Evidence of Accelerating Mismeasurement of Growth and Inflation in the US in the 21st Century

ESCoE 2020 Conference on Measurement
September 17, 2020
London UK

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** The views expressed today are my own and not necessarily those of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.*

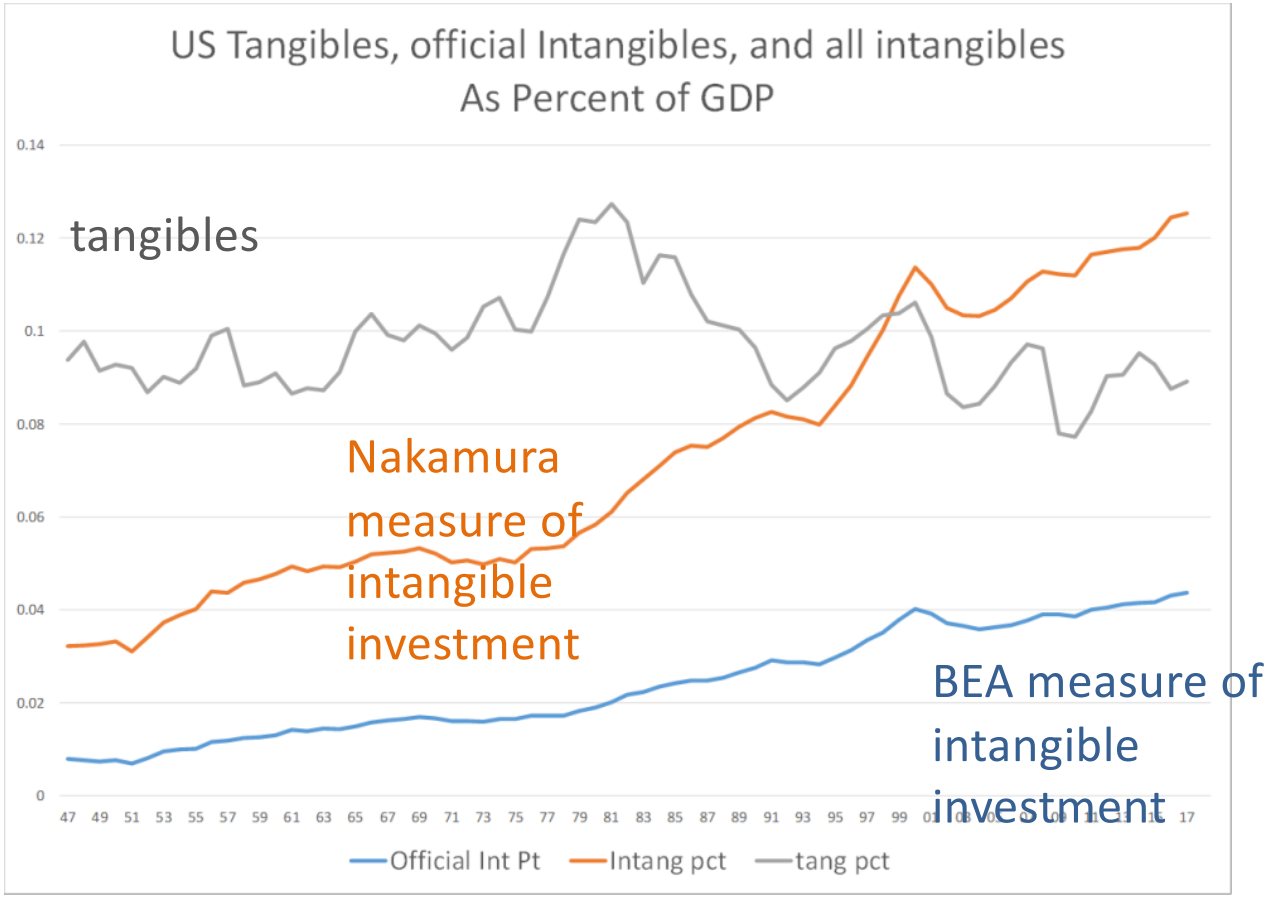
Overview

- This talk is about how little we know about true inflation and growth
  - The 21st century US economy makes measuring growth more difficult.
  - New products, free products
- Mismeasured intellectual property investment and consumption
- Inflation and growth mismeasurement accelerated at least 1 % since the mid-1990s: true output grows faster, inflation is slower
  - 1983-1995, 1 % mismeasurement
  - 2005-2017, 2 % mismeasurement
- Productivity growth is strong and prices are likely deflating in the US (and around the world)

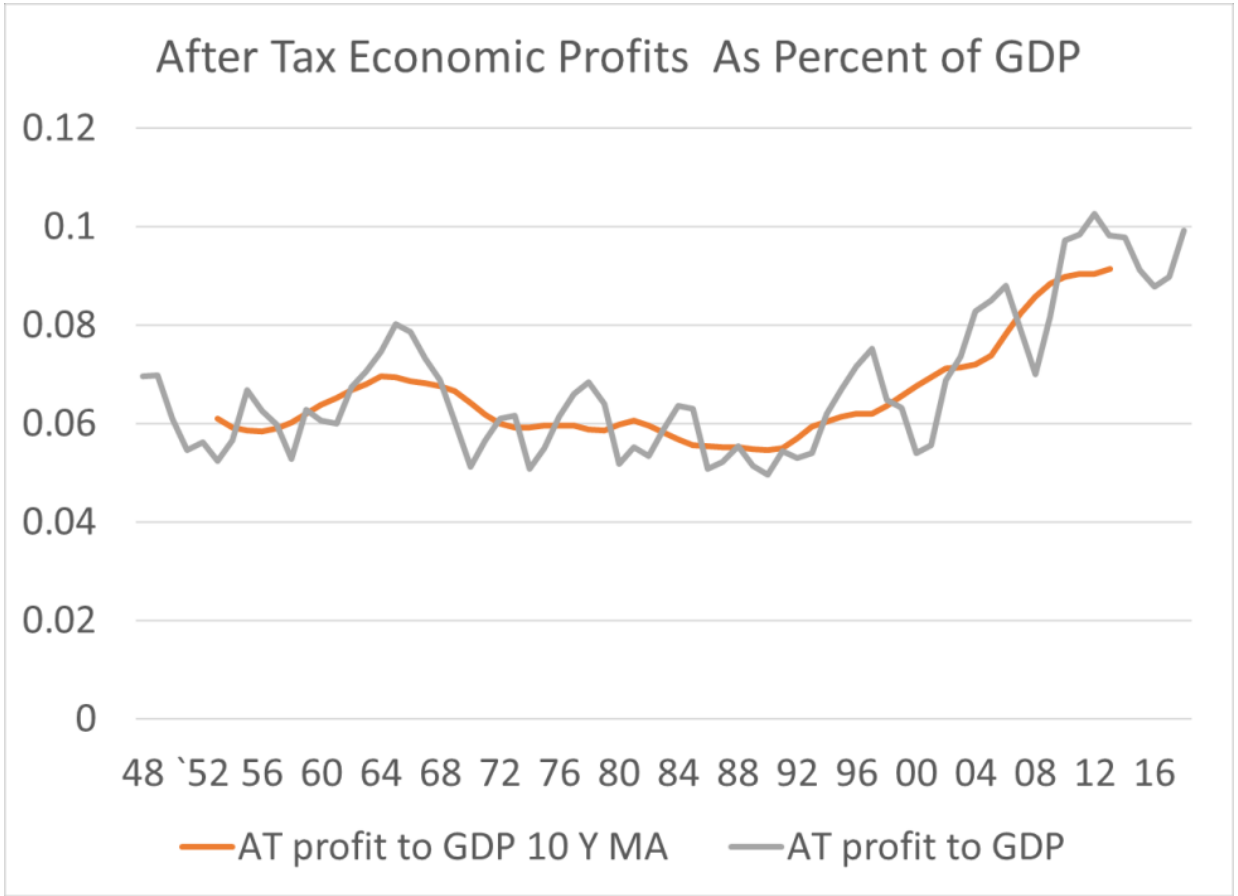
Puzzle: Fast corporations, slow growth

- In the US, we have high corporate investments in innovation, products that are successful worldwide, and high profits
  - but historically weak GDP growth per capita and real interest rates
- Our national account statistics fail to capture much of the benefits of innovation and these errors have accelerated
- Ultimately, we may be growing too fast, not too slowly
  - The economy is changing at rates that households and all our institutions are having trouble adapting to

US corporations are investing in new product development at twice to three times past rates



Intangible investments generate large US Corporate profits: 9 % of GDP compared to 6 % in 1980s



Broad Measurement Problems: Consumption

- Consumption has changed a lot since 2005
  - iPhones, Androids, iPads, Amazon prime, Kindle, Google Maps, Uber, AirBnb, Spotify, Youtube, Netflix, Khan Academy, Tesla Model 3, Drones
  - Consumers love new varieties and product variety is accelerating
  - Many consumers suffer from excess quantity consumption (obesity, untidiness)
- Consumers consume information and novelty (entertainment, etc.)
- Innovative products have always been hard to quantify
  - Quantitative growth easier to measure than qualitative change
- Zero resource cost products replace costly products
  - With Internet 2.0, everything that can be digitized has zero reproduction cost

Consumption, continued

- Real consumption and the real rate of interest are welfare concepts
- Since Samuelson and Hicks, we have known that real consumption depends on the expenditure function
  - How much a given level of utility costs
  - And a cost-of-living price index is the cost of buying a constant level of utility
- The real rate of interest is also welfare based
  - How much utility does a marginal dollar buy today compared to tomorrow?

Broad Measurement Problems: Intangibles

- Intangible investment replaces tangible investment
  - Creating software, knowledge, new goods, brands
  - We deflate intangibles with input costs and add average productivity
    - But we don't measure these input costs well, many input prices are falling rapidly measured by price per unit
    - And obsolesencence is rapid
    - SpaceX, Cloud computing, DNA sequencing and editing, electric batteries, drones, 3D printing, big data, AI, all developed rapidly since 2005
  - Data is a new intangible investment, not in GDP
    - Hugely valuable for biology, Internet business, data science, and AI

Has mismeasurement accelerated?

- More rapid change in products on the market
  - In 1983-4 and in 1995, BLS found products permanently disappeared in 25 months on average from CPI survey
    - By 2015 they disappear in 20 months (Groshen et al, 2017)
  - Between 1995 and 2015, product disappearance rate increased by 25 %
- Our standard procedures don't measure quality improvements when new products appear
  - Our CPI and PPI measure changes in narrowly defined goods and services
  - But quality, not quantity, is the main way the economy now improves
    - For ex, an hour of a doctor's time or an hour in a classroom are different products than they were in 1965
  - So we need custom ways to deal with these: but there are myriad new products

To understand rising profits look at Alphabet, Amazon, Apple and Facebook

- After-tax profits rose $72 B from 2007 to 2017
  - 18 percent of total US domestic corp aftertax profits gain of $400 B
- Apple
  - iPhone (2007), iPhone Apps (2008), iPad (2010), Siri (2011)
  - 2 billion iPhones and Androids worldwide 2018, 2-4 hours daily use
- Google
  - Google maps (2005), Youtube(2005), Android (2008), Waymo (2009), Deepmind (2010),
- Amazon
  - Amazon Prime (2005), AWS (2006), Kindle (2007), Alexa (2012)
- Facebook
  - Open to all (2006), WhatsApp (2009), Snapchat(2011)
  - 1.5 billion daily active users on Facebook and 1 billion on Whatsapp!

How Can we Have Big Profits, Fast Change and Slow Measured Growth?

- The consumer products of Google, Facebook, Amazon, and Apple do show up not as increases in PCE growth but as decreases
- Free Products: Google and Facebook, Youtube
  - Zero prices incompatible with inflation and output measures
  - Free products replace tangible merchandise such as DVDs and film
- Unmeasured quality change: Amazon,
  - Low costs translate into measured lower output, not lower inflation: outlet bias implies worse service
  - But Amazon delivers to your home
- Outsourcing: Apple
  - Apple looks like an importing wholesaler in economic statistics

New papers on the valuation of variety

- BLS calculations show rate of product turnover in CPI has risen by 25 %, as products disappear permanently 5% monthly up from 4 % monthly in mid-1990s
- Aghion et al (AER, 2019) measure the consumption value of new outlets: inflation overstated by
  - 0.52 % in 1983-95
  - 0.65 % in 2006-2014 (acceleration about 25%, consistent with product disappearance rate)
  - This is for nonfarm businesses. Largest impact from hotels and restaurants.
- Niemann and Vavra (2019) argue that product variety at nondurable retail stores could add:
  - 0.8 % in 2004-2016 to annual welfare gains
  - If 25 % acceleration, then I conjecture: 0.64 in 1983-95
  - Variety gains largely within outlet, so maybe additive with Aghion et al
  - Data applies to some 20 percent of PCE,

Internet Valuation

- Q3, 2017 time spent per day on Internet for Adults 18+: about 4 hours a day!
  - Internet use time 2007: less than1 hour. 4x increase!
  - The difference was smartphone and tablets.
- What is this time worth?
  - Goolsbee and Klenow (2006) calculation values free Internet using time inputs at the wage rate
  - It now implies in 2017 12 % of full income is value of the Internet, up from 2 % in 2005
  - Applying to PCE, $4000 per person, 0.8 % faster annual growth
  - Brynjolfsson et al asked users what they would have to be paid to not use the different parts of the Internet: over $30 thousand.

Internet valuation, continued

- What we pay to access Internet:
  - Wifi: 0.5 % of PCE, cellphone services: 0.9 % of PCE
- From 2008 to 2017, consumer byte flows over wifi grow 40 % a year and cellphone byte flows grow 60 % a year (Cisco VNI)
  - If we count bytes as the relevant quantity, Internet and cellular access raise PCE growth by 0.8 percentage point (Abdiriham et al, 2019)

Summarizing consumption

- Between 1995 and 2017, PCE growth mismeasurement accelerated by
  - Internet: 0.8 %
  - Outlets: 0.13 %
  - Nondurable goods variety: 0.03 %
- Other areas:
  - Meds, Eds, Hardware, Software, Entertainment, LEDs
  - Pharma alone probably 0.1 % acceleration

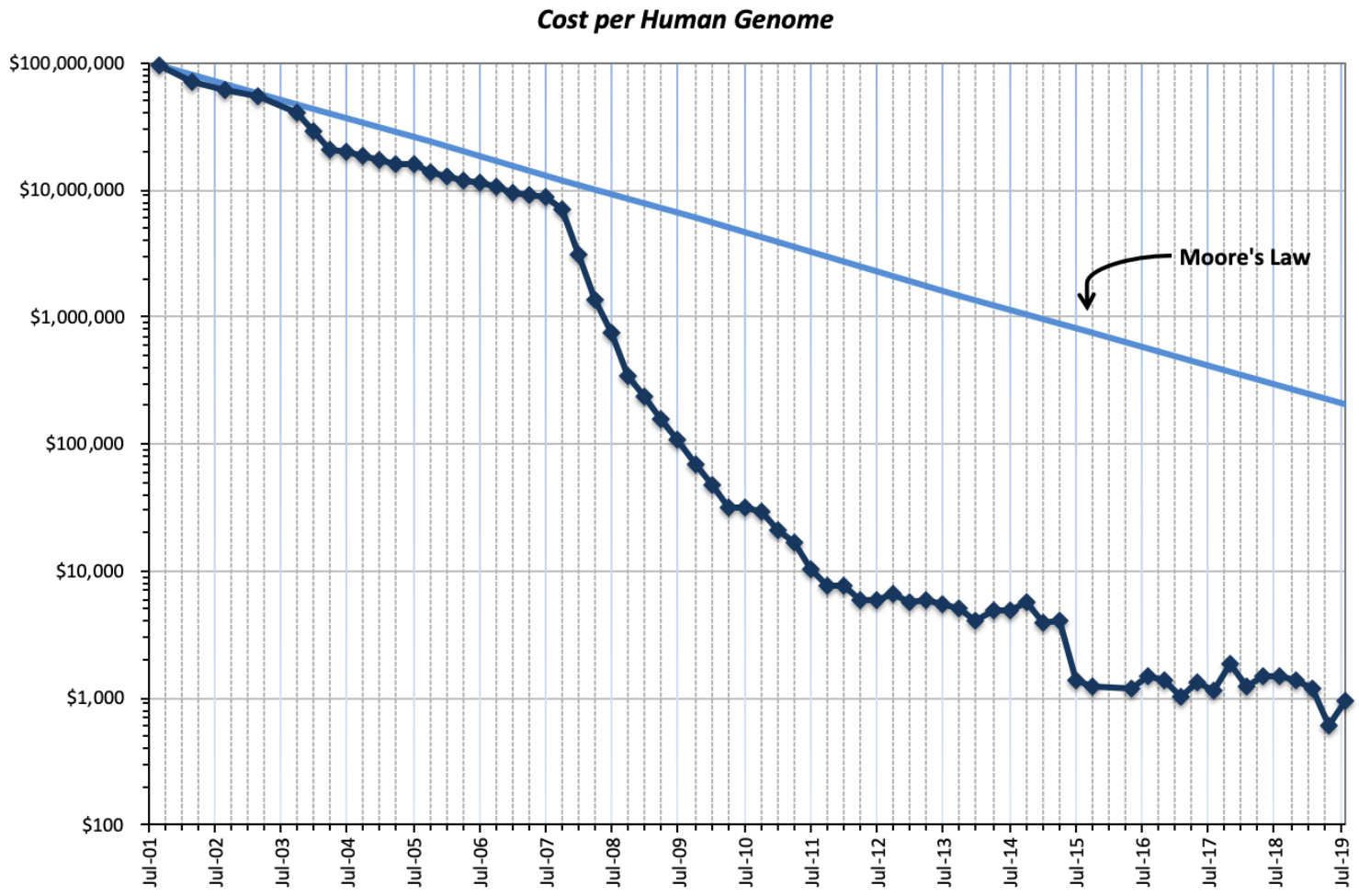
Not just consumption: All US corporations invest more in intangibles

- There has been a steady increase in the rate of investment in intangibles: new product development
  - Software, R&D, Advertising and marketing new products, organizational capital, plus unmeasured data
- The average public corporation (Kahle and Stulz, 2017) invests more in R&D than tangibles (relative to assets): the reverse was true in 1995
- Intangible investment creates intellectual property that has sparked a huge rise in corporate economic profits (and market value)
  - But we don't know how to deflate intangibles
  - Intangible deflators rose 0.3 percent annually, 2007-2017

An explosion of progress: big price drops for intangibles

Rates of Improvement of Selected R&D and Data Inputs			
Type	Time period	Improvement	Annual Rate of Change
Moore's Law	1958 to 2014	Doubles every two years	41 %
Consumer Internet Bytes	2008 to 2017	19 X	39 %
Cellular Bytes	2008 to 2017	200 X	59 %
DNA Sequencing	2007 to 2017	1000 X	100 %
DNA manipulation	2012 to 2018	150 X	130 %
Startup Cloud computing	2006 to 2007	100 X to 1000 X	10000 % +
Cloud computing, price declines	2010 to 2016	2 X to 3X	10-20 %
Rocket development	2007 to 2015	10 X	33 %
Rockets, cost per flight	2007 to 2015	3 X	14 %
AI, Libratus to Pluribus training	2017 to 2019	6000X	7600 %
Sensor, Lidar	2007 to 2016	9 X	27 %
LEDs, cost per lumen	1975 to 2017	16000 X	23 %

Cost of Human Genome Sequencing falls 10,000-fold since 2007, faster than Moore's Law



Falling costs of intangible investment: biology

- Wholesale price of complete human genome sequencing fell 10 thousand times
  - More than 1 million human genomes sequenced
  - Illumina valuation $40 B
  - Same fall in price for sequencing coronaviruses
- From 2012 to 2018, genome editing costs fall from $25 thousand per edit to $65 (CRISPr-Cas9)

Falling cost of intangible investment: Internet startups

- Cloud computing, 2009 to 2016, AWS prices fall 2-3X (Byrne et al)
  - Much more efficient use of servers implies lower rates of investment in computers
- But for Internet startups, startup costs fell by 100X to 1000x from 2005 to 2009
  - No longer need to buy servers, routers, etc. in advance
- Venture capital model changes dramatically to accommodate cheapness of experimentation (Ewens et al , 2018)

Software

- 2.4 percent of GDP in 2016 up from 0.9 percent in 1995
  - Note: R&D now includes software investment in R&D, which adds $121 B to software in 2016
  - Minimum estimate of investment
    - My estimate is 5 % of GDP
  - Software depreciation is 33 % a year.
    - Since software does not suffer from physical deterioration, this should approximate the rate of technical progress
    - To be very conservative, estimate at 8 % per year
  - Acceleration of 0.22 percent in GDP

Software example: Artificial Intelligence

- Carnegie Mellon team creates superhuman AI: Poker game of Texas Hold ‘Em
- Libratus: beats top players one-on-one (2017)
  - $1 million compute time to train
- Pluribus: beats top players in multiplayer game (2019)
  - $150 in compute time to train
  - 6000x improvement for harder task!
- Fast rate of software technological progress

SpaceX and Space commercialization

- Developed Falcon9 rocket for $390 million
  - NASA estimate for procurement cost: $4 billion
- Price per flight $61 million relative to Atlas 5 ($170 million) to deliver payload to low earth orbit (LEO)
  - Most satellites, include International Space Station, are at LEO
  - Plans to reuse all parts of launch rocket is further decreasing costs
- SpaceX valuation $30 B +
- Space commercialization now has many startups

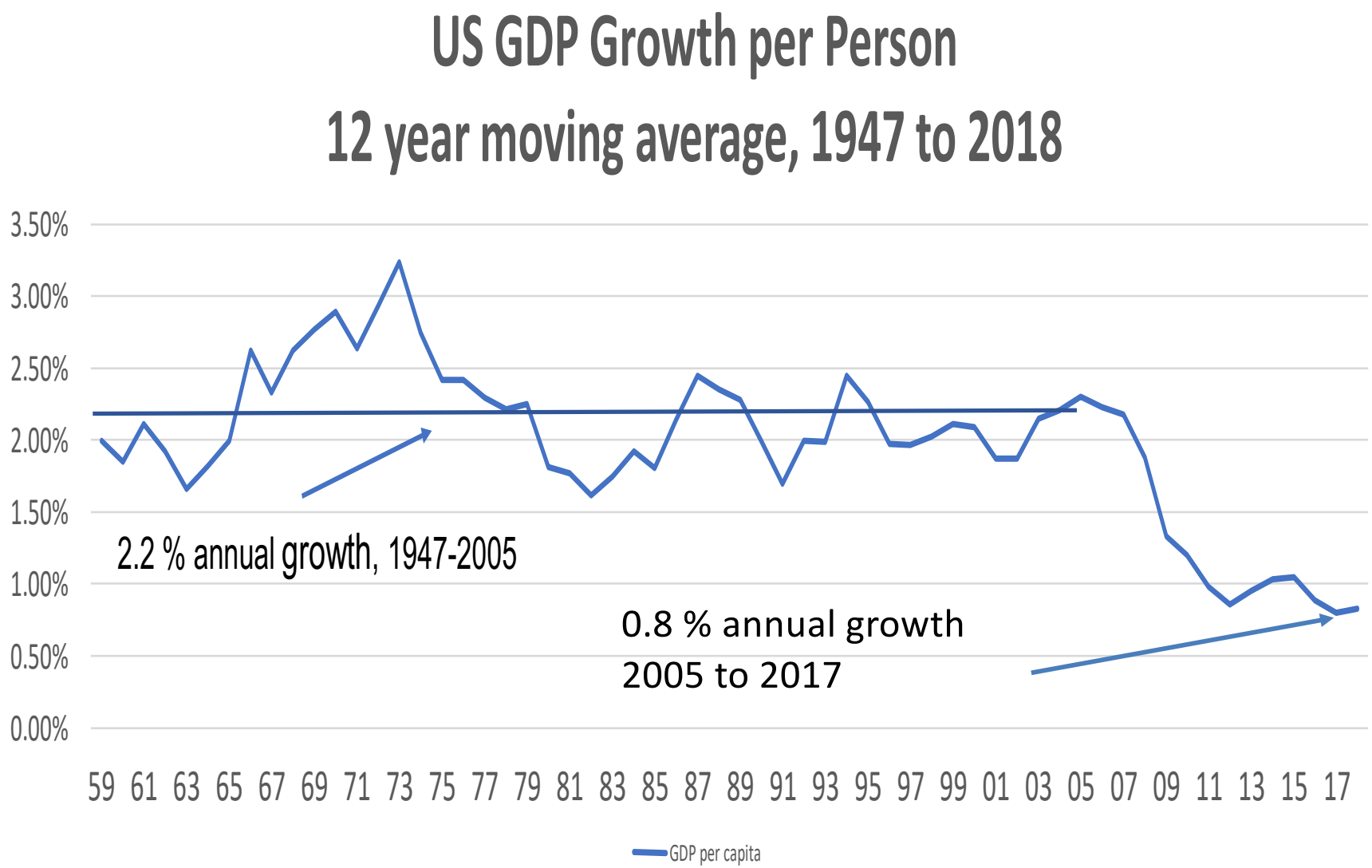
Mismeasurement accelerated maybe 1 % or more

Some Elements of Potential Acceleration of Mismeasurement, 2005-2017 relative to 1983-95				
Mismeasurement Issue	Impact on GDP, Growth rate, 1983-85	Impact on GDP, Growth rate, 2005-2017	Acceleration of mismeasurement	Source
Outlet Bias	0.52	0.65	0.13	Aghion et al (2019)
Variety bias	0.09	0.11	0.02	Niemann and Vavra (2018) and author's estimate
Internet	0	0.44 (0.56)	0.44 (0.56)	Byrne and Corrado (Author's estimate)
Pharmaceuticals	0.065	0.155	0.09	Author's calculation
Software	0.135	0.36	0.225	Author's calculation
Other Intangibles	0.38	0.5	0.12	Author's calculation
Cloud Computing	0	0.1	0.1	Byrne et al (2019)
Total Mismeasurement	1.190	2.315	1.125	

Two percent a year is a big error!

- These problems require new approaches
  - In the short run: a second measure of GDP (Hulten and Nakamura, Coyle and Nakamura, Brynjolfsson et al)
  - Lots of work by lots of economists as we reach for consensus on new procedures
  - Need economics profession to deeply engage with measurement

GDP growth per capita has plummeted: did it really?



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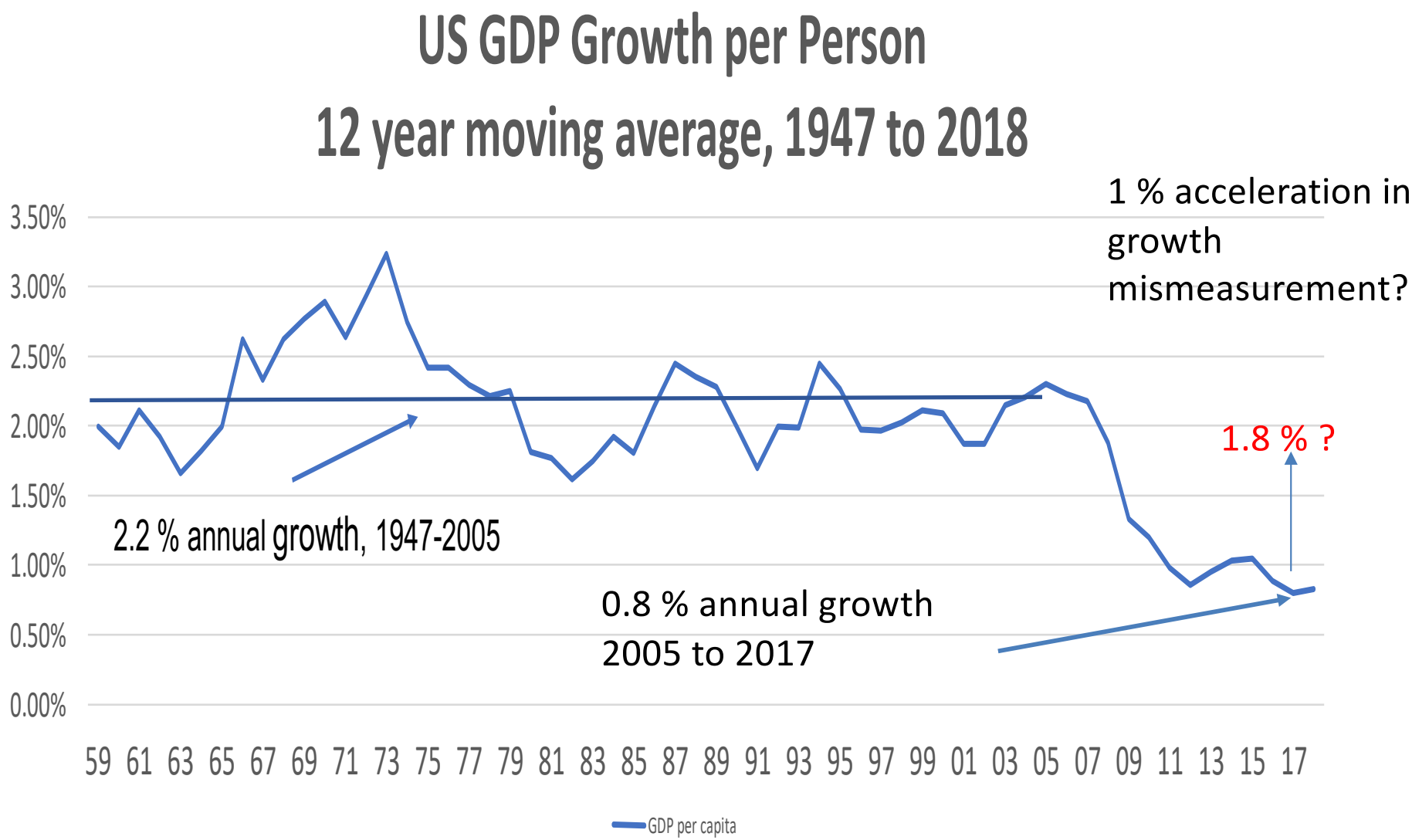
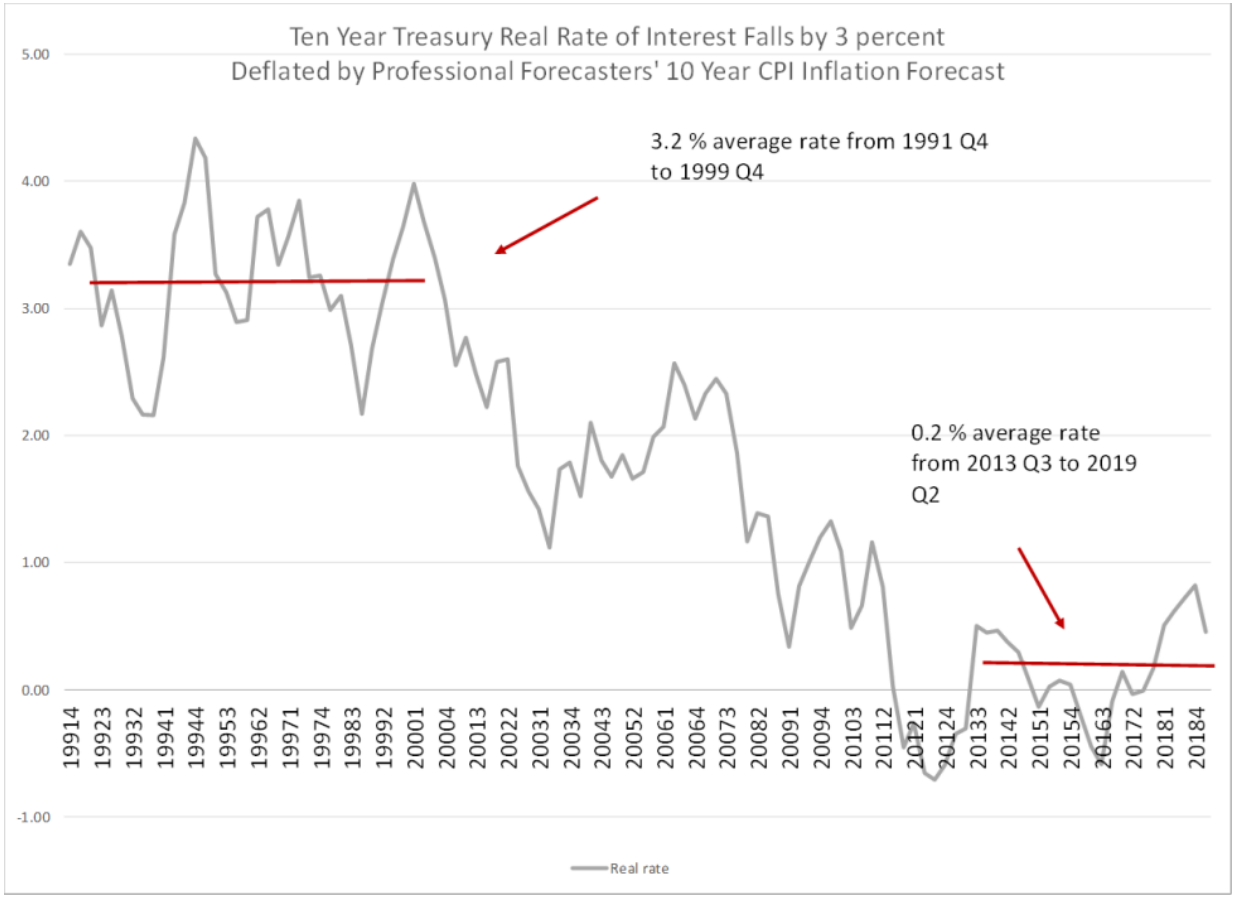


Real long-term interest rates have fallen 3 percentage points to near zero – but have they really?



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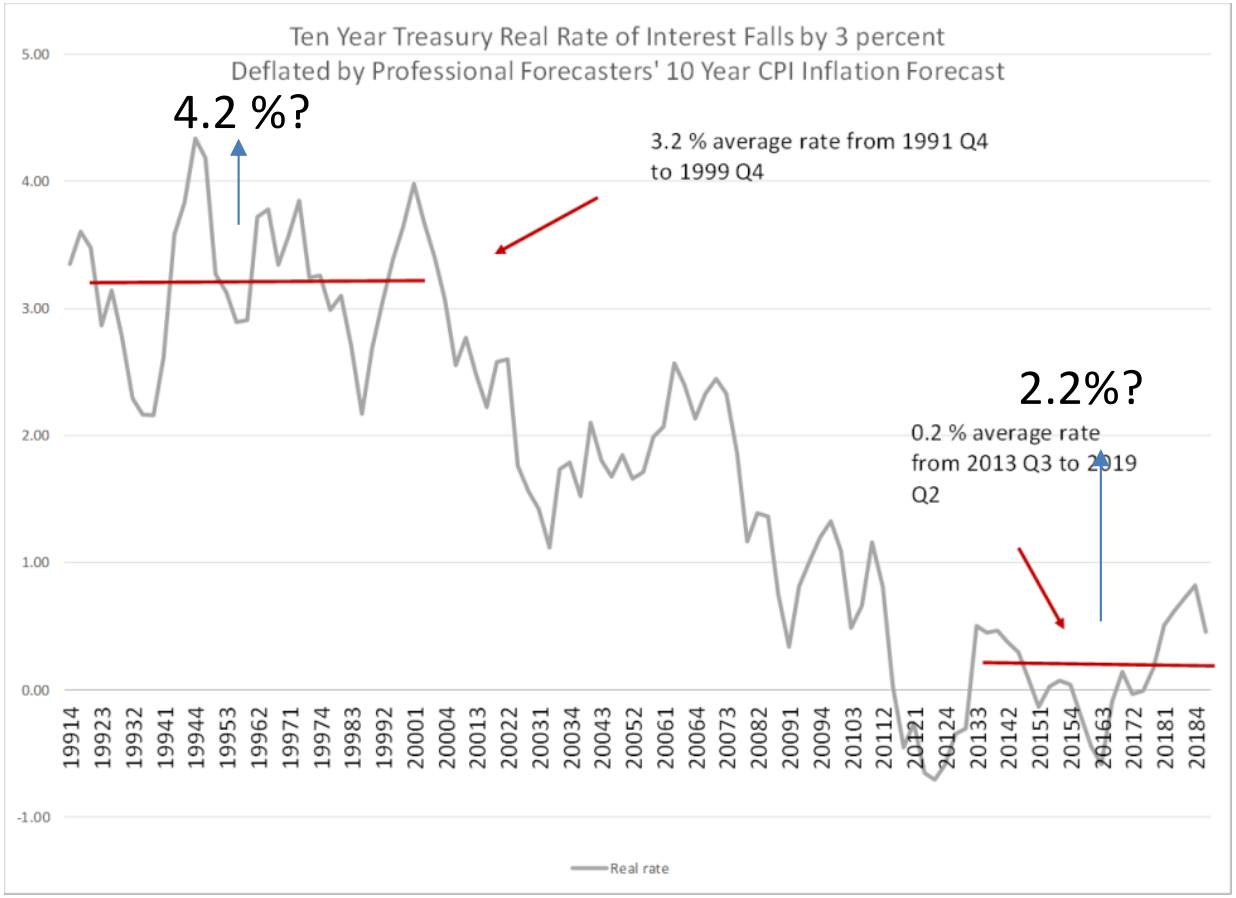

Why are people so unhappy?

- Maybe superfast change is the problem, not slow growth!
- Social and ethical problems caused by:
  - High cost and rapid depreciation of human capital
  - Two-way mass communication
    - Lack of privacy, hacking, and bots
  - Genome manipulation
  - Robots, self-driving cars, drones: what if someone dies?
  - Space commercial exploitation: no current laws
  - Brain-machine interfaces: little regulation
  - Inequality from wealth increases
  - Climate and social change

Summary

- Without a credible measure of aggregate welfare, economists' ability to make macro policy recommendations will be increasingly attenuated.
- In the short run, we may need two kinds of GDP
  - Expanded GDP (Hulten, Nakamura) or GDP-B (Brynjolfsson et al)
- We are a long ways from a complete new picture, but a tremendous amount of research has been launched.
- Coordinating this research and maintaining it statistically over time so that we can make time series, is the big task ahead.
- Statistical agencies need much more money and much more help from top economists!

Thank You!

- I greatly appreciate your time
- The main purpose of this talk is to provoke conversation about how to advance improved measurement

Sensors

- The development of the self-driving car is being facilitated by rapid declines in sensor prices
- Lidar (the laser equivalent of Radar) works better than other systems in bad weather, offers better detail
- Lumina's cost $75000 in 2005-7; in 2014, $7500; prototype expected to be $500 to $1000 in 2022 in production quantities

Lithium batteries

- Price of batteries has fallen from $1160 to $156 and is reportedly now $100 per kwh of storage capacity
- Tesla Model 3 requires 75 kwh: price has fallen from $80,000 per car to $7500.
- New Tesla battery cheaper and to last 1 million miles
  - Batteries transferred to the next car!
- Backup batteries for solar power now pay for themselves
  - Transfer power from daytime to night

Nonsoftware Intangibles

- Rose from 7.5 % of GDP to 10 % of GDP from 1995 to 2017
- Rates of depreciation 15 % or faster
- If deflator should be falling 5 % a year, mismeasure is 0.38 % from 1983 to 1995 and 0.5 % from 2005 to 2017