Long-Run Implications of Investment-Specific Technological Change

Greenwood, Hercowitz, Krusell (*AER*, 1997)

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Sargent Reading Group

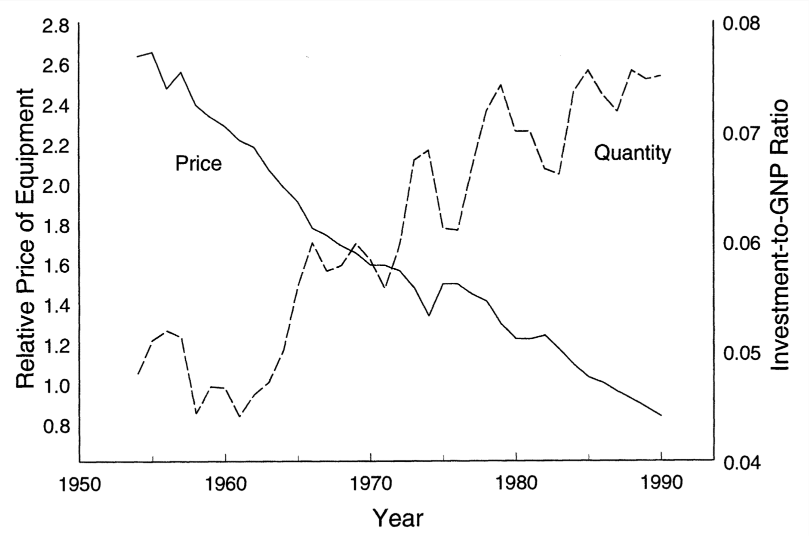
Facts

Postwar U.S. equipment investment:

1. **Low frequency**: relative price of equipment has declined, while equipment to GNP ratio has increased
2. **High frequency**: negative correlation between detrended relative price of new equipment and new equipment investment

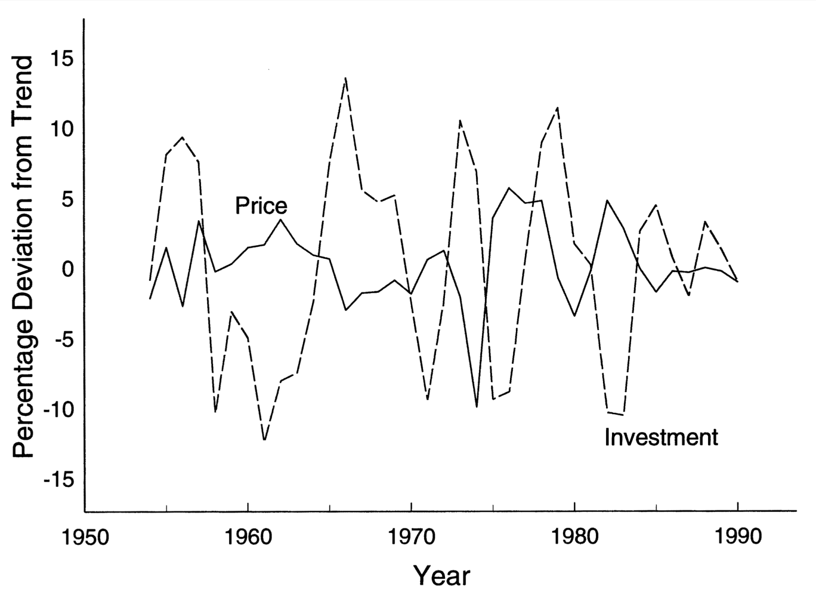
Technological advances have made equipment less expensive, triggering increases in accumulation in the short and long run.

Facts



Relative Price of Equipment
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
Price
Quantity
0.08
0.07
0.06
0.05
0.04
Investment-to-GNP Ratio
1950
1960
1970
1980
1990
Year

Facts



Percentage Deviation from Trend
15
10
5
0
-5
-10
-15
Price
Investment
1950
1960
1970
1980
1990
Year

Question

What is the quantitative role of investment-specific technological change in U.S. growth?

- Production of capital goods becomes more efficient
- Want to disentangle this form of productivity change from the traditional Hicks-neutral form

Methodology:

- Vintage capital model in general equilibrium framework
- Characterize BGP and calibrate to NIPA data
- **Main finding**: investment-specific technological change accounts for 60% of growth in output per hours worked

Model

Representative agent maximizes expected value of lifetime utility:

$$\mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t U(c_t,\ell_t)\right]$$

with: $U(c,\ell)=\theta\log c+(1-\theta)\log(1-\ell)$.

Production of final output requires labor ℓ, and **two types of capital**, equipment k_e and structures k_s, according to:

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

z is total-factor (neutral) productivity

Output can be consumed, or invested in equipment or structures:

$$y = c + i_e + i_s$$

Capital evolution:

$$k_s' = (1 - \delta_s)k_s + i_s$$
$$k_e' = (1 - \delta_e)k_e + i_e q$$

q and z follow Markov processes with average growth rates of γ_q and γ_z, respectively

Government: $\tau = \tau_k(r_e k_e + r_s k_s) + \tau_\ell w \ell$

Investment-Specific Technological Change, q

Affects equipment only:

1. Relative price of structures + structures-to-GNP ratio are stationary
2. Less productivity change in structures than in equipment

Interpretations:

1. Price of producing new equipment $\frac{1}{q}$ declines over time
2. Each period, a new vintage of equipment is produced, whose productivity, q, increases over time, while its price stays fixed

Requires investment in order to affect output, whereas neutral technological change does not.

Aggregate state is $\lambda = (s, z, q)$, where $s = (k_e, k_s)$.

A **competitive equilibrium** is a set of allocation rules $c = C(\lambda)$, $k'_e = K_e(\lambda)$, $k'_s = K_s(\lambda)$, $\ell = L(\lambda)$, pricing and transfer functions, $w = W(\lambda), r_e = R_e(\lambda)$, $r_s = R_s(\lambda)$, $\tau = T(\lambda)$, and an aggregate law of motion for capital stocks $s' = S(\lambda)$ such that:

1. Households and firms optimize (firms make zero profits), taking as given the aggregate state, prices/transfers, and the law of motion
2. The economywide resource constraint holds in each period

Balanced Growth (Deterministic Version)

- z and q follow:

$$z_t = \gamma_z^t, \quad q_t = \gamma_q^t$$

- Growth rates:
  - **Along a balanced growth path**: output, consumption, investment grow at the same rate g
  - But from accumulation equation, equipment grows faster, at rate $g_e = g\gamma_q$
  - Production function implies $g = \gamma_z g_e^{\alpha_e} g^{\alpha_s} \implies$ restrictions on growth rates:

$$g = \gamma_z^{\frac{1}{1-\alpha_e-\alpha_s}} \gamma_q^{\frac{\alpha_e}{1-\alpha_e-\alpha_s}}$$

- Can transform the problem so that all variables are stationary
- Can show that a steady state exists in these transformed variables $\implies$ balanced growth path in the original model

- Rental price of equipment is falling along a balanced growth path:

$$zF_1(k_e, k_s, \ell) = \alpha_e \left(\frac{k_s}{k_e}\right)^{\alpha_s} \left(\frac{z^{\frac{1}{1-\alpha_e-\alpha_s}} \ell}{k_e}\right)^{1-\alpha_e-\alpha_s}$$

  at rate $\frac{1}{\gamma_q}$
- But real interest rate, $zF_1(k_e, k_s, \ell)q$ (return from investing a unit of consumption goods in equipment) stays constant
  - Cost of unit of equipment in terms of consumption, $\frac{1}{q}$, is also declining at rate $\frac{1}{\gamma_q}$
- Like the standard neoclassical growth model, we get constant interest rate, capital/labor shares, etc, plus:
  1. Declining price of equipment
  2. Faster growth rate of equipment compared to output

Quantitative Analysis

Data

- Interpret U.S. data through this framework to determine the contributions of the two types of technological change
- Output, consumption, investment in data are measured in **consumption units** (like in model): nominal variables from NIPA divided by consumption deflator
- q: Gordon's (1990) equipment price index

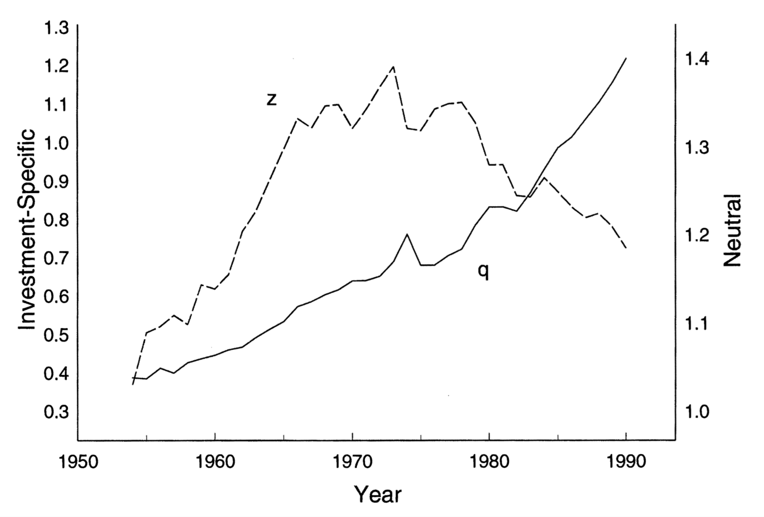
Calibration

- Need to set: $\underbrace{\beta, \theta}_{\text{preferences}}, \underbrace{\alpha_e, \alpha_s, \delta_e, \delta_s, \gamma_q, g}_{\text{technology}}, \underbrace{\tau_k, \tau_\ell}_{\text{tax rates}}$
- Choose them so that balanced growth path is in line with 6 features from the data:
  - growth rate of output per capita
  - fraction of time spent working
  - capital share
  - two types of investment to GNP
  - after-tax return on capital...
- Use equations characterizing balanced growth to back these out

Procedure

- We have a direct observation on q: use this with the model to impute a series for neutral (residual) technological change
- Specifically:
    - Given data on i_e and q, iterate on:
    $$k_e' = (1 - \delta_e)k_e + i_e q$$
    initial k_e was set at its balanced growth level given initial y
    - This gives us a time series for capital, and using data on ℓ and y, we can back out a series for z from the production function
    - Use balanced growth restriction to determine the importance of the two components
- Construct their own measure of equipment to adjust BEA's measure for quality

q vs. z



$$\gamma_q = 3.21\%, \gamma_z = 0.39\%$$

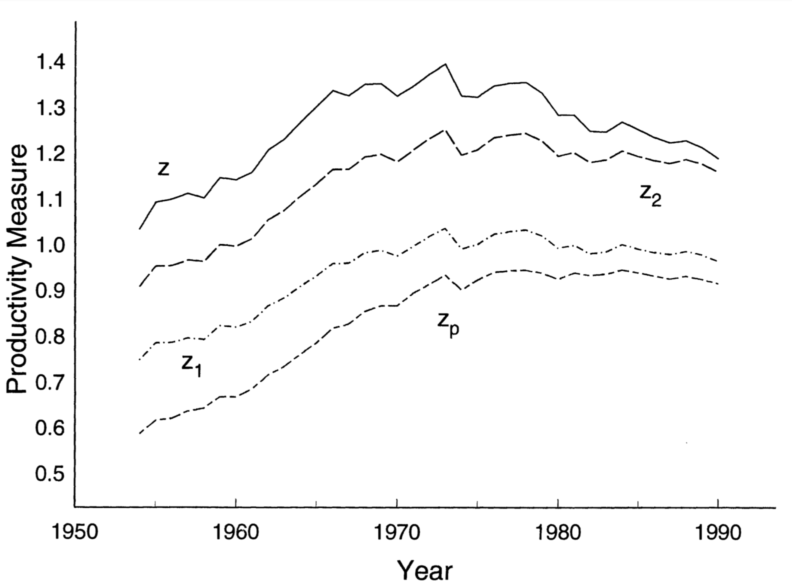
Results

How does picture of TFP growth change when investment-specific technological change is incorporated into the analysis?

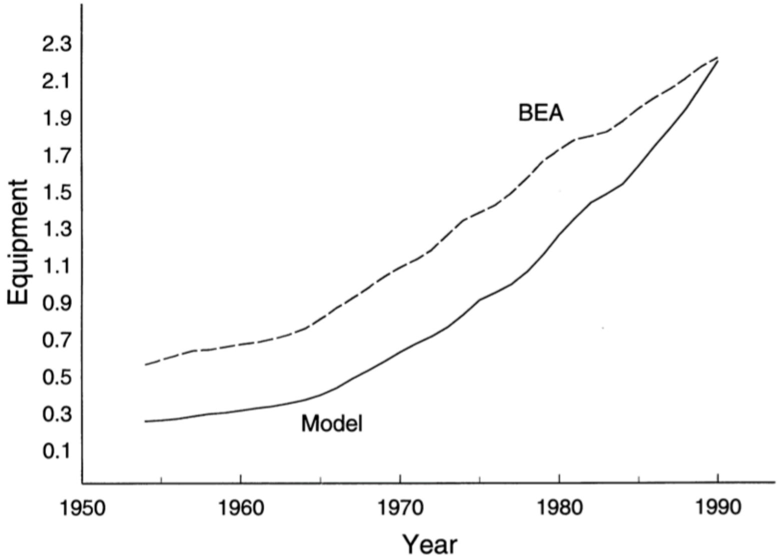
1. No strong long-run trend in z
2. Downturn in TFP in the 1970's
    - Pickup in q coincides with slowdown in z
    - Had we aggregated the two stocks of capital together, the magnitude of the downturn would not have been as large

production function	q?	TFP growth per year
$y = z_p \ell$	no	1.24%
$y = z_1 k^{\alpha} \ell^{1-\alpha}$	no	0.71%
$y = z_2 k_e^{\alpha_e} k_s^{\alpha_s} \ell^{1-\alpha_e-\alpha_s}$	no	0.68%
$y = z k_e^{\alpha_e} k_s^{\alpha_s} \ell^{1-\alpha_e-\alpha_s}$	yes	0.39%

Solow Residuals



Equipment Stock



Importance of Investment-Specific Technological Change

How do the two sources of technological change contribute to growth in output per hour worked? Use the approximation:

$$g = \gamma_z^{\frac{1}{1-\alpha_e-\alpha_s}} \gamma_q^{\frac{\alpha_e}{1-\alpha_e-\alpha_s}}$$

and growth rates: $\gamma_q = 3.21, \gamma_z = 0.39$

- In the data, growth rate of output per hour is 1.24
- With only investment-specific technological change, this would be 0.77
- With only neutral technological change, this would be 0.56

$\implies$ 58% from q, 42% from z

Conclusions

- Data suggest that investment-specific technological change is important for growth
- Vintage capital model allows for increasing equipment-to-GNP ratio and declining relative price of capital goods, while preserving standard features of neoclassical growth model
- When the BGP is calibrated to U.S. data, they find:
    1. Investment-specific technological change accounts for the major part of growth
    2. Productivity slowdown of 1970's is more dramatic when technological improvement in the capital goods-producing sector is taken into account