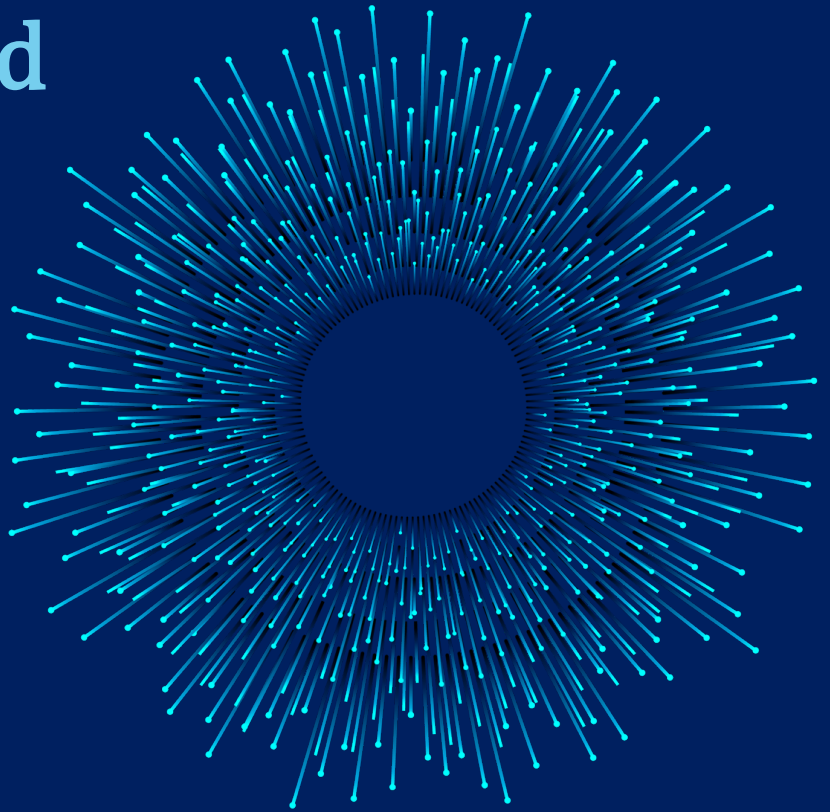
Digitization, Data and Digital Capital

ERIK BRYNJOLFSSON
STANFORD DIGITAL ECONOMY LAB

JIS Data Value Creation Workshop

2021.02.04



What is a GPT?

GPTs (Bresnahan & Trajtenberg, 1996)

1. Pervasive

2. Able to be improved on over time

3. Able to spawn complementary innovations

IT, especially AI, is a GPT

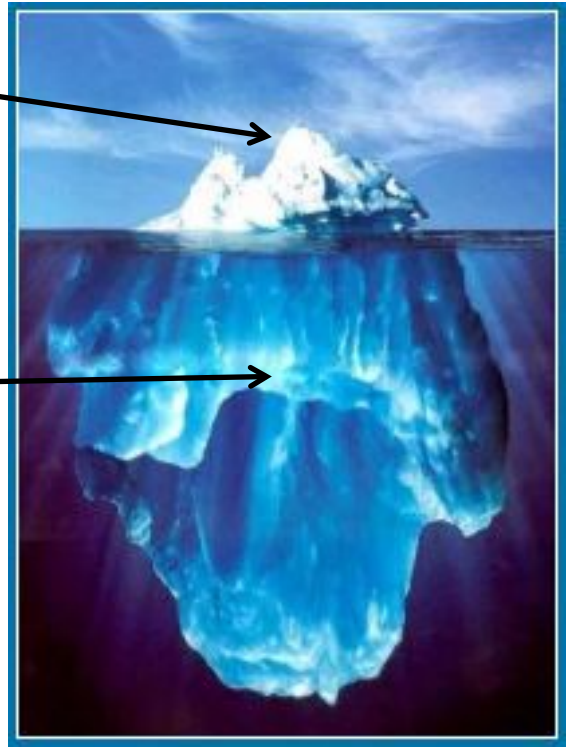
GPTs Drive Economic Growth

1. Pervasive
   - Key capabilities of classification, labeling, perception, prediction and diagnosis are core to broad range of tasks, occupations and industries *(Brynjolfsson, Rock and Syverson, 2017)*
2. Able to be improved on over time
   - Essence of machine learning is improving over time (Brynjolfsson & Mitchell, 2017)
   - 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

Computerization > Computers

Technology (10%)

IT-related Intangibles aka "Digital Capital": Data (Big and Small), Complementary Skills and Business Processes (90%)



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Preview: IT Intangibles are Large and Growing

1. The market value of Digital Capital rose sharply during the late 1990's but then fell in the early 2000's then rose again after 2010.
   - The recent rise coincides with a wave of innovations based on big data, data science, and most recently, AI

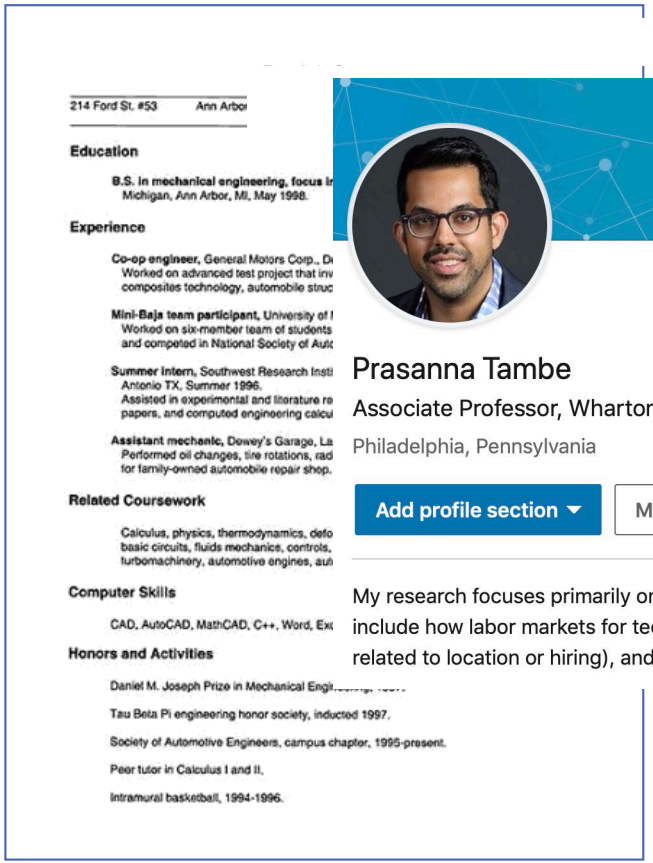
2. Most fluctuations in value can be attributed to changes in Digital Capital quantities, not prices.
   - An exception is the dot.com boom and bust, which was price-driven
   - Digital Capital accounts for about 20%-25% of the levels of physical capital for firms in our sample, with AI-related intangibles accounting for a rapidly growing share

3. "Superstar" firms account for most of the increase in Digital Capital

Preview: Changing IT Intangibles add to productivity

4. Digital Capital corresponded with several waves of changing skills.
   - First, the employment of systems and network administrators in the late 1990's,
   - Then web designers and database engineers in the early and mid 2000's, and
   - Finally data science and artificial intelligence experts after 2011
5. The contribution of Digital Capital to productivity growth during was about double that of IT capital stock.
   - However, AI related intangibles do not yet appear to be contributing measurably to productivity or output
   - Instead, it creates a Productivity J-curve

Employment histories posted online provide rich information about firms and workers



214 Ford St. #53 Ann Arbor

Education

B.S. in mechanical engineering, focus in
Michigan, Ann Arbor, MI, May 1998.

Experience

Co-op engineer, General Motors Corp., D
Worked on advanced test project that inv
composites technology, automobile struc

Mini-Baja team participant, University of
Worked on six-member team of students
and competed in National Society of Auto

Summer intern, Southwest Research Insti
Antonio TX, Summer 1996.
Assisted in experimental and literature re
papers, and computed engineering calcu

Assistant mechanic, Dewey's Garage, La
Performed oil changes, tire rotations, rad
for family-owned automobile repair shop.

Related Coursework

Calculus, physics, thermodynamics, defo
basic circuits, fluids mechanics, controls,
turbomachinery, automotive engines, aut

Computer Skills

CAD, AutoCAD, MathCAD, C++, Word, Exc

Honors and Activities

Daniel M. Joseph Prize in Mechanical Engi

Tau Beta Pi engineering honor society, inducted 1997.

Society of Automotive Engineers, campus chapter, 1995-present.

Peer tutor in Calculus I and II.

Intramural basketball, 1994-1996.

Prasanna Tambe

Associate Professor, Wharton School @ U.Penn (OIDD)

Philadelphia, Pennsylvania

Add profile section

More...

The Wharton School

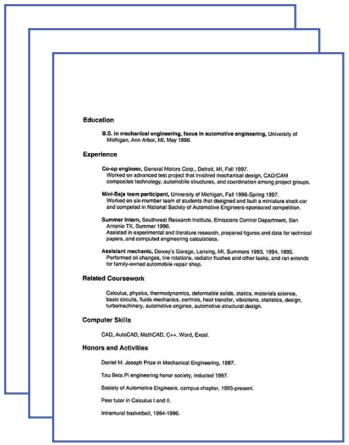
University of Pennsylvania - The Wharton School

See contact info

See connections (500+)

My research focuses primarily on the economics of technology and labor. Specific research interests include how labor markets for technical skills (e.g. data science) impact corporate decisions (e.g. related to location or hiring), and understanding the labor market for AI skills. Much of this research u...

Online employment databases: Employment histories for millions of US workers



Education

B.S. in mechanical engineering, focus in automotive engineering, University of Michigan, Ann Arbor, MI, May 1998.

Experience

Co-op engineer, General Motors Corp., Detroit, MI, Fall 1997.
Worked on advanced test project that involved mechanical design, CAD/CAM composites technology, automobile structures, and coordination among project groups.

Mini-Baja team participant, University of Michigan, Fall 1996-Spring 1997.
Worked on six-member team of students that designed and built a miniature stock car and competed in National Society of Automotive Engineers-sponsored competition.

Summer intern, Southwest Research Institute, Emissions Control Department, San Antonio TX, Summer 1996.
Assisted in experimental and literature research, prepared figures and data for technical papers, and computed engineering calculations.

Assistant mechanic, Dewey's Garage, Lansing, MI, Summers 1993, 1994, 1995.
Performed oil changes, tire rotations, radiator flushes and other tasks, and ran errands for family-owned automobile repair shop.

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Calculus, physics, thermodynamics, deformable solids, statics, materials science, basic circuits, fluids mechanics, controls, heat transfer, vibrations, statistics, design, turbomachinery, automotive engines, automotive structural design.

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CAD, AutoCAD, MathCAD, C++, Word, Excel.

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Leading online job search site provided resumes for about 40 million workers including fielded data

150 million employer-employee combinations

Can step backward through employment histories to create longitudinal measures

Employee Data		
Employee	Education	Occupation
Employee 1	4 Years College	IT
Employee 2	4 Years College	Sales

Employee Work History Data				
Employee	Employer Name	Job Title	Start Date	End Date
Employee 1	Firm Name 3	Project Manager	5-01-2006	Present
Employee 1	Firm Name 2	Software Engineer	9-01-2003	3-15-2006
Employee 2	Firm Name 2	Director of Technology	4-01-2006	Present
Employee 2	Firm Name 1	MIS Manager	1-01-2006	3-20-2006

What are some challenges with using these data sources?

1. **Uneven sampling across firms, occupations, industries or regions**
   - Somewhat mitigated by sample size
2. **Biases in employee characteristics (job hoppers?)**
3. **Significant missing data on interesting characteristics such as college or degree obtained**
4. **People lying on their resumes?**
5. **Logistical issues**
   - Potentially significant technical barriers
   - Proprietary data (e.g. PR concerns, releasing data)

Framework

- **Estimate total market value of IT-related assets (Brynjolfsson, Hitt & Yang, 2002)**

$$MV_{it} = \alpha_i + \sum_{j=1}^{J} (1 + \lambda_j^*) K_{j,it} + controls + \varepsilon_{it}^v$$

Firm Market Value

Physical Asset Stocks

Regressions of assets on market value, balanced panel

Table 4: Regressions of assets on market value, balanced panel

	OLS	OLS	OLS	OLS	FE	LAD
	(1)	(2)	(3)	(4)	(5)	(6)
PPE	1.764***	1.603***	1.740***	1.305***	1.124***	1.168***
	(0.184)	(0.191)	(0.177)	(0.254)	(0.184)	(0.040)
Other assets	0.938***	1.014***	0.901***	1.738***	1.840***	1.663***
	(0.174)	(0.206)	(0.167)	(0.366)	(0.336)	(0.057)
IT capital	15.002		5.164			
	(10.819)		(11.072)			
IT labor		9.199**	6.951	11.899	16.906**	8.860***
		(3.664)	(5.729)	(7.256)	(8.525)	(1.351)
Constant	7,158.233	−3,835.031*	7,037.395	−3,561.147		−858.390
	(6,054.834)	(2,308.417)	(6,069.005)	(3,546.841)		(652.631)
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed-effects	No	No	No	No	Yes	No
Industry fixed-effects	Yes	Yes	Yes	Yes	No	Yes
Observations	1,398	2,448	1,398	7,017	7,017	7,017
R^2	0.732	0.745	0.733	0.822	0.907	
Adjusted R^2	0.722	0.740	0.724	0.820	0.904	

Table notes: This table reports results from the regression $MV_{it} = PPE_{it} + OASSET_{it} + IT_{it} + \epsilon_{it}$. MV is market value, PPE is property, plant, and equipment, IT is IT capital, and $OASSET$ is all other assets. It uses data from the balanced panel. Column (1) is an OLS regression using the IT capital measures with the sample restricted to the years 1987-1998. Column (2) is an OLS regression using the IT employment measures with the sample restricted to the years 1987-1998. Column (3) is an OLS regression using the IT capital and IT employment measures with the full sample for the years 1987-1998 for which both measures are available. Column (4) uses the IT employment measures for the full sample of years. Column (5) adds firm fixed effects to the specification used in column (4). Column (6) is a least absolute deviation (LAD) regression. Standard errors are clustered on firm and shown in parentheses, with *, **, and *** denoting significance at the 10%, 5%, and 1% level, respectively.

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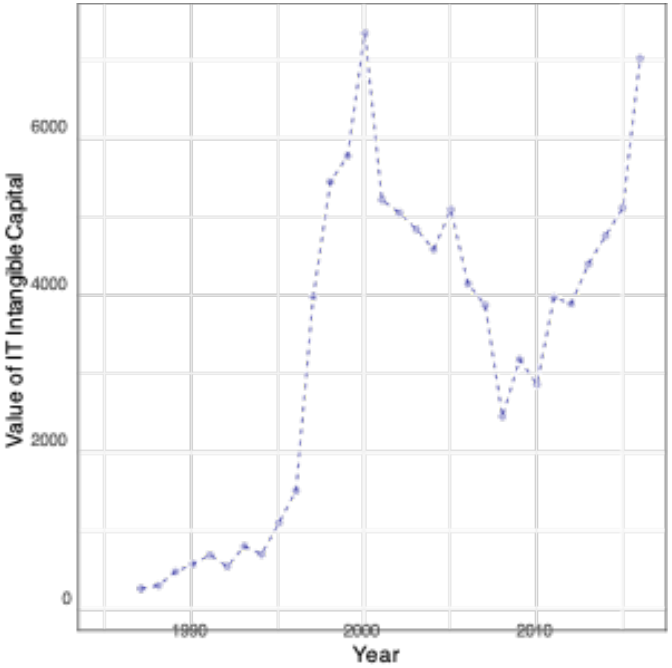
Market value of Digital Capital



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How much of market value is due to price vs. quantity?

- **Separate into price and quantity (Hall, 2002)**

Definition of Intangible Value

$$v_t = p_t q_t$$

Optimal Investment w/Adjustment Costs

$$\alpha_c \frac{q_t - q_{t-1}}{q_t} = p_t - 1$$

p_t, q_t are shadow price and quantity of ITIC (unknowns)

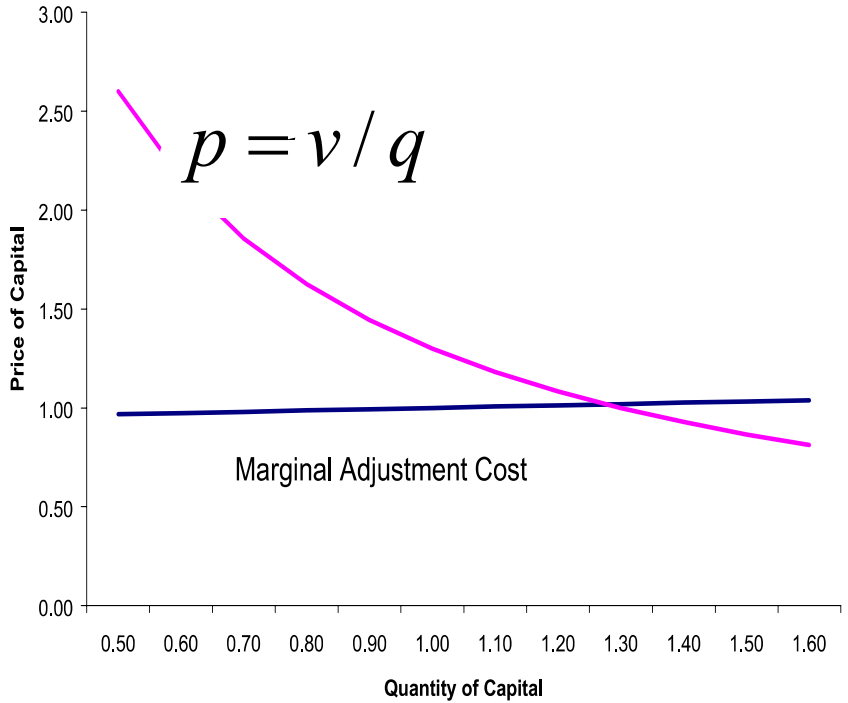
α_c is the IT adjustment cost parameter ($\alpha_c = 3$)

$q_0 = 0$ (no initial ITIC stock)

v_t is ITIC value (we compute this)

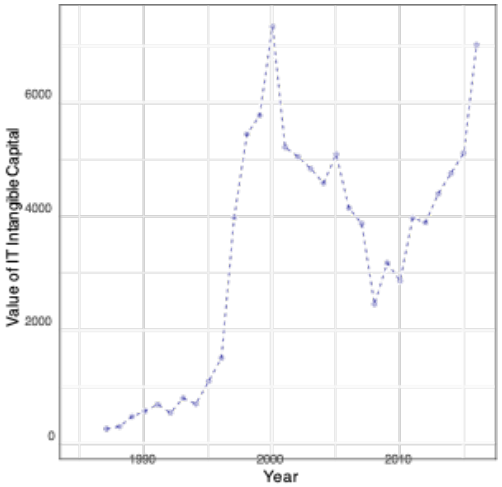
From R. Hall (2001)

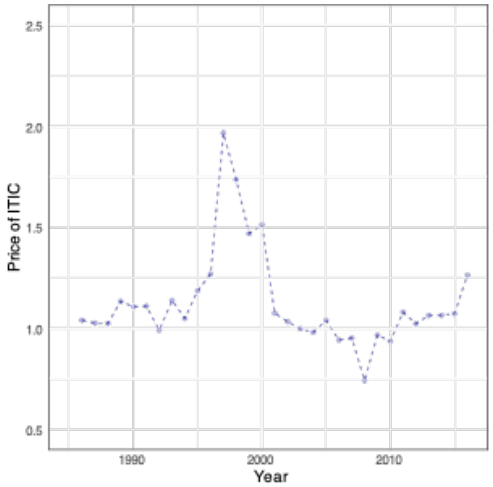
Visualizing the Quantity Revelation Theorem

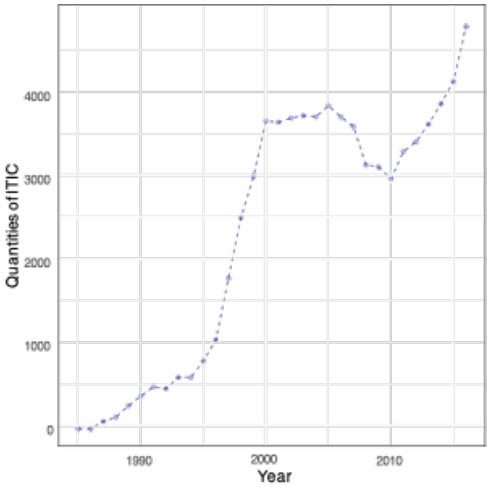


Based on R. Hall (2001)

Market value = Price x Quantity







Market value of Digital Capital = Price of Digital Capital + Quantity of Digital Capital

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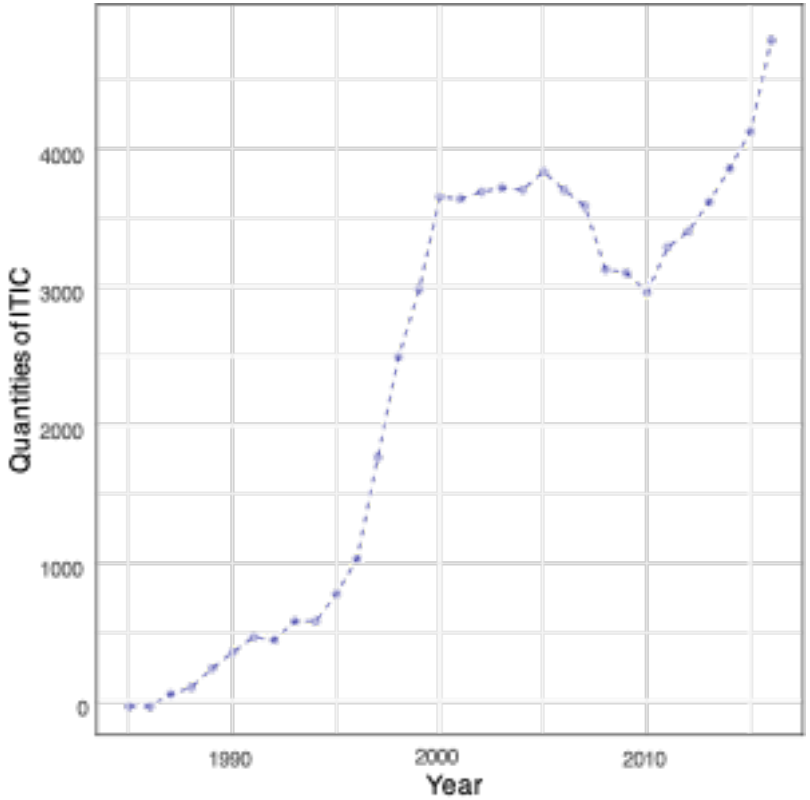
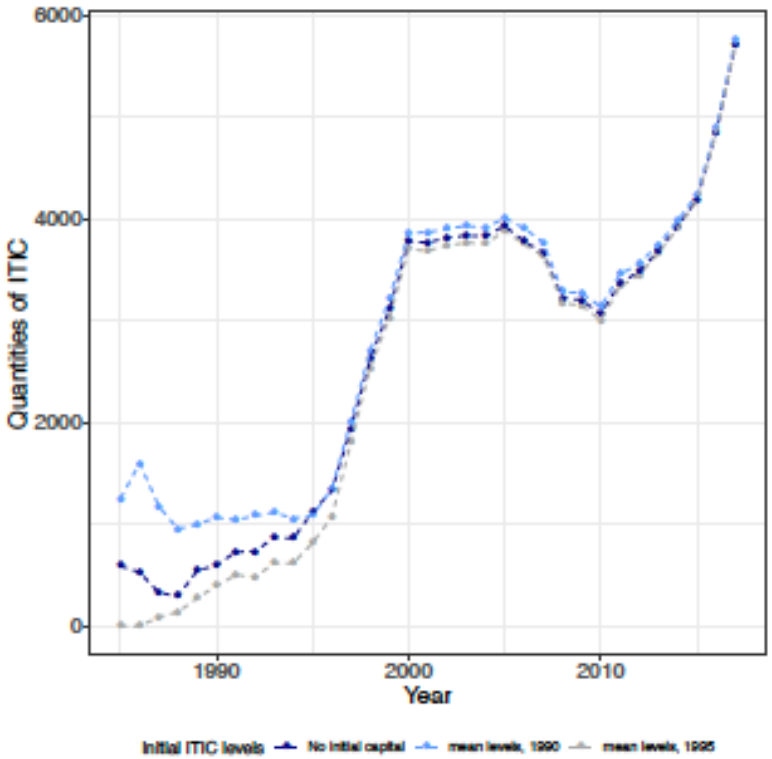
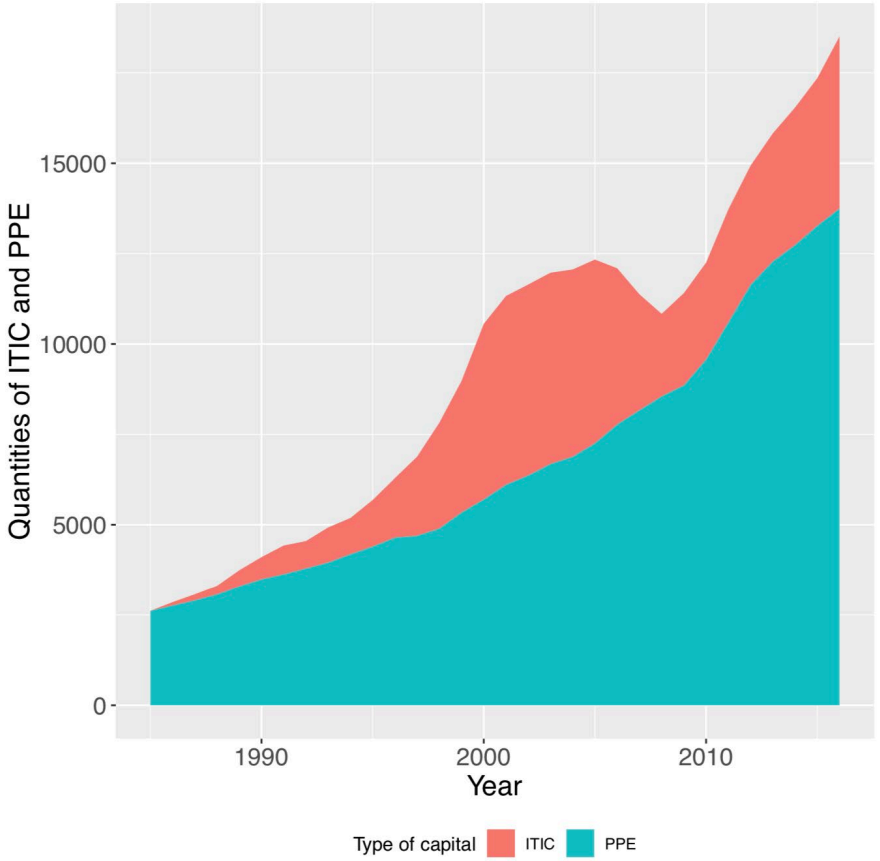
Quantities of digital capital



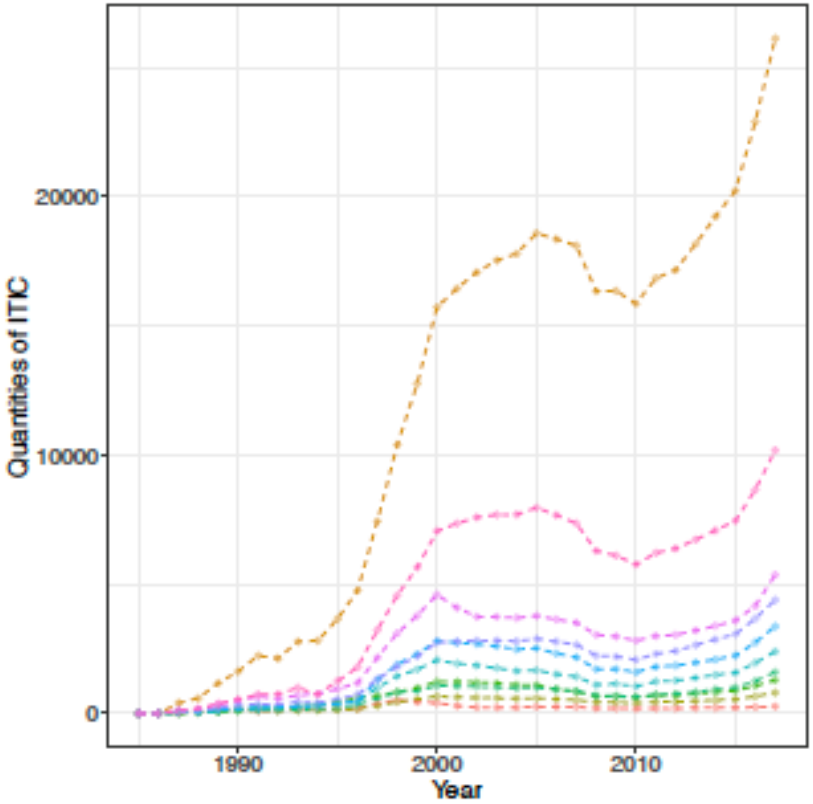
Sensitivity to model parameter values: Initial Digital Capital levels



Digital Capital and Property, Plant and Equipment are Both Growing



Superstars:
Digital Capital prices and quantities by deciles



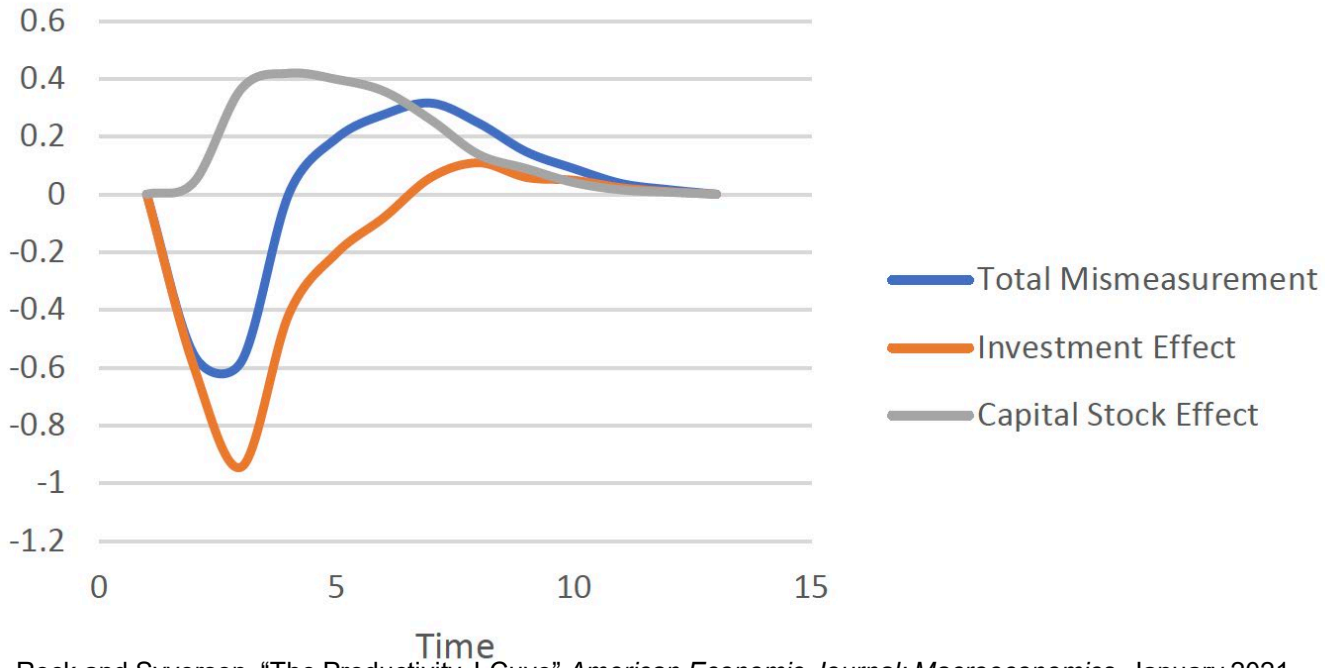
Growth Accounting with Digital Capital

- **Adding previously unmeasured digital 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 λ/z, the ratio of the shadow price of investment to the purchase price of capital
- Physical component of GPT may be small relative to the required investments in data, org change, training, etc.

The Productivity J-Curve



Source: Brynjolfsson, Rock and Syverson, "The Productivity J-Cuve" *American Economic Journal: Macroeconomics*, January 2021

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Productivity Scenario

- **Self-driving cars:**
  - Total investment in autonomous vehicle technology from 2014-2020 was over $200 Billion
  - Number of chauffeurs replaced is 0

- **But potential *future* impact is large:**
  - BLS reports 3.5 million “motor vehicle operators”
  - Suppose autonomous cars replaced ~40% of them, or 1.5 million

    => ~ 1.7% increase in labor productivity

    => Over 15 years, an additional 0.11%/yr

  Also, call centers, healthcare, retailing, insurance, legal, banking, warehouses, factories, education, etc.

Summary: IT Intangibles are Large and Growing

1. We can measure the market value of Digital Capital, which include data.

2. More fluctuations in Digital Capital can be attributed to changes in quantities, rather than prices.
   - Digital Capital accounts for about 20%-25% of the levels of physical capital for firms in our sample.

3. Most of the increase in Digital Capital is concentrated in a small set of "superstar" firms that are pulling away from the rest.

4. In cross-sectional regressions, Digital Capital predicted double the productivity contribution of IT capital.

5. Digital Capital and other intangibles affect estimates of growth in the macro-economy and productivity

6. GPTs required intangibles like digital capital. This creates a *Productivity J-curve*

To Learn More:

Stanford Digital Economy Lab:
https://digitaleconomy.stanford.edu/

Erik Brynjolfsson:
https://www.brynjolfsson.com/

AI & Future of Work Resources:
https://digitaleconomylab.stanford.edu/AIfowResources

Measuring the Economy:
https://www.measuringtheeconomy.org/