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

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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

Image Recognition
Vision Error Rate

- Algorithms
- Human

30%
0%

2010 2016
Machine Learning Has Crossed an Important Threshold

Image Recognition
Vision Error Rate

- Algorithms
- Human

container ship, motor scooter, leopard, mushroom, cherry, Madagascar cat
Google Home Speech Recognition

Word Error Rate

- 8.5%
- 6.8%
- 6.1%
- 4.9%
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

Notes: Trend growth rates are obtained using HP filter, assuming a l=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

- Avg. LP
- Avg. TFP
- Avg. TFPua

Productivity Growth by Decade
“A Measure of our Ignorance”

![Graph showing 10 Year Avg. Labor Productivity Growth (%) vs. First 10 Year Period and Subsequent 10 Years. The graph indicates a relationship between the two periods with a slight upward trend.]

Labor Productivity
“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  @jivincent

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 intelligence team to work harvesting energy.

In a blog post today, DeepMind Senior Researcher James Alt, who leads the team that develops artificial intelligence for Google, describes how Google has trained its AI team to reduce the power consumption of one of Google's largest data centers by 15 percent. The team, which is headquartered in London, built an algorithm that learns the optimal way for cooling the data center through machine learning.

The system was tested on a minor scale and reduced the power consumption by 15 percent. Alt says the findings will help with the development of a larger-scale solution that will be rolled out to other data centers.

DeepMind has already been hard at work, training its AI to perform tasks that were previously thought to be too complex for computers. The team has been working with Google to develop a robot that can walk on its own, and it has even developed an AI-powered game that can play against a human.

The team's latest project is to develop an AI that can learn to control the cooling in a data center. The AI, known as DeepMind Energy, is trained using a reinforcement learning algorithm, which allows it to continuously adjust its cooling strategy based on feedback from the environment.

In the past, data centers have relied on manual adjustments to control their cooling systems. However, this approach is not always effective, and it can lead to energy waste and increased costs. DeepMind Energy, on the other hand, learns to optimize its cooling strategy in real-time, which can result in significant energy savings.

Alt says that the team has already tested DeepMind Energy in a small-scale setting, and the results have been promising. The team is now working on a larger-scale implementation, which will be rolled out to other data centers.

Alt predicts that the technology will have a significant impact on the tech industry, as data centers account for a significant portion of the world's energy consumption. He says that the team is optimistic that the technology will be able to reduce energy consumption by 20 percent or more.
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

Labor Productivity in the Portable Power and IT Eras
History’s Lens on Today’s Paradox

Labor Productivity in the Portable Power and IT Eras

- Portable Power
- IT
History’s Lens on Today’s Paradox

Labor Productivity in the Portable Power and IT Eras

- Portable Power
- Portable Power (cont.)
- IT
Coinvention Ain’t Easy
The Ecommerce Revolution wasn’t finished in 1999
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

• AI 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

Objection classification error rate

First use of deep learning

Copyright © Erik Brynjolfsson
Enlitic Detects Cancer
Siri
Voice recognition

Skype
Real time
Translation

Automated Insights
Authoring News Stories

Copyright © Erik Brynjolfsson
Accuracy and Questions Answered on Jeopardy!

Human champions

Copyright © Erik Brynjolfsson
Productivity isn’t everything

[Graph showing trends in Productivity and Median Family Income from 1945 to 2015]
### Productivity Growth Regressions

<table>
<thead>
<tr>
<th>Productivity Growth Regressions</th>
<th>(1) Labor Productivity Growth (10 Year)</th>
<th>(2) Total Factor Productivity Growth (10 Year)</th>
<th>(3) Utilization-Adjusted Productivity Growth (10 Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous 10 Year Productivity Growth</td>
<td>0.0857 (0.132)</td>
<td>0.136 (0.121)</td>
<td>0.158 (0.137)</td>
</tr>
<tr>
<td>Constant</td>
<td>1.949*** (0.297)</td>
<td>0.911*** (0.145)</td>
<td>0.910*** (0.189)</td>
</tr>
<tr>
<td>Observations</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.009</td>
<td>0.023</td>
<td>0.030</td>
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Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Tobin’s Q – Tech vs. the Rest

Market Value to Book Value (Q Ratio) for Compustat Firms
1996-2016

Q-Ratio (All Firms)  Tech Co. Q-Ratio (NAICS 51 and 334)
Computerization > Computers

IT Capital (10%)

Technological Complements (15%)

Organizational Complements (75%)

*Intangible Assets are more important in the Information Economy*

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Adoption of management practices

18.3% of establishments scores > 0.75

27.3% of establishments scores < 0.5

Source: Bloom, Brynjolfsson et al. Management In America, 2016
Productivity Growth in Recent Business Cycles

<table>
<thead>
<tr>
<th>Period</th>
<th>Average Annual Percent Change</th>
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<tbody>
<tr>
<td>1947-73</td>
<td>2.8</td>
</tr>
<tr>
<td>1973-79</td>
<td>1.2</td>
</tr>
<tr>
<td>1979-90</td>
<td>1.5</td>
</tr>
<tr>
<td>1990-2000</td>
<td>2.2</td>
</tr>
<tr>
<td>2000-2007</td>
<td>2.6</td>
</tr>
<tr>
<td>2007-2015</td>
<td>1.3</td>
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</table>

Source: U.S. Bureau of Labor Statistics