Long-Run Implications of Investment-Specific Technological Change

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How to measure (speed of) technological progress?

- Production function approach, e.g.:
  - Y$=F(z, L, K)$, technology z, labor L, capital K
  - It takes a model to define *technology* (where does z go?)
  - Can get z as a (Solow) residual
  - Quality of K is technology? Definition and measurement of inputs is crucial in defining and measuring technology!
- We only observe pY per product
  - Need to measure output like-for-like: quality-adjust prices[1]
  - Need to aggregate: e.g. Thornqvist Index
- Price and product changes informative of *relative* change
  - Gordon (1990) quality-adjusts price series for investment
- Greenwood, Hercowitz, and Krusell (1997):
  How much of technological growth is investment-specific?
- Cummins and Violante (2002):
  Product and industry level productivity

[1] Can also quality-adjust quantities, or use economic depreciation rates rather than physical ones - right choice depends on model!

How to adjust prices for quality

Cf. Triplett (2006)

- For existing products
  - *Matched-model method*
  - Control for changes in characteristics
  - E.g. compare prices of computers with the same speed
- For new products
  - *Hedonic method*
  - Have a (regression) model of price in terms of characteristics, apply to new product
  - E.g. what was the price of a quantum computer before it existed? Extrapolate existing model of price for speed
- Official price series (e.g. BEA) are often lacking in this regard
  - Some adjustment (matched-model), can depend on category
  - Procedures often change over time
  - Hedonic methods capture more technical change
  - Gordon (1990) made own series using both methods for investment goods (1947-1983)

Greenwood, Hercowitz, and Krusell (1997)

Long-Run Implications of Investment-Specific Technological Change

- Two stylized facts suggest significant technological change in the production of new equipment
  1. Quality-adjusted price declines, amount of investment increases
  2. Negative cyclical correlation between price and investment
- How important is this versus other sources of productivity growth?
- Also:
  - Embed long-run trends on equipment into model with otherwise balanced growth and usual stylized facts
  - Discuss some ways to make technological growth endogenous in this setting

Empirical Background

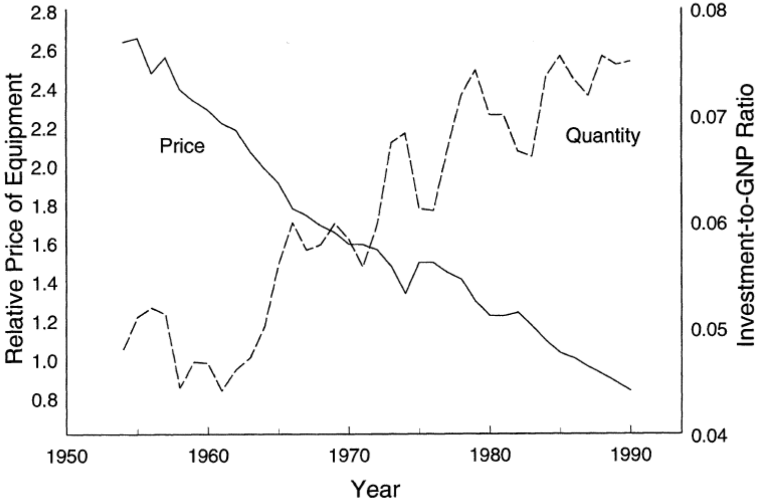


FIGURE 1. INVESTMENT IN EQUIPMENT

- Price series quality-adjusted
- Quantity relative to GDP

Model (preferences)

- Representative agent maximizes (c consumption, l labor)

$$E[\sum_{t=0}^{\infty} \beta^t U(c_t, l_t)] \tag{1}$$

$$U(c_t, l_t) = \theta \ln c + (1-\theta)\ln(1-l), \quad 0 < \theta < 1 \tag{2}$$

- Key is production side, here we just get labor supply
- Will omit some rebating of taxes, equilibrium definition

Model (production)

- Output y, equipment k_e, structures k_s, labor l, TFP z

$$y = zF(k_e, k_s, l) = zk_e^{\alpha_e} k_s^{\alpha_s} l^{1-\alpha_e-\alpha_s} \tag{3}$$

$$0 < \alpha_e, \alpha_s, \alpha_e + \alpha_s < 1 \tag{4}$$

- Investment in equipment i_e and structures i_s normalized in *final output terms*:

$$y = c + i_e + i_s \tag{5}$$

- Structures production is the same as consumption goods:

$$k_s' = (1 - \delta_s)k_s + i_s, \quad 0 < \delta_s < 1 \tag{6}$$

- Equipment production: investment-specific cost/technology q:

$$k_e' = (1 - \delta_e)k_e + i_e q, \quad 0 < \delta_e < 1 \tag{7}$$

- Depreciation is *physical* in both cases,
  not *economic* (=value change of assets)

Balanced growth

- Usually capital-specific technological progress is hard to reconcile with
  - Constant interest rate
  - Constant capital-to-GDP
- This paper: equipment grows faster than output, but relative price in terms of output falls
- With fixed growth rates of z, q:
  - Balanced growth with constant interest rate, constant income shares, constant consumption- and structures-to-GDP

Model to Data

- Model variables are theoretical constructs: think in changes
- Gordon (1990) quality-adjusted equipment price series (extended and) used as $p = 1/q$
- GDP, consumption, equipment and structures investment are *in consumption terms*, so deflate by non-durables non-housing consumption deflator (also net out housing from GDP), hours for labor
- Use physical depreciation rates; create capital stocks by perpetual inventory; assume starting point on balanced path
- Calibrate parameters to match some moments, amongst others:
  - GDP growth per hour worked 1.24%
  - equipment investment-to-GDP 7.3%
  - structures investment-to-GDP 4.1%

Results

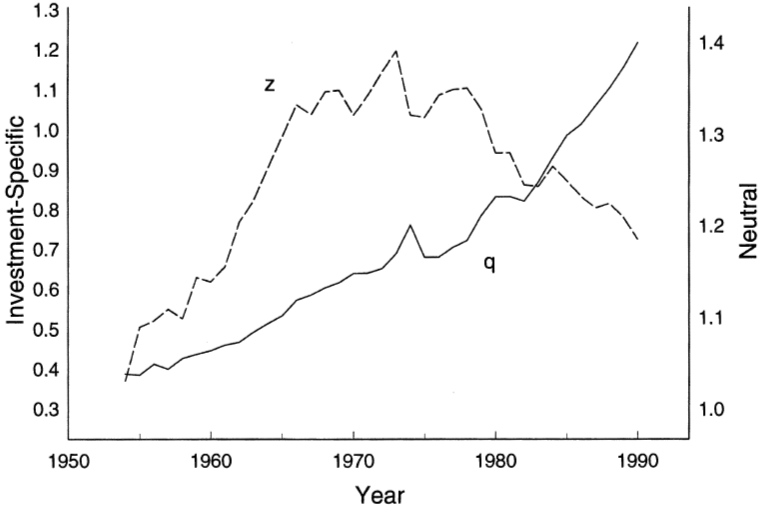


FIGURE 3. TECHNOLOGICAL CHANGE

- q makes up 60% of growth, z 40%
- Finding driven by quality adjustment

Cummins and Violante (2002)

Investment-Specific Technical Change in the US (1947–2000): Measurement and Macroeconomic Consequences

- Measures technological progress in much the same spirit, focuses on equipment investment at product and industry level
- Extend series of Gordon (1990) by (crude) extrapolation of relationship to non-adjusted series
  - Equipment and Software important in postwar growth, esp. 90s
  - True for all industries: General Purpose Technology
- Touches upon related issues
  - Technological gap as a predictive measure
  - Technological gap and (returns to) human capital (follow-up on Nelson and Phelps (1966))
  - Some interesting comments on labor shares, mark-ups, etc

Basic Setup

- Final goods x_t are produced competitively, with constant returns to scale of capital labor
- They can be used for consumption c_t^*, or in the production of efficiency-units of investment goods i_t^*:

$$i_t^* = q_t x_t \tag{8}$$

- q_t is investment-specific technology (as before!)
- Competition in the investment goods sector implies

$$p_t^{i^*} i_t^* = p_t^{c^*} x_t \tag{9}$$

- $p_t^{i^*}$, $p_t^{c^*}$ are *constant-quality* or *efficiency-unit* prices
- Combining implies (as before!)

$$\frac{p_t^{i^*}}{p_t^{c^*}} = \frac{1}{q_t} \implies \Delta q_t = \Delta p_t^{c^*} - \Delta p_t^{i^*} \quad (\Delta = \text{growth rate}) \tag{10}$$

Results

- Quality adjustment increases productivity growth in Equipment and Software by 2.5%
- Investment specific technical change grows to 6% in 90s
- Information Processing Equipment and Software (IPES) technology grew at an average rate of 23.5%, peaking in the 60s and 70s
- Industry level investment data show large dispersion in industry level technological growth, but dispersion stays relatively stable
- Position of industry in distribution of technology growth became more persistent in 80s and 90s
  - Suggests IPES is general purpose technology
  - Seems like this idea could be formalized and measured
- Implied capital stock grows much faster than NIPA
- Implied depreciation (*physical*) is lower than NIPA (*economic*)

Growth Accounting

- Simple regression based growth accounting exercise
  - Use adjusted capital series
  - Use an education and composition adjusted series for labor
- Capital is 54% of postwar growth, labor 32%, TFP 14% and negative contribution in 80s and 90s
  - This is partial equilibrium:
    TFP may have caused some of the capital and labor increase
  - Authors do some work, report even bigger role for capital
- What drove up labor productivity in 1995-1999?
  - Candidates: capital (IPES and other) quantity and quality, labor quality and quantity, TFP
  - Mostly TFP, also IPES
- Split components into trend and cycle (forward looking?)
  - Cyclical component is 30% to 90%
  - Hard to say whether TFP is trend or cycle

Technological Gap: Definition

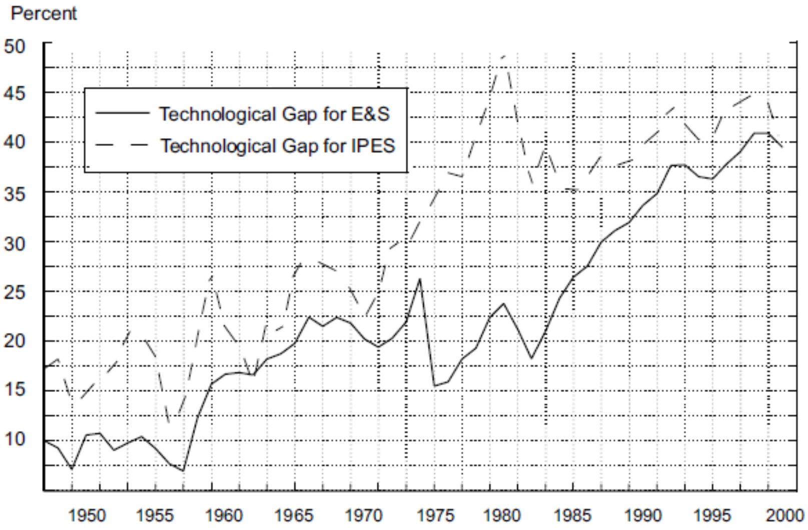
- Follows Hulten (1992)
- Denote quality-adjusted stock as k_{et}^*, unadjusted as $\tilde{k}_{et}$
- Average efficiency level (aggregate of q_t over capital vintages):

$$Q_t^e = \frac{k_{et}^*}{\tilde{k}_{et}} \tag{11}$$

- Technology gap:

$$\Gamma_t^e = \frac{q_t^e - Q_t^e}{Q_t^e} \tag{12}$$

Technological Gap: Measurement



Technological Gap and Human Capital

- Nelson and Phelps (1966):
  - Rate of implementation of latest technology depends on educational attainment, current gap
  - (Presumably also on prices)
- Authors bring this idea to data

Technological Gap and Human Capital: Empirics

Table 8: OLS Estimates of Nelson-Phelps Adoption Equation (1948–99)

Variable	(1)	(2)	(3)	(4)	(5)
$\log(\Gamma_{t-1})$	0.84	0.84	0.72	0.66	0.67
	(0.05)	(0.05)	(0.12)	(0.12)	(0.14)
Share of Young Workers (ages 16-24)	—	0.46	0.67	2.75	2.83
		(0.85)	(0.87)	(1.23)	(1.35)
Share of College Graduates	—	—	0.93	10.9	11.0
			(0.84)	(4.44)	(4.49)
Share of Female Workers	—	—	—	-10.5	-10.4
				(4.57)	(4.62)
Share of Self-employed	—	—	—	—	0.27
					(1.82)
Durbin-Watson	1.59	1.62	1.53	1.49	1.50
$\bar{R}^2$	0.85	0.85	0.85	0.87	0.87

Each column contains estimates of a separate equation in which the dependent variable is $\log(\Delta Q_t)$.

Standard errors on coefficients are in parentheses.

Discussion of Assumptions: Factor Shares, Mismeasurement

- What if shares of capital in the consumption and investment sector differ?
  - Authors argue this leads to even larger technological growth ($\alpha_c > \alpha_i$, capital-labor ratio κ growing)

$$\Delta p_t^{c^*} - \Delta p_t^{i^*} = \Delta q_t - (\alpha^c - \alpha^i)\Delta \kappa_t \tag{13}$$

- What if quality improvements in consumption goods were neglected?
  - If understated by factor u_t^c, then $p_t^c = u_t^c p_t^{c^*}$
  - If positive, overstating technological change
  - Authors argue this may be an issue, but expect it to be small

Discussion of Assumptions: Markups

- What if markets are not competitive?
  - Non-competitive price $\tilde{p}_t = (1 + \mu_t)p_t$, mark-up μ_t
  - Profits $\Pi_t = \tilde{p}_t y_t - c_t$
  - For competitive price we have $p_t y_t = c_t$
  - Then $\mu_t = \pi_t/(1 - \pi_t)$, with profit rate $\pi_t = \Pi_t/(\tilde{p}_t y_t)$
- Data: Mark-ups are falling in both sectors
  - Seems surprising given recent findings claiming rising mark-ups
  - Would overestimate technical change if mark-ups, but effect is small

Conclusions and Onward

- Some methodology available for measuring technological progress, as well as speed of progress
  - Data are key, not always available
- Interaction with human capital?
  - Speed of progress and adjustment of labor skills
  - Complementarity and vintages
- Falling labor share since early 80s
  - Coincides with relative rise of investment-specific productivity
  - Coincides with growing technological gap (and income inequality)
- Productivity glut
  - Technological growth is not constant
  - Is balanced growth what we should expect? If so, why?

Literature I

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