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

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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 our ignorance: how little we know about true inflation and growth
  - The 21st century economy makes measuring growth more difficult.
  - New products, free products
  - Evolving products, markets, and business models
- This paper collects recent research and evidence on the acceleration of mismeasurement comparing 1983-1995 to roughly 2005-2017
- I find faster growth and slower inflation
  - 1983-1995, 1 % mismeasurement
  - 2005-2017, 2 % mismeasurement
- My best guess: Productivity growth is strong and prices are deflating in the US (and around the world)

Puzzle: Fast corporations, slow growth

- In the US, we have large corporate investments in innovation generating highly profitable innovative products
  - But historically weak GDP growth per capita and real interest rates
  - These successful innovations don't show up in GDP! Why?
- I examine the 4 big Internet corporations that are now 18 % of market cap of S&P 500
- And I gather many recent studies of products and investments
- I show 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

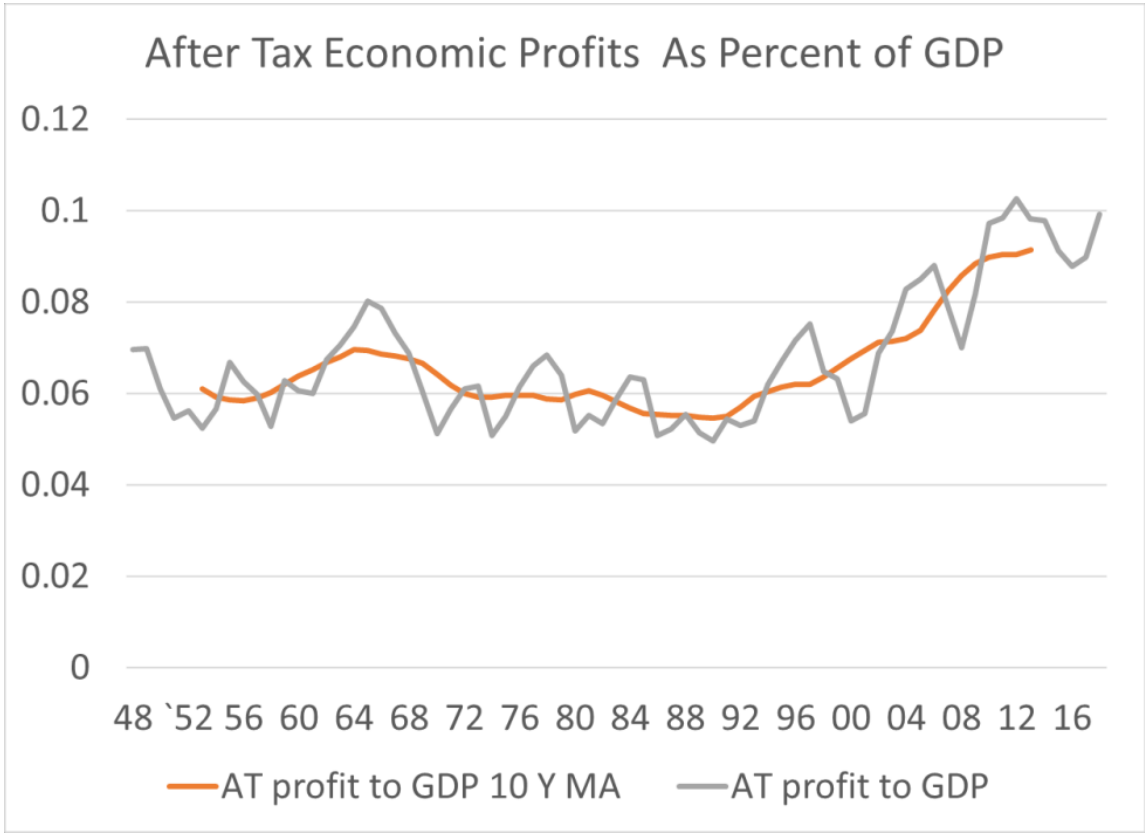
Example: Innovation acceleration in pandemic

- What is the real value of Covid vaccines for US?
  - Costs government ~$40 for each complete vaccination:
    - Resource cost to vaccinate 350 million people: $14 B
- What is its inflation rate? Need to compute shadow price for 2020
  - What would Americans have paid to get our jabs last year?
  - Value to US consumers: surely more than $500 each=>$175 B in 2021
    - Adds 0.8 % to real GDP! Inflation rate impact is -0.8 %!
    - Several ways to calculate this rate of inflation and real growth, most much larger
  - Recorded only at resource cost, no impact on real output
- As measured in accounts, pharmaceutical productivity is declining more than 2 % a year

US corp investments in intangibles have quadrupled since the 1950s

- BEA-measured investment in intellectual property went from 1 % of GDP to 4 %
- Corrado et al and my estimates are roughly three times as large, exceeding business investment in tangibles
- Kahle and Stulz (2017): Average US corporation invests more in R&D alone than in tangibles

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



Central measurement issues: Missing transactions

- We economists are trained on supply and demand curves,
  - We rely on transactions which deliver prices and quantities
  - We distrust shadow prices
- Inflation is measured as a change of price of a fixed good, identical over time
- When new goods appear, they don't have a prior period price
  - Need a shadow price, hard to calculate
  - What is the shadow price of Covid vaccine in early 2020?
- Intangibles are created in-house, unlike plant and equipment: no visible transaction
  - Much harder to create nominal and price measures
    - We have essentially given up

Broad Measurement Problems: Intangibles

- Intangible investment replaces tangible investment
  - In official GDP, we deflate intangibles with input costs and add average productivity, so no impact on productivity
    - Intangible investment prices falling rapidly, but unrecorded
    - As intangibles replace tangibles, less deflation
  - Data is a new intangible investment, not in GDP
  - Intangible assets are not tied down geographically, unlike tangible assets
    - Apple can export its IP to Ireland without a transaction
    - “Domestic” part of GDP becomes harder to measure

Broad Measurement Problems: Consumption

- Consumption has changed a lot since 2005
  - iPhones, iPads, Amazon prime, Kindle, Google Maps, Uber, AirBnb, Spotify, Netflix, Khan Academy, Tesla Model 3, DNA genealogy
  - Consumers love new varieties and product variety is accelerating
  - Innovative products have always been hard to quantify
- Zero resource cost products replace costly products
  - With Internet 2.0, everything that can be digitized has zero reproduction cost, often zero price
- Consumers consume information and novelty (entertainment, etc.)—what are the units to be measured?

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 price changes in narrowly defined goods and services
  - 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 too many new products

Alphabet, Amazon, Apple and Facebook are large part of innovative expenditure

- In 2017, these accounted for 13 % of all US corporate R&D
- After-tax profits of Big 4 increased $72 B from 2007 to 2017
  - Total US domestic corp aftertax profits rose $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 not appear as increases in PCE growth but as decreases
- Free Products: Google Search and Facebook, Youtube and Instagram
  - Zero prices incompatible with inflation and output measures
  - Free products replace tangible merchandise such as CDs and film
- Unmeasured quality change: Amazon
  - Lower prices at Amazon are not shown as deflation:
    - New outlet bias
  - Amazon's lower prices show up as reduced retail services
  - But Amazon delivers to your home!
- Outsourcing: Apple
  - Apple looks like an importing wholesaler in economic statistics
  - It imports iPhones from China—not in US GDP
  - Its IP is recorded in Ireland

Summarizing consumption

- Between 1995 and 2017, PCE growth mismeasurement accelerated by
  - Internet: 0.8 % a year added to PCE understatement
    - Goolsbee and Klenow, Byrne and Corrado, Abdirahman et al. , Brynjolfsson et al all show this rate or worse
  - Outlets: 0.13 % (Aghion et al)
  - Nondurable goods variety: 0.03 % (Niemann and Vavra)
- Other areas:
  - Meds, Eds, Hardware, Software, Entertainment, LEDs
  - Pharma alone probably 0.1 % acceleration

An explosion of progress: big price drops for consumer goods and 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 %

Falling costs of intangible investment: biology

- Price of complete human genome sequencing fell 10 thousand times 2005 to 2017
  - More than 1 million human genomes sequenced
  - Illumina valuation $40 B
  - Parallel fall in price for sequencing coronaviruses
- From 2012 to 2018, genome editing costs fall from $25 thousand per edit to $65 (CRISPr-Cas9)

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!

- We misdiagnose our economy
- 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

Why are people so unhappy? Why deaths of despair?

- Maybe superfast change is the problem, not slow growth!
- Social and ethical problems caused by speed:
  - High cost and rapid depreciation of human capital
  - Two-way mass communication
    - Lack of privacy, hacking, and bots
    - Threat to democracy and mental health
  - 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 and 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 improve measurement
- This is not the fault of US statistical agencies:
  - They are the best in the world
  - And are woefully underfunded

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

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)

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

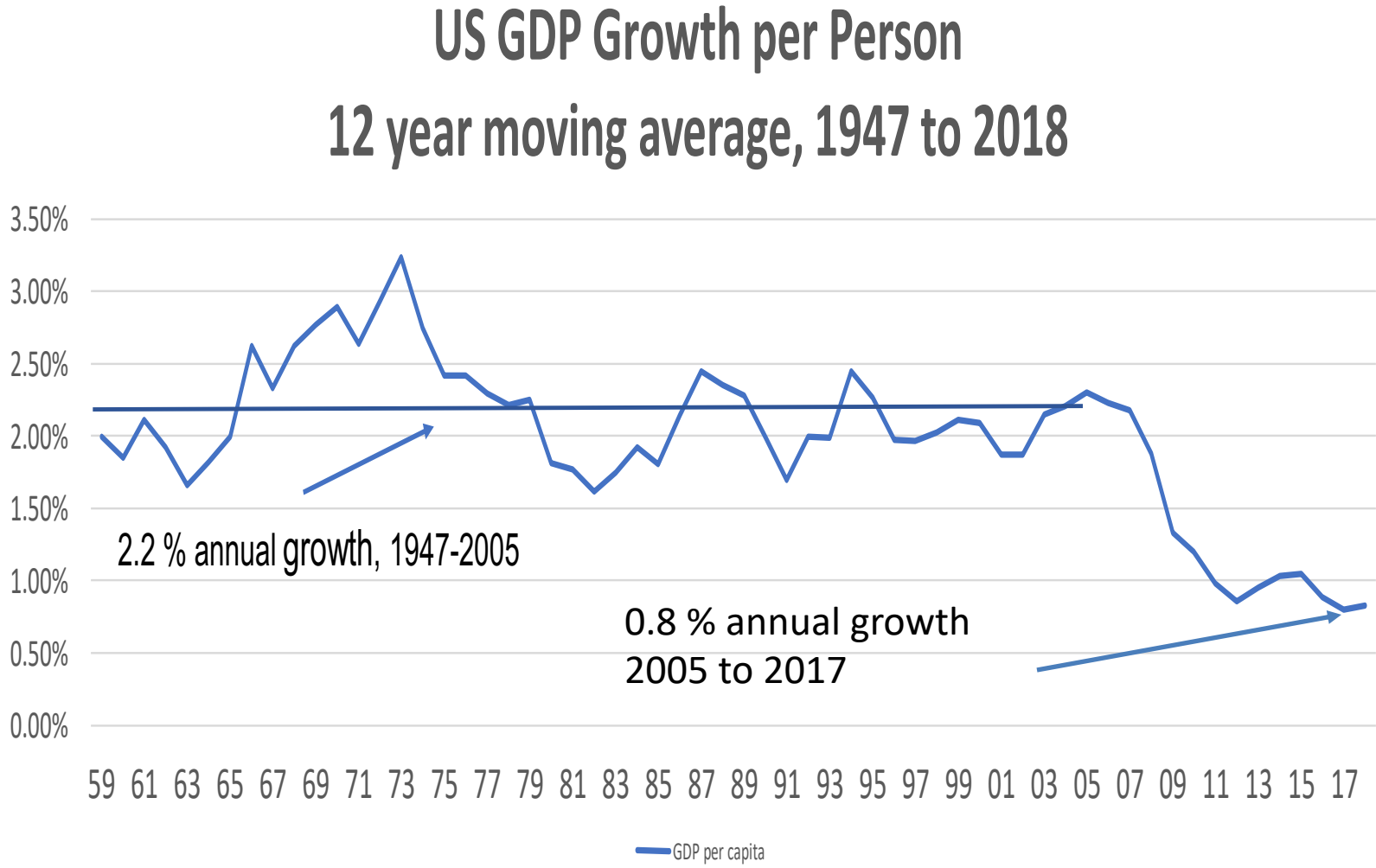
Lithium batteries

- 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

GDP growth per capita has plummeted: did it really?



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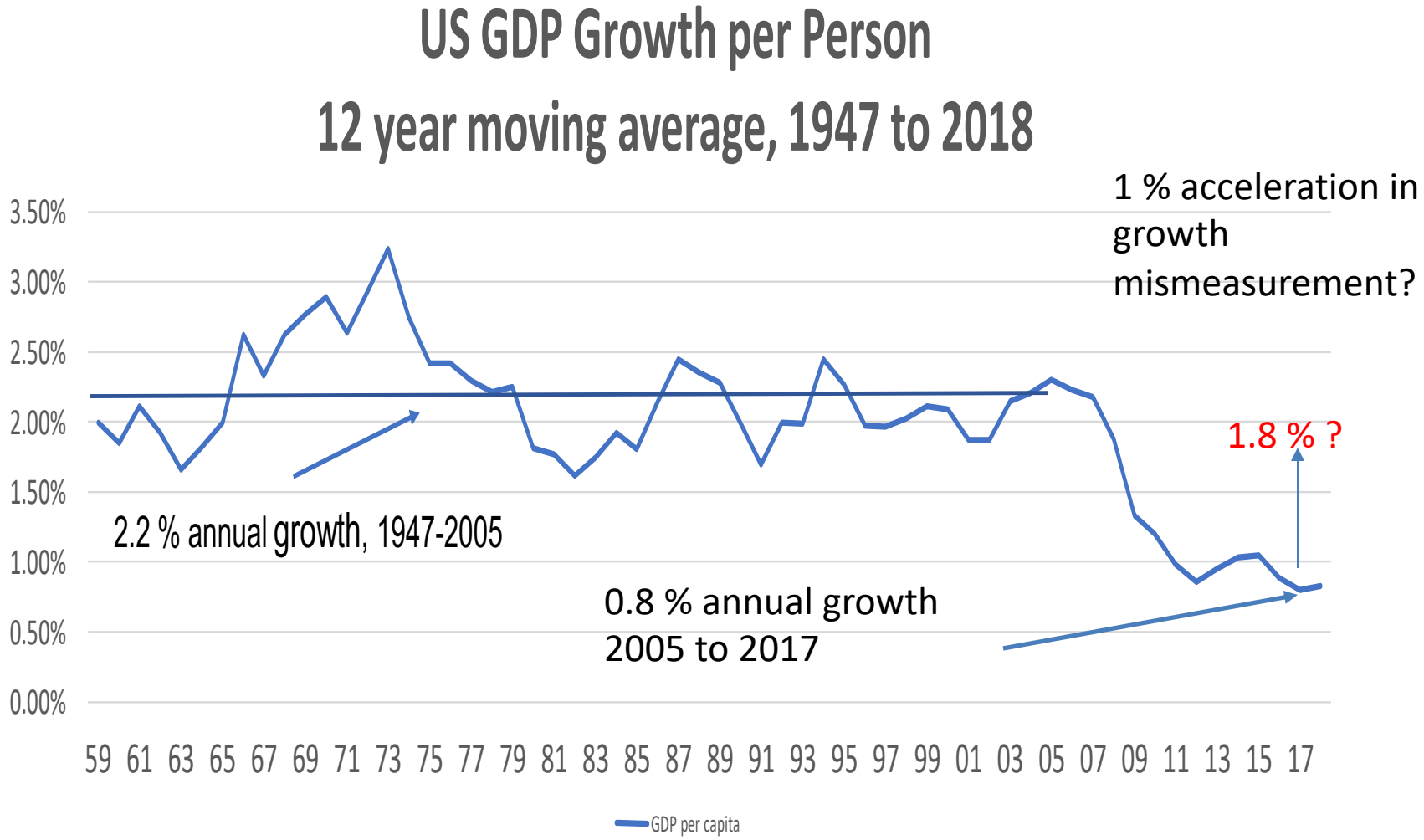

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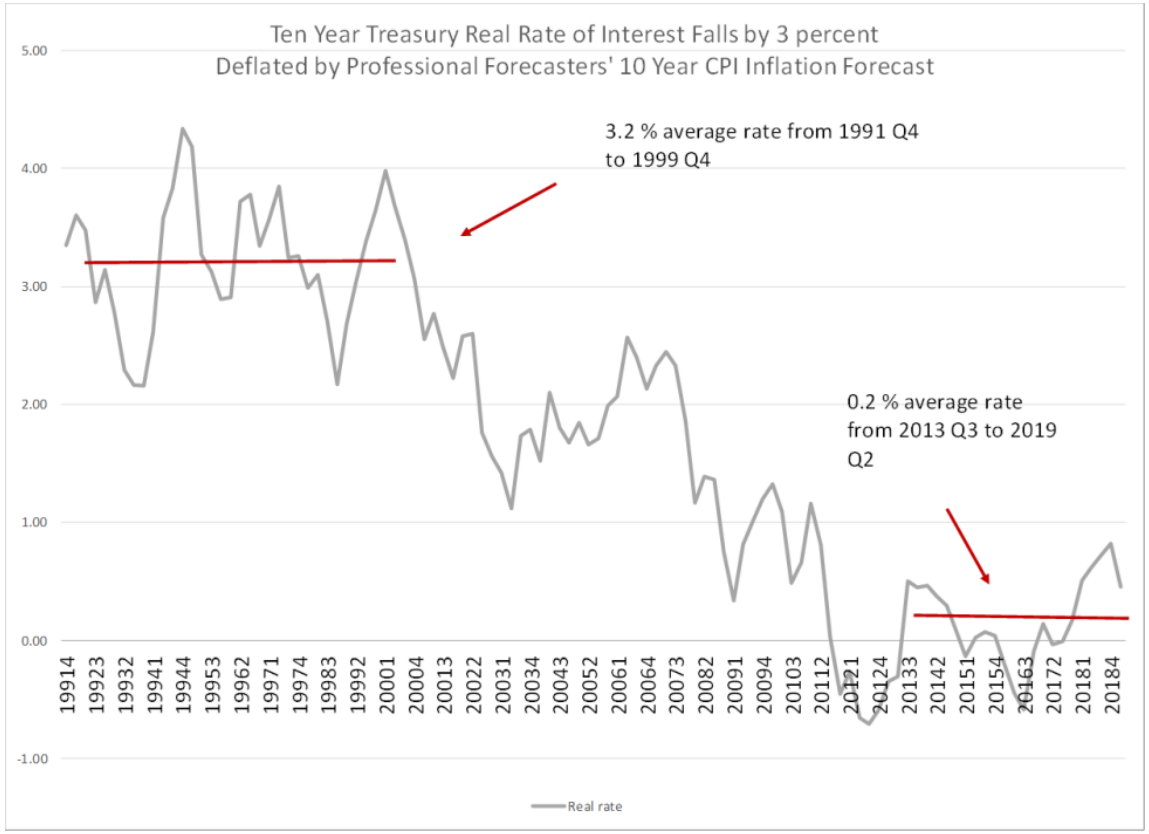

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