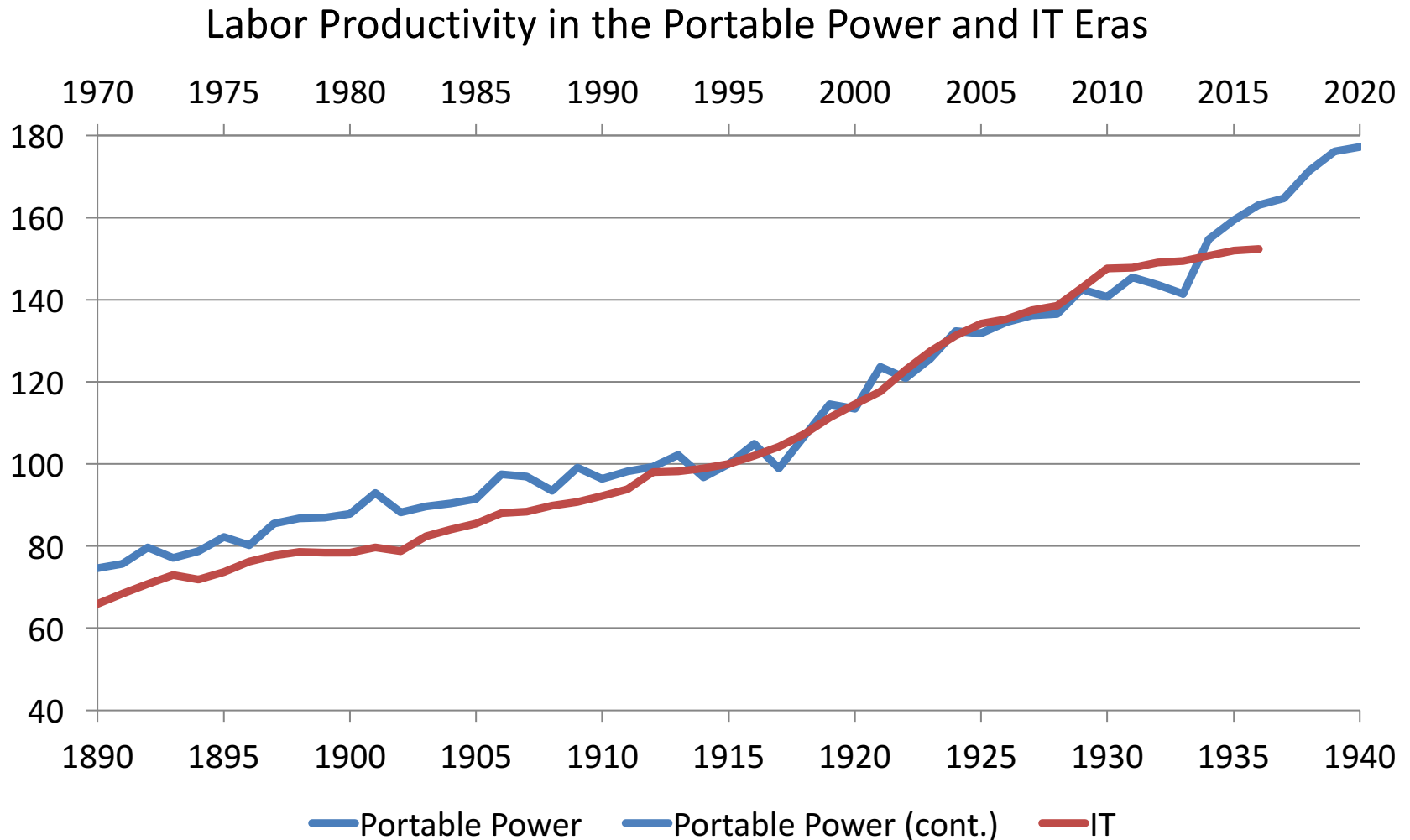
# History's Lens on Today's Paradox



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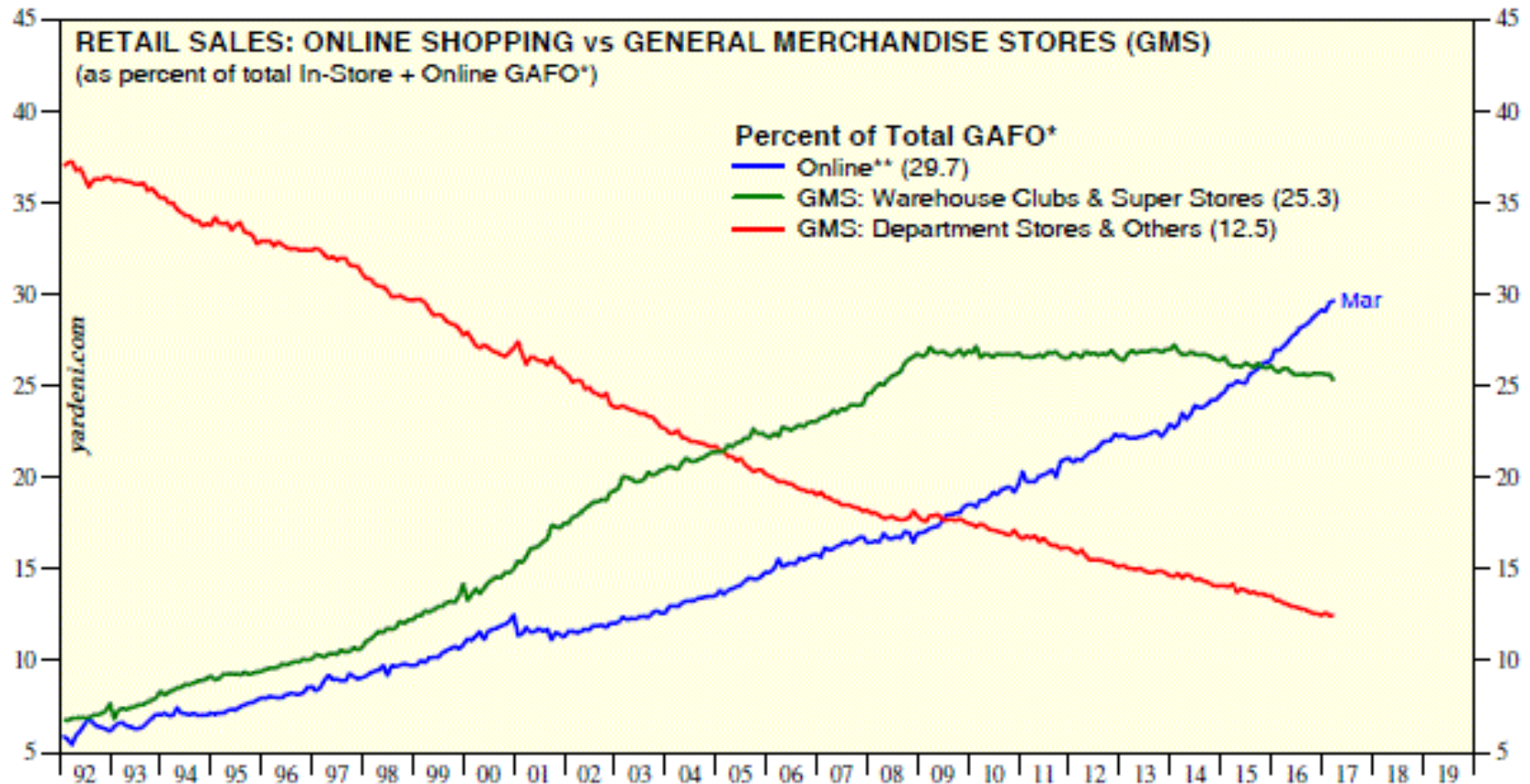
# History's Lens on Today's Paradox



# Coinvention Ain't Easy



# The Ecommerce Revolution wasn't finished in 1999



\* GAFO (general merchandise, apparel and accessories, furniture, and other sales) includes retailers that specialize in department-store types of merchandise such as furniture & home furnishings, electronics & appliances, clothing & accessories, sporting goods, hobby, book, and music, general merchandise, office supply, stationery, and gift stores.

\*\* Electronic shopping and mail order houses.

Source: Census Bureau and Haver Analytics.

# Expected Productivity Effects of AI

- Easiest way to think about this is to note that AI is a type of intangible capital
- Labor productivity and TFP:
  - AI adds to intangible capital stock
  - Effects on metrics will depend on whether we measure this increase
  - Reasons to think AI measurement will be hard
  - Measured TFP can even fall early if tangible inputs are used to build up intangible AI stock



# Firm Value and Intangible Capital Goods

- Combining Q-Theory and Standard Growth Accounting (Hall 2000; Yang and Brynjolfsson 2001)

$$V(0) = \sum_{j=1}^J \lambda_j(0) K_j(0)$$

- Firm Value  $V$  is sum of capital stock varieties ( $K$ ) priced at the “shadow” cost of investment  $\lambda_j$  at time 0
- Adjustment Costs and Intangibles can be treated similarly
- All capital investments have significant intangible component
- Market prices reflect valuation

# Growth Accounting

- With unmeasured intangible capital, growth accounting equation becomes:

$$g_Y = \left( \frac{pF_K K}{Y} \right) \left( \frac{\dot{K}}{K} \right) + \left( \frac{pF_N N}{Y} \right) \left( \frac{\dot{N}}{N} \right) + \left( 1 - \frac{\lambda}{z} \right) \left( \frac{zI}{Y} \right) \left( \frac{\dot{I}}{I} \right) + \left( \frac{F_t}{F} \right)$$

- Key component is  $\frac{\lambda}{z}$ : the ratio of the shadow price of investment to the purchase price of capital (details in appendix)
- Physical / marketed component may be small relative to the required investments in org change, training, etc.

# Conclusion

- The modern productivity paradox of technological optimism and the disappointing current empirical reality has a plausible solution
- Implementation and restructuring lags story says these two things not in conflict
- Indeed, story implies they are an internally consistent and necessary result of GPT invention and diffusion
- But realizing benefits of AI will not be automatic
- Nor will understanding AI's effects on the economy be for us researchers

# Extra slides

It's difficult to make predictions,  
especially about the future  
- *Neils Bohr*

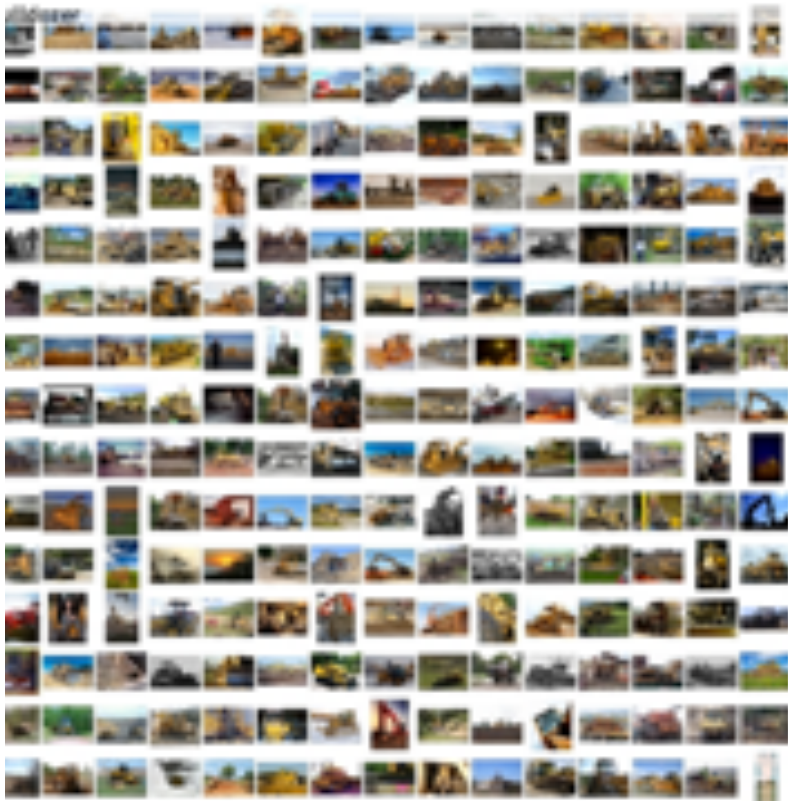
## Humans vs. Machines

### 3 Big Changes 2006 to 2016:

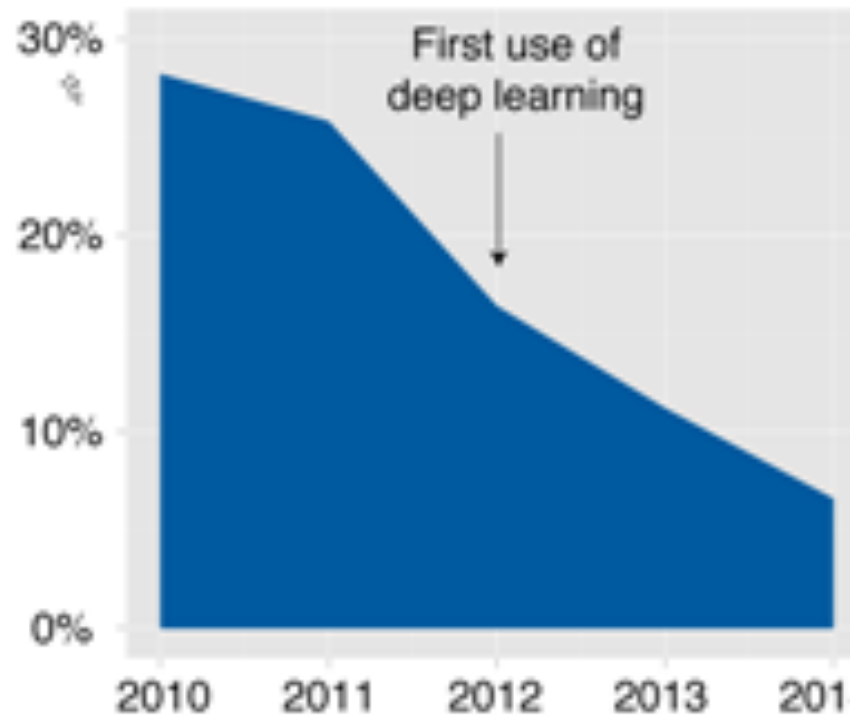
1. Interacting with physical world
  - Vision and other senses
  - Mobility and Robotics
2. Language
  - Voice recognition
  - Natural language processing
  - Creating narratives
3. Problem Solving
  - Answering unstructured questions
  - Pattern recognition and classification

# Improvements in Vision

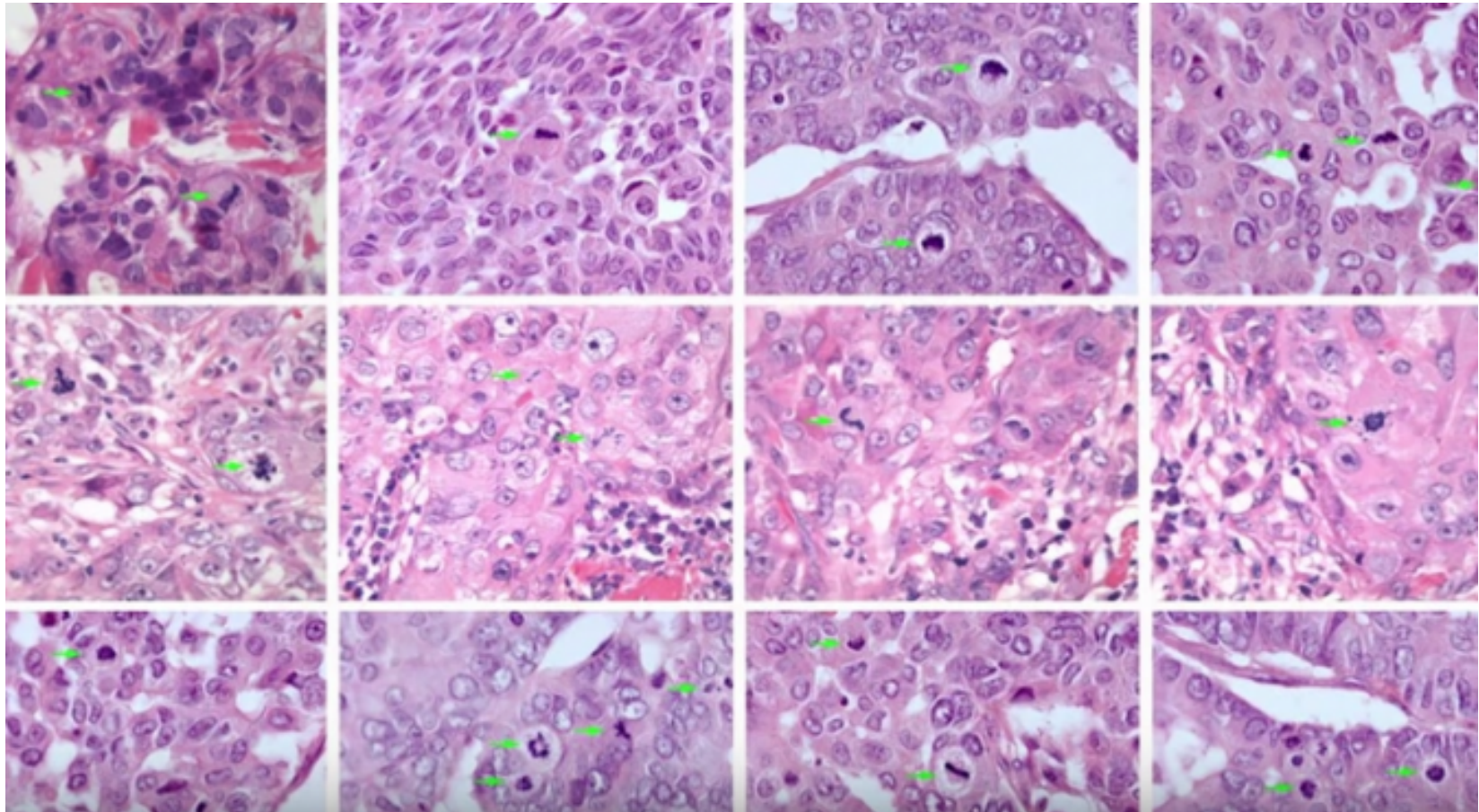
ImageNet examples



Object classification error rate



# Enlitic Detects Cancer







# Siri

## Voice recognition



# Skype

## Real time Translation



# Automated Insights

## Authoring News Stories

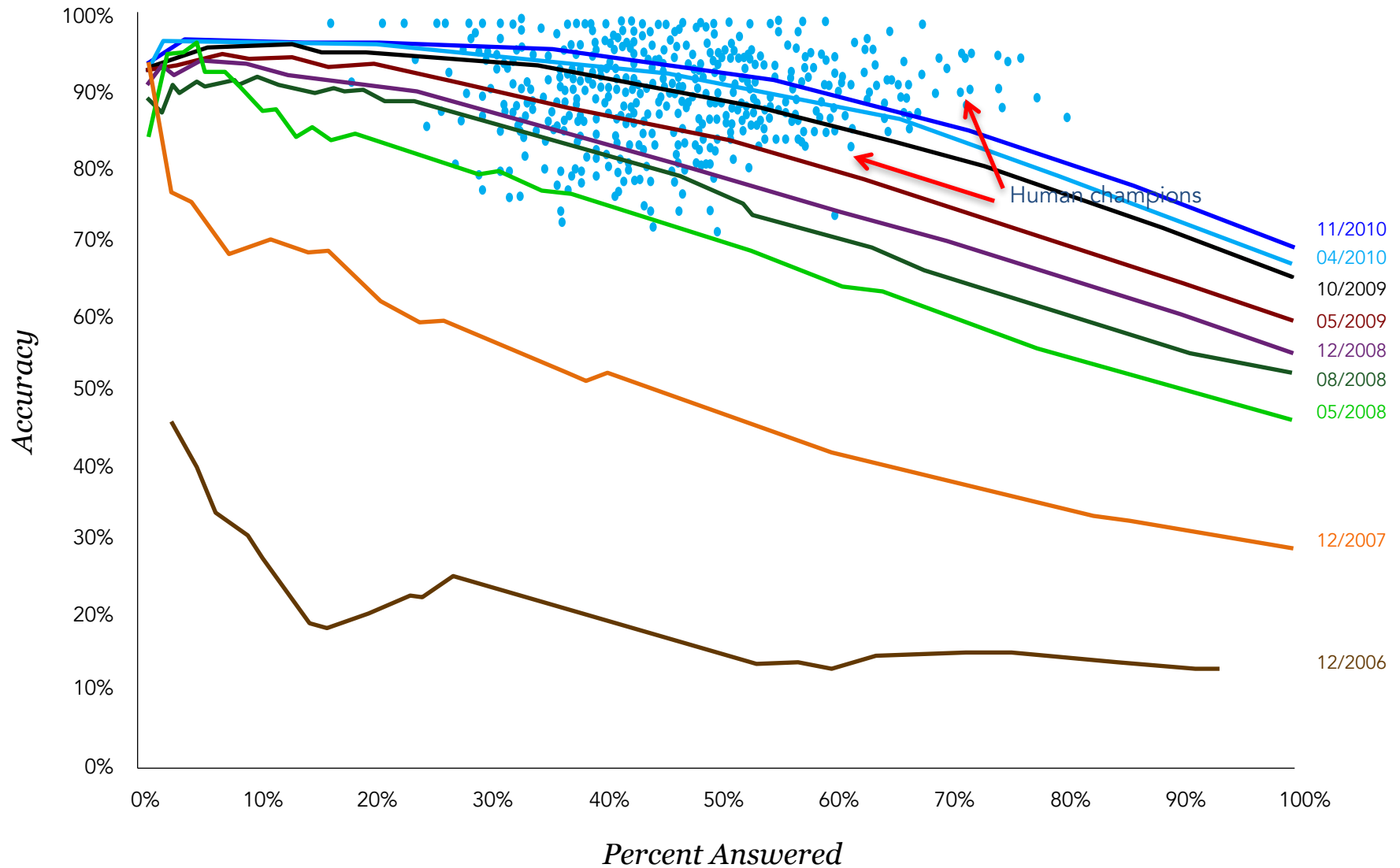


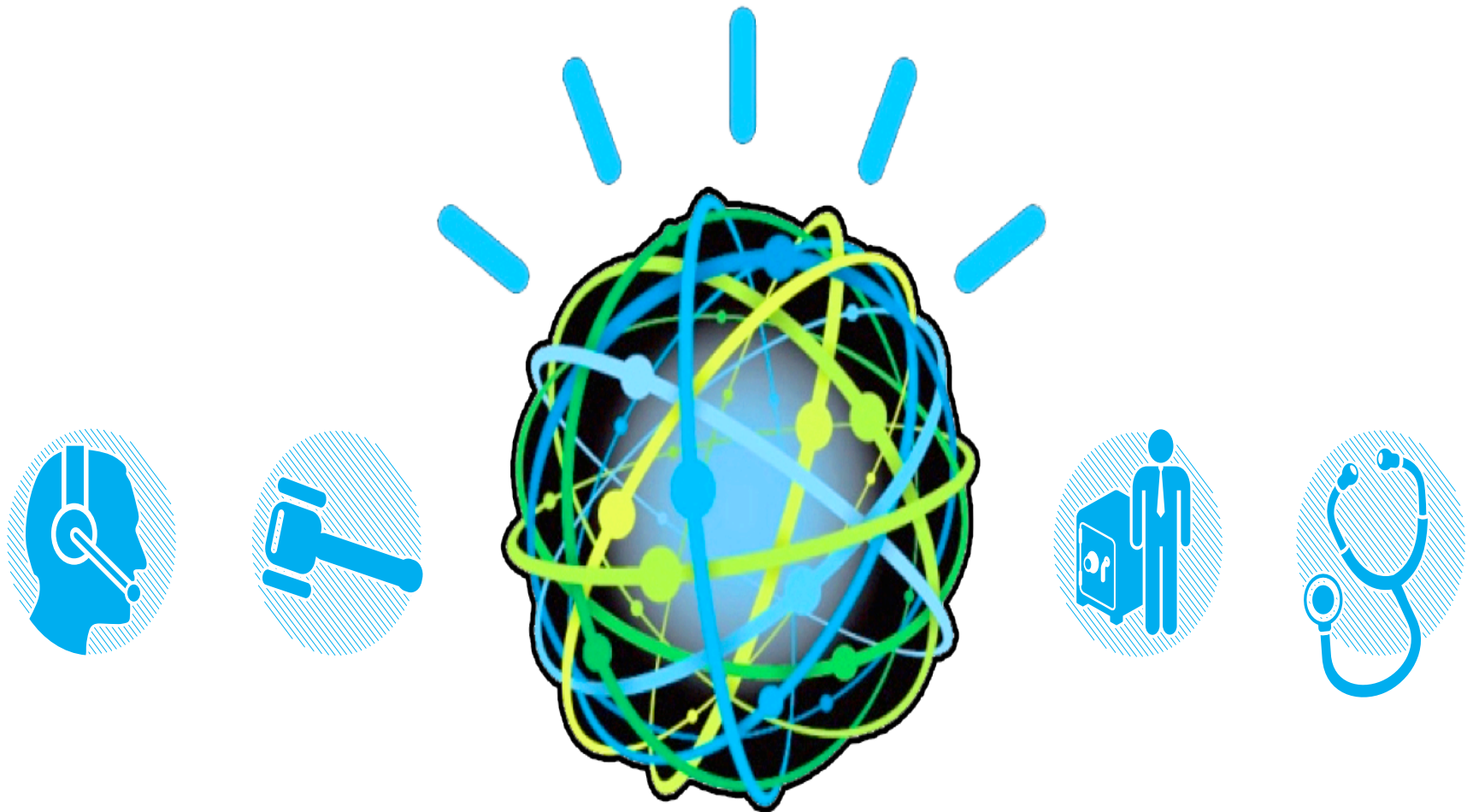
Narrative Science®

Our technology application  
generates news stories, industry  
reports, headlines and more —  
at scale and without human  
authoring or editing

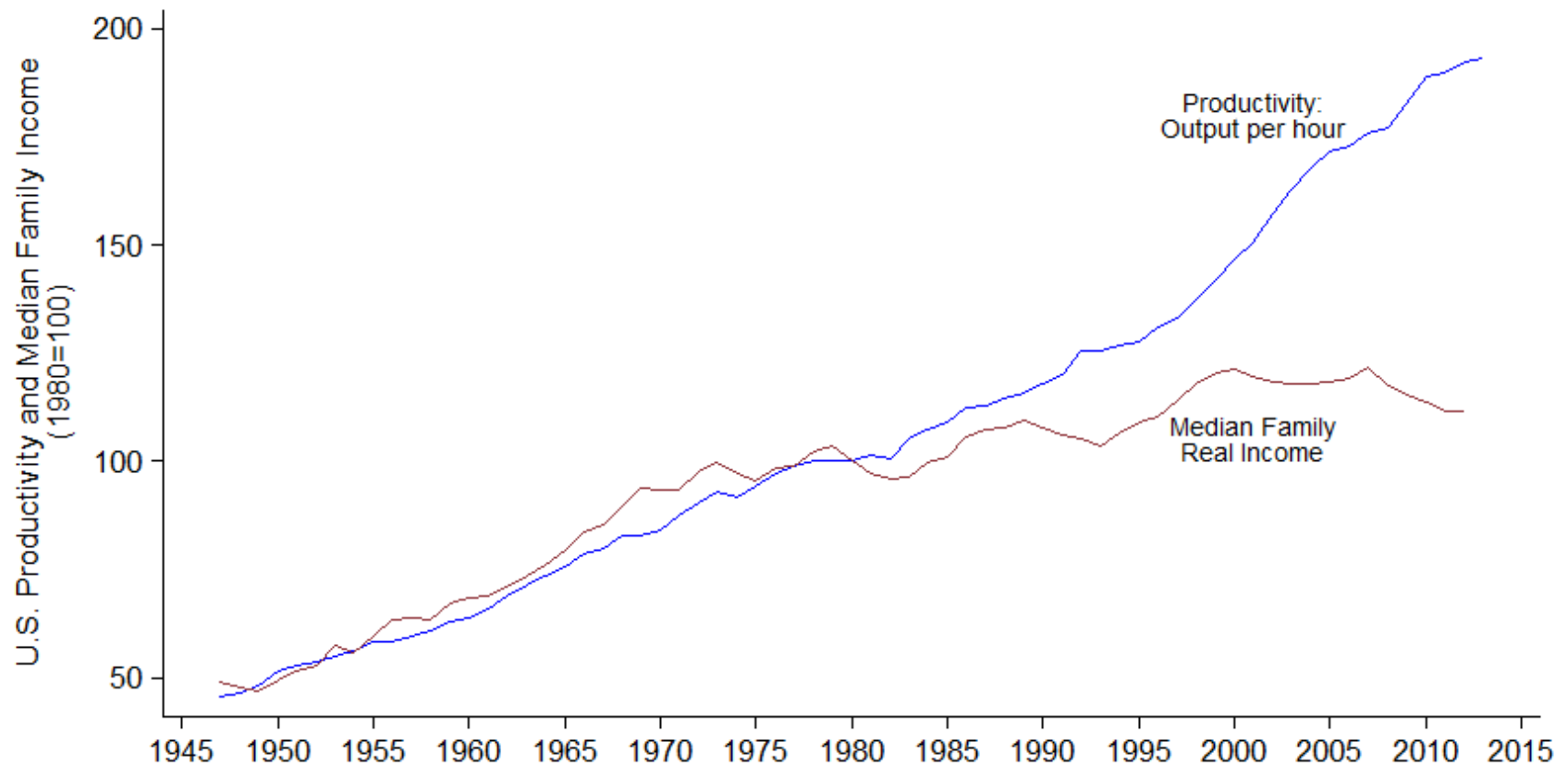


# Accuracy and Questions Answered on *Jeopardy!*





# Productivity isn't everything





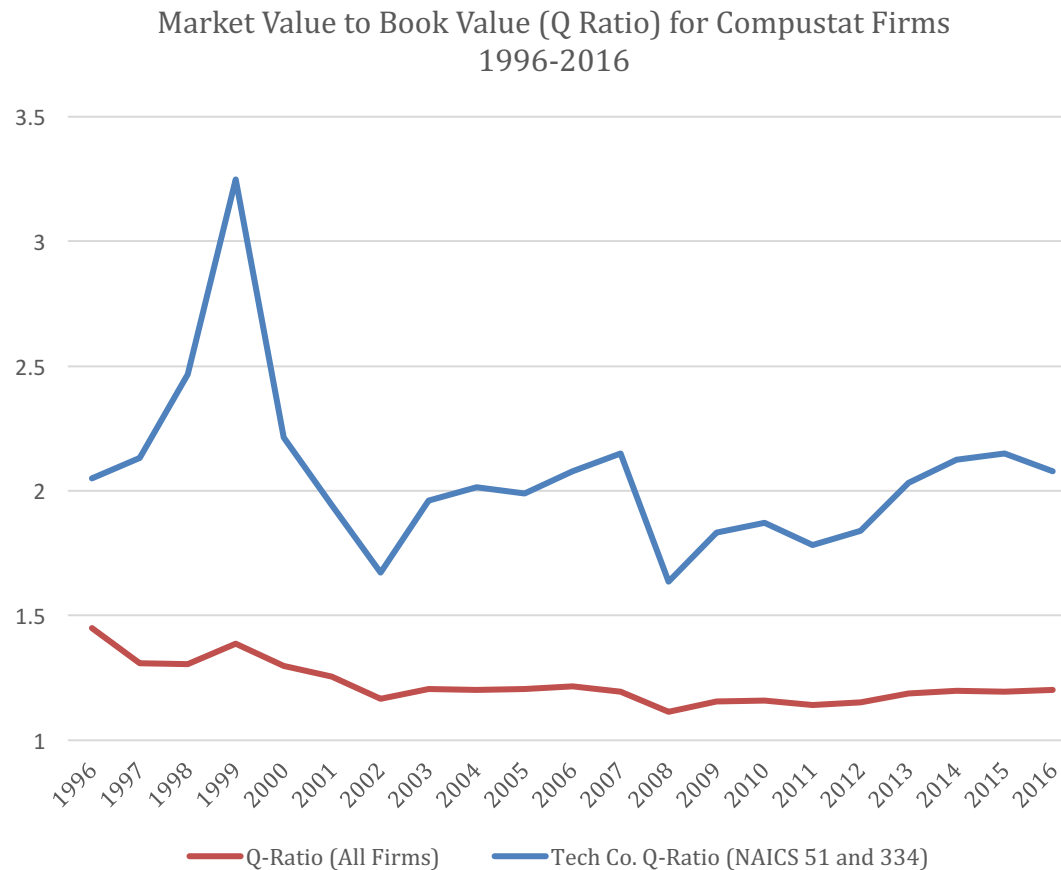
# “A Measure of our Ignorance”

Productivity Growth Regressions	(1) Labor Productivity Growth (10 Year)	(2) Total Factor Productivity Growth (10 Year)	(3) Utilization-Adjusted Productivity Growth (10 Year)
Previous 10 Year Productivity Growth	0.0857 (0.132)	0.136 (0.121)	0.158 (0.137)
Constant	1.949*** (0.297)	0.911*** (0.145)	0.910*** (0.189)
Observations	50	50	50
R-squared	0.009	0.023	0.030

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

# Tobin's Q – Tech vs. the Rest



# Computerization > Computers

**IT Capital (10%)**

**Technological  
Complements (15%)**

**Organizational  
Complements (75%)**

*Intangible Assets*  
*are more important in  
the Information Economy*

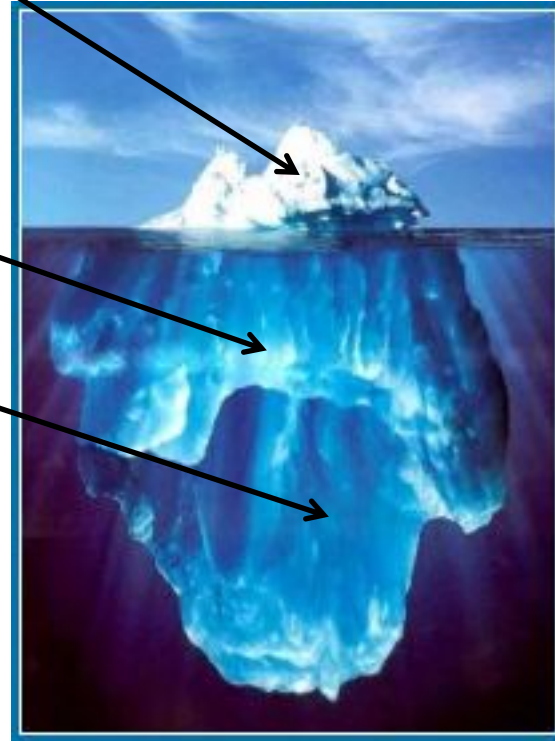
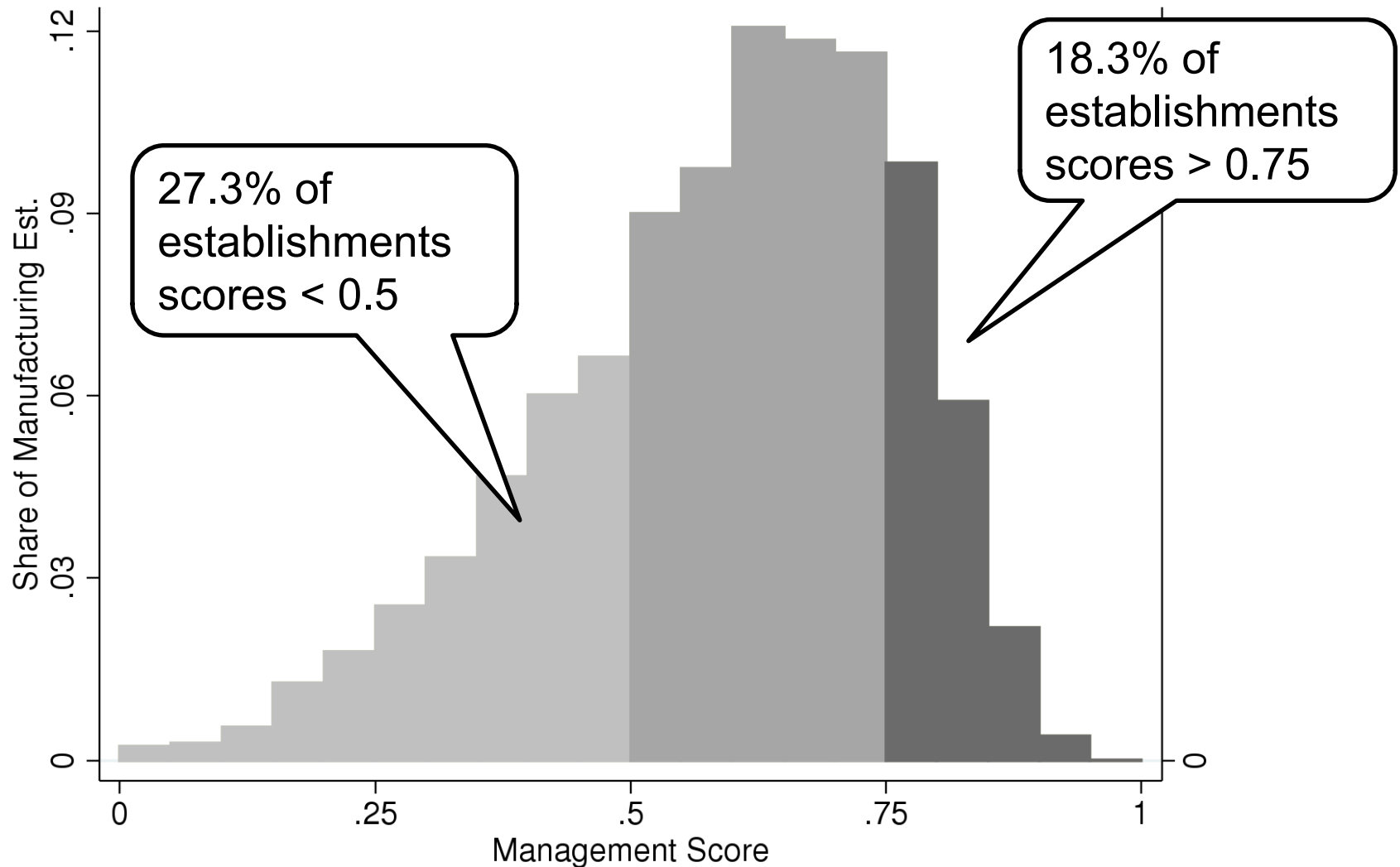


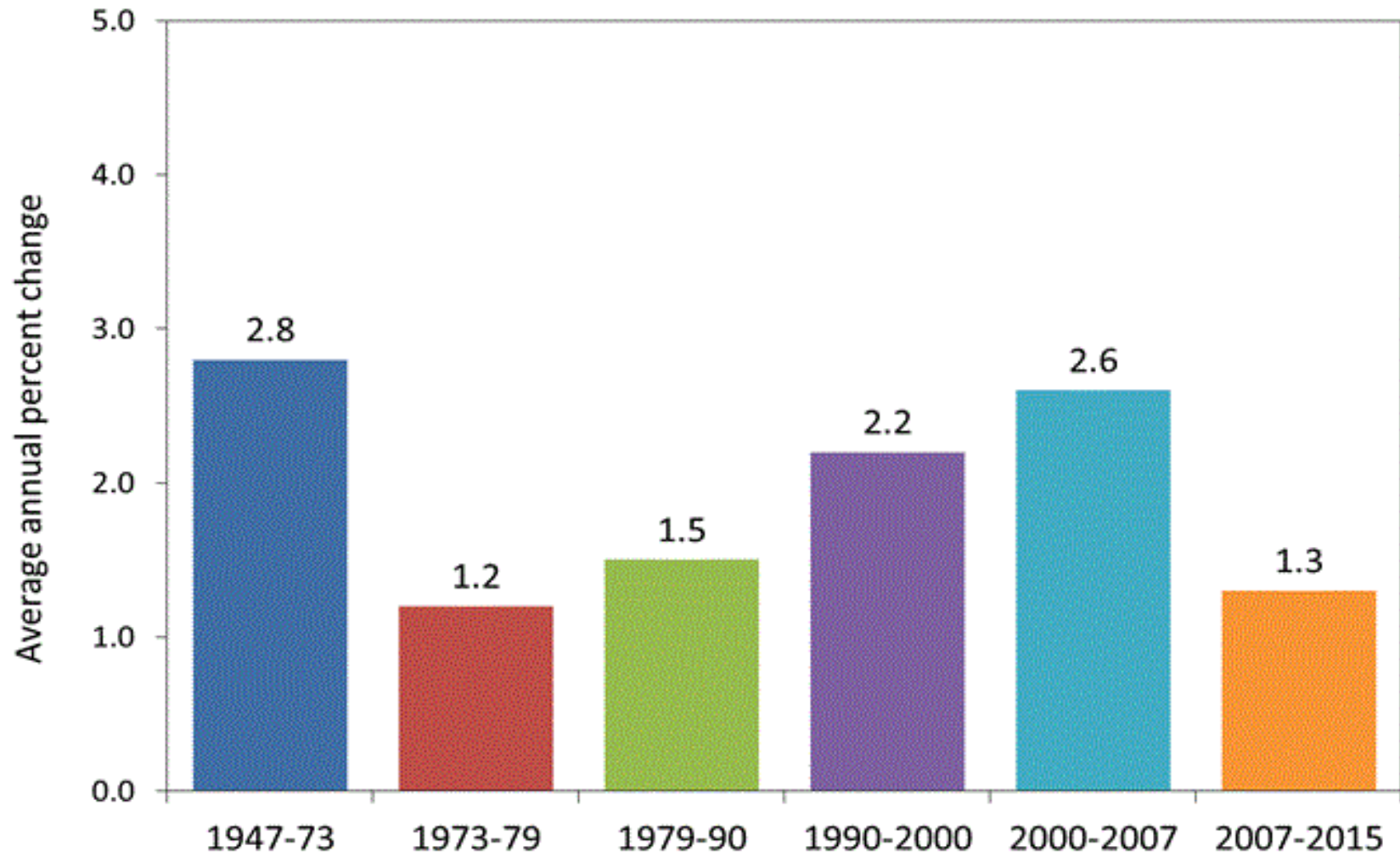
Image by Ralph Clevenger



# Adoption of management practices



# Productivity Growth in Recent Business Cycles



Source: U.S. Bureau of Labor Statistics