Digitization and Intangible Capital

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NBER Digitization Tutorial
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MIT MANAGEMENT SLOAN SCHOOL

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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

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Expected Productivity Effects of GPTs

- **Key insight**
  - GPTs require complementary intangible capital
- **Effect on TFP**
  1. GPTs are associated with an increase in intangible capital stock
  2. Effects on metrics will depend on whether we measure this increase
  3. Intangible measurement is difficult
  4. Therefore, *measured* TFP will miss intangible output.

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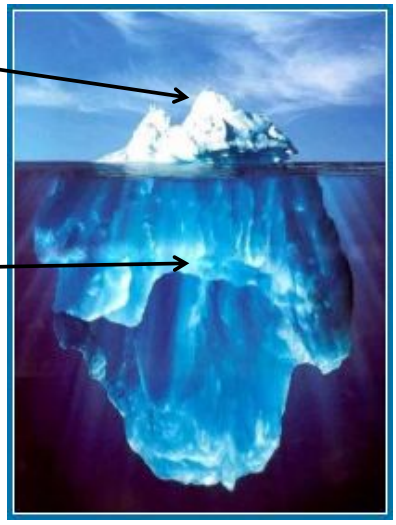
Measuring IT-Related Intangibles (Computerization > Computers)

Technology (10%)

Complementary Skills and Processes (90%)



Source: Brynjolfsson, Hitt and Fitoussi, 2008

Image by Ralph Clevenger

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Story: IT-Related Intangible Capital

- **Consistent evidence of seemingly-high returns to IT capital**
  - Productivity levels and long run growth:
    - 3x theoretical value (Brynjolfsson and Hitt, 1996; Lichtenberg, 1995; Jorgenson and Stiroh 2000; Oliner and Sichel 2001; Stiroh, 2002; Brynjolfsson and Hitt 2003)
  - Market value: $10 per $1 of capital
    - e.g. (Brynjolfsson, Hitt, Yang, 2002; Brynjolfsson, Hitt, Fitoussi, 2006; Brynjolfsson and Saunders 2008)
- **Explanation: Consistent with broader evidence of intangible assets**
  - (Black and Lynch 1996; Hall 2000, 2002; Basu et al 2004; Abowd et al 2005; Jorgenson, Ho, and Stiroh 2005; Corrado, Hulten, and Sichel 2005; Corrado and Hulten 2009; Bloom, Sadun, and Van Reenen 2012; Fernald 2012; and many many others …)
  - The explanation is not that IT returns are a free lunch…
  - …but that *measured* IT capital inputs are too low because intangible investments are not treated as capital

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Open questions

1. **Are high values for IT capital due to price or quantity?**
   - High *prices* suggest implementation difficulties or quasi-rents that could simply disappear
   - High *quantity* is likely to have long-run economic impact

2. **What has happened to the contribution of IT since 1998?**
   - Most firm-level IT productivity studies are before the dot-com boom and subsequent bust
   - Microeconomic data on IT spending after mid-1990s are not as reliable

Preview: IT Intangibles are Large and Growing

1. The market value of ITIC rose sharply during the late 1990's but then fell in the early 2000's.
   - It began to rise again from 2010 onward, coinciding with a wave of innovations based on big data, data science, and most recently, AI

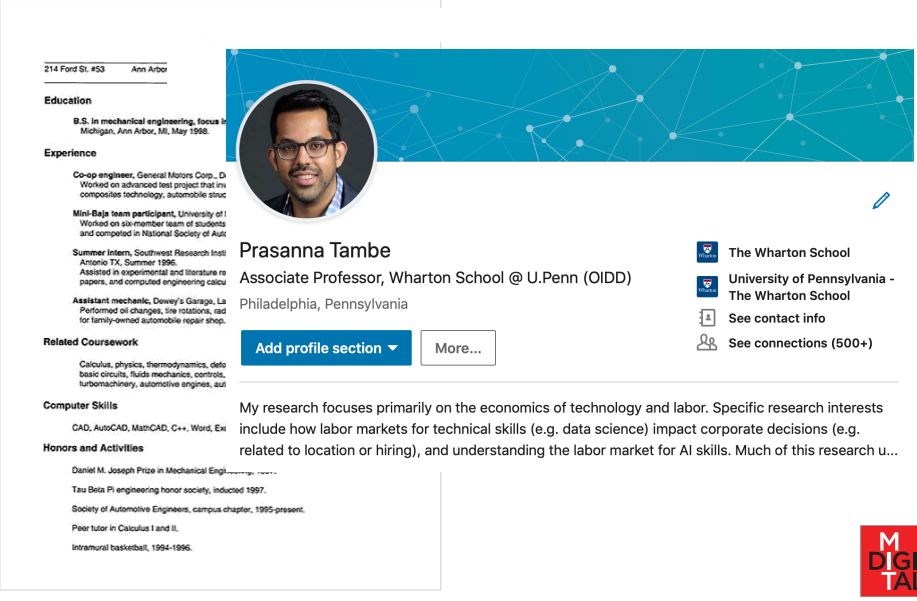
2. Except the dot.com boom and bust, most of these fluctuations in value can be attributed to changes in ITIC quantities, rather than prices.
   - ITIC accounts for about 20%-25% of the levels of physical capital for firms in our sample, with AI-related intangibles accounting for a rapidly growing share

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

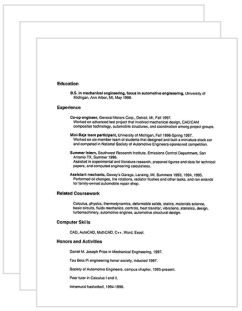
Preview: Changing IT Intangibles add to productivity

4. ITIC 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 ITIC 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



Online employment databases: Employment histories for millions of US workers



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?

- **Uneven sampling across firms, occupations, industries or regions**
  - Somewhat mitigated by sample size
- **Biases in employee characteristics (job hoppers?)**
- **Significant missing data on interesting characteristics such as college or degree obtained**
- **People lying on their resumes?**
- **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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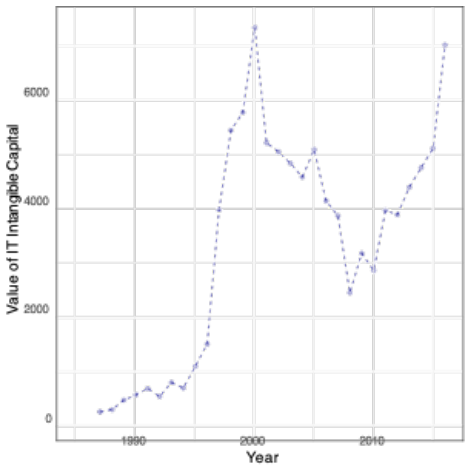
Market value of IT intangible capital



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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)

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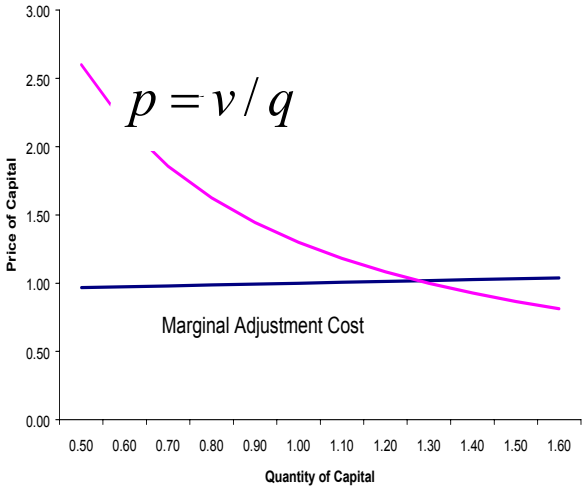
Visualizing the Quantity Revelation Theorem



Based on R. Hall (2001)

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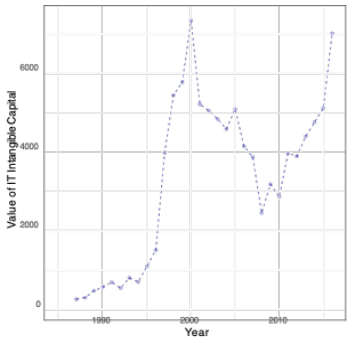
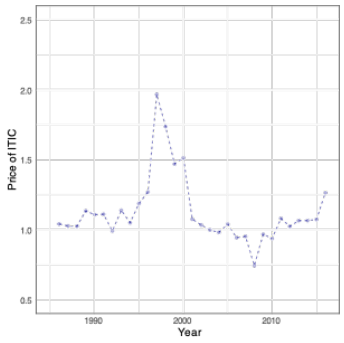
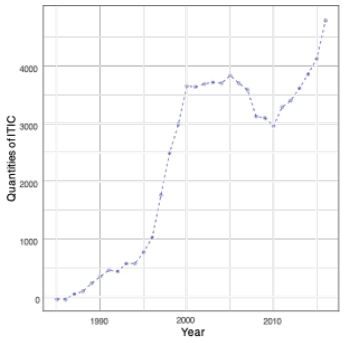
Market value = Price x Quantity







Market value of ITIC = Price of ITIC + Quantity of ITIC

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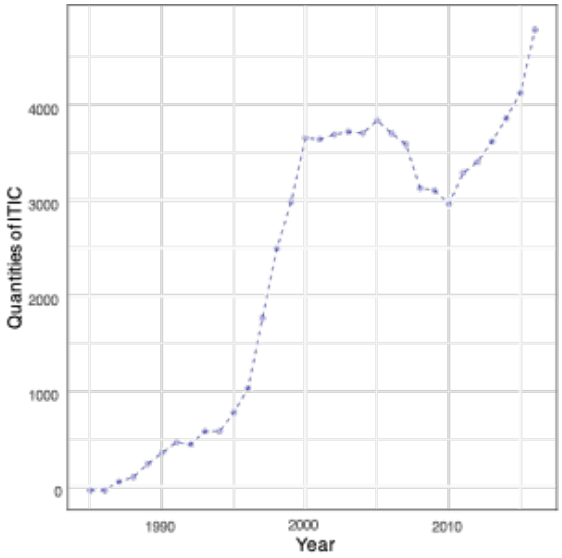
Quantities of IT intangible capital



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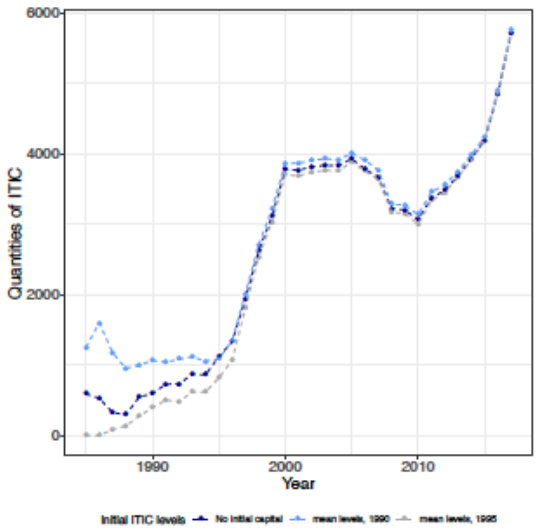
Sensitivity to model parameter values: Initial ITIC levels



(b) Initial ITIC levels

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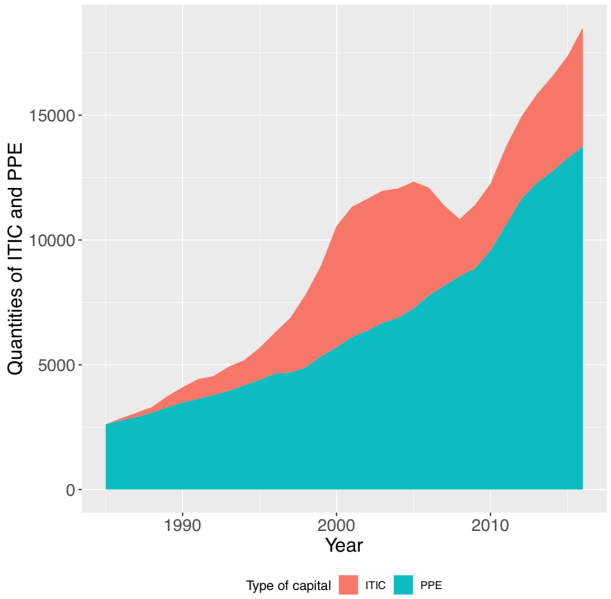
IT-related Intangible Capital and Property, Plant and Equipment are Both Growing



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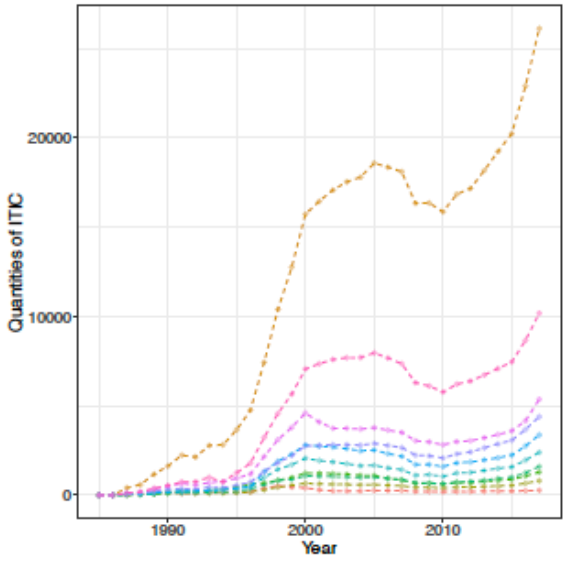
Superstars: ITIC prices and quantities by deciles



(c) ITIC quantities by market value (10%)

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Question: Will TFP be Underestimated or Overestimated?

Answer: It depends

1. TFP will be underestimated to the extent that tangible inputs are used to build up intangible stock.
   - During investment period, we are creating unmeasured output
2. TFP will be overestimated to the extent that intangible assets are harvested to create output.
   - During harvest period, we are using unmeasured input
3. In long-run steady-state, these two effects should exactly offset
   - Zero mismeasurement

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 at time 0
  - Adjustment Costs and Intangibles can be treated similarly

- GPT investments require significant intangible components and adjustment costs
- 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 λ/z, the ratio of the shadow price of investment to the purchase price of capital (details to come)
- Physical / marketed component of GPT may be small relative to the required investments in org change, training, etc.

The New Growth Accounting

So then the difference between real TFP growth and measured TFP growth is:

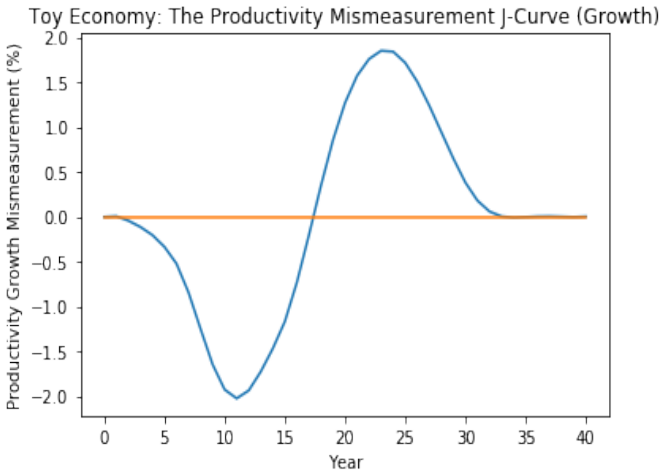
$$g^*_{TFP} - g_{TFP} = \sum_{j=0}^{J}\left(\frac{\lambda_j}{z_j} - 1\right)\left(\frac{z_j I_j}{Y}\right)(g_{I_j} - g_k) \qquad (11)$$

Three parts to difference: adjustment costs, investment share, difference in growth rates.

This is the (Growth) Productivity J-Curve:

As the growth rate of investment exceeds the overall capital growth rate, this difference is positive. Then, as investment growth slows, the difference is negative, and eventually converges to zero.

Growth J-Curve



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Productivity Scenario

- **Self-driving cars:**
  - Total investment in autonomous vehicle technology from 2014-2017 was $80 Billion (Brookings, 2018)
  - 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.

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Summary: IT Intangibles are Large and Growing

1. We can measure the market value of ITIC.
2. More of these fluctuations in ITIC can be attributed to changes in quantities, rather than prices. ITIC accounts for about 20%-25% of the levels of physical capital for firms in our sample.
3. Most of the increase in ITIC is concentrated in a small set of "superstar" firms that are pulling away from the rest.
4. In cross-sectional regressions, ITIC predicted double the productivity contribution of IT capital, though AI is not yet adding to productivity.
5. ITIC and other intangibles affect estimates of growth in the macro-economy and productivity
6. GPTs required intangibles which create a *Productivity J-curve*

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Questions and Comments?

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