R&D, Productivity, and Market Value

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Overview

- Econometric measurement of private returns to R&D investment
  - dates back to Griliches 1958 *JPE* article
- Today
  - Sophisticated methodology based on conventional economic modeling
  - Applicable to other innovation investments, not just R&D
  - Important unresolved questions and conundrums

Previous analytic surveys

- Griliches 1979 (*Bell Journal of Economics*)
- Griliches 1996; published as Chapter 4 of Kuznets lectures 1999
- Hall 1996 (In Barfield and Smith, AEI/Brookings)

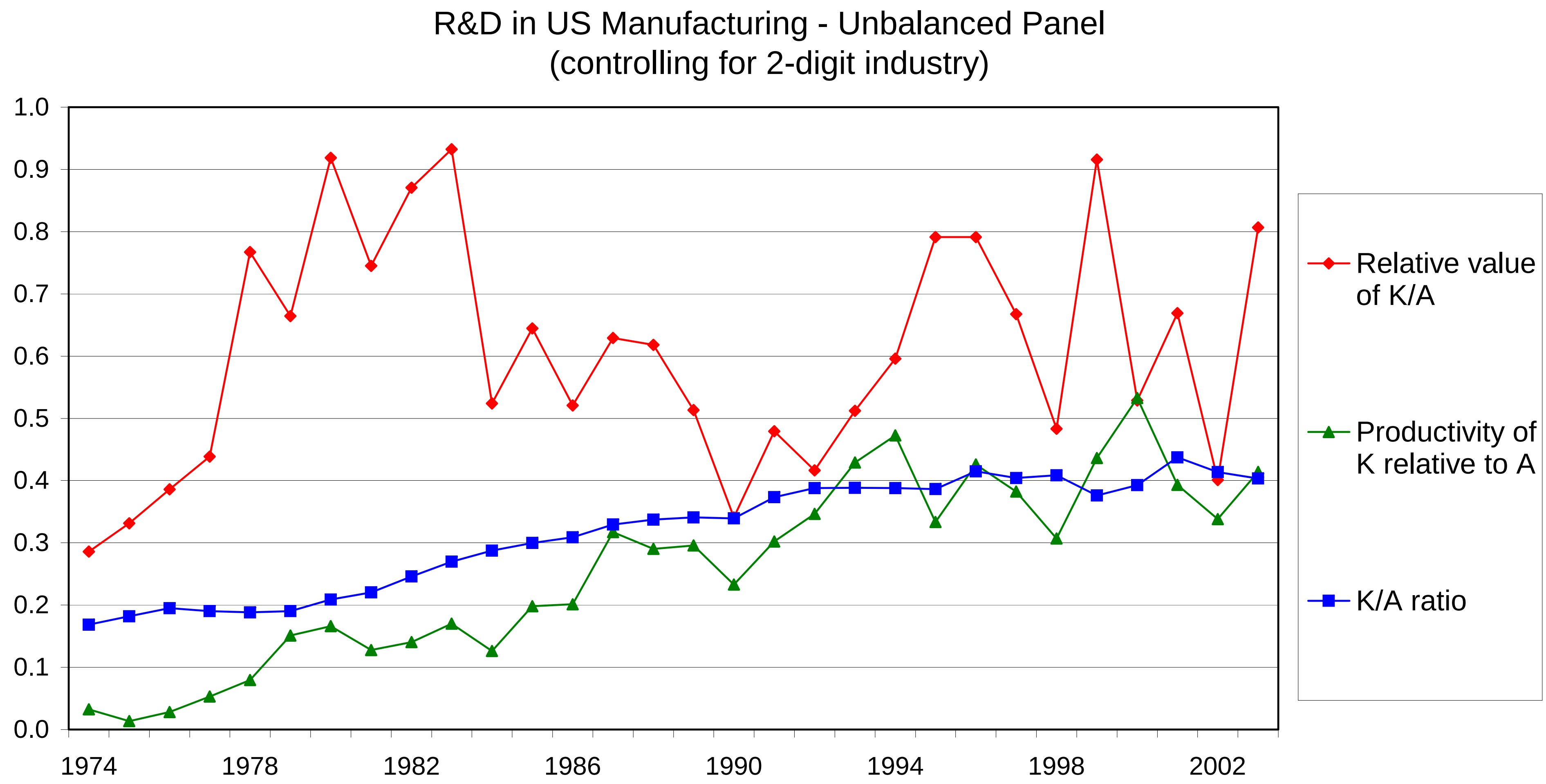
Measurement overview (outline)

- Treat R&D as investment under (considerable) uncertainty
- *Ex post* evaluation - productivity
  - Revenue, output or profits as a function of R&D capital stock
- *Ex ante* evaluation – market value
  - Current financial market value of the firm as a function of R&D capital stock

Depreciation of R&D

- Assumption: R&D creates a stock of knowledge (*K*)
- What is its depreciation?
  - At the firm level, the rate at which returns to *K* decline
  - The result of Schumpeterian competition - endogenous to the behavior of competitors
  - Sometimes called private obsolescence
- Do we need to estimate it?
  - Yes, to estimate net rate of return
  - Yes, to construct knowledge stock

Trends in R&D Productivity



Some puzzles

- Has the productivity of R&D increased or declined?
  - Or has the pace of Schumpeterian competition increased?
- How do we reconcile
  - Market value and productivity results?
  - R&D intensity and R&D growth versions of production function?
  - Firm and industry results?

Productivity framework

- Cobb-Douglas production (first order log approximation to prod function)
- Line of business, firm or industry level
- Variety of estimating equations:
  - Conventional production function
  - Partial productivity
  - R&D intensity formulation
  - Semi-reduced form (add variable factor demand equations)

Productivity framework (cont.)

$$Y = AL^{\alpha} C^{\beta} K^{\gamma} e^{u}$$

where L = labor

C = capital

K = research or knowledge capital

u = random shock

Productivity framework (cont.)

Take logarithms and model the intercept with year and firm (or industry) effects:

$$y_{it} = \eta_i + \lambda_t + \alpha l_{it} + \beta c_{it} + \gamma k_{it} + u_{it}$$

$$i = 1, \ldots, N \qquad t = 1, \ldots, T$$

Simultaneity: shock *u* may possibly be correlated with the current (and future) input levels.

Correlated firm effects: *η* may also be correlated with the input levels.

R&D input measurement

- Deflation
  - No good measure of “real” costs of R&D
  - With time dummies, little bias from deflation
- Stock computation (δ assumed =15%)

$$K_t = (1-\delta_K)K_{t-1} + R_t$$

$$\left[\Rightarrow K_t \cong R_t / (\delta_K + g_R)\right]$$

- Externalities
  - How to measure the external knowledge that is useful to a particular firm or industry?

Econometric issues

- Co-movements over time and space
  - Variables of interest tend to move together for a number of reasons
- Simultaneity between outputs and inputs
  - Favorable productivity experience leads to increased R&D input
- Low variation of RHS variables within unit over time
  - R&D highly serially correlated, so the lag or depreciation structure difficult to pin down

Output deflation

Productivity growth regressions at the firm level:

(1) $\Delta y_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma\Delta k_{it} + \Delta u_{it}$

(2) $\Delta s_{it} = \Delta y_{it} + \Delta p_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma\Delta k_{it} + \Delta u_{it}$

where *s* is revenue and *y* is deflated output

If (2) is estimated instead of (1), we obtain an estimate of

$$\gamma_S = \gamma_Y + \gamma_P$$

The *revenue* productivity of R&D is the sum of

- *true* productivity
- the effect R&D has on the prices at which goods are sold due to
  - quality improvements (decreases)
  - product differentiation (increases)

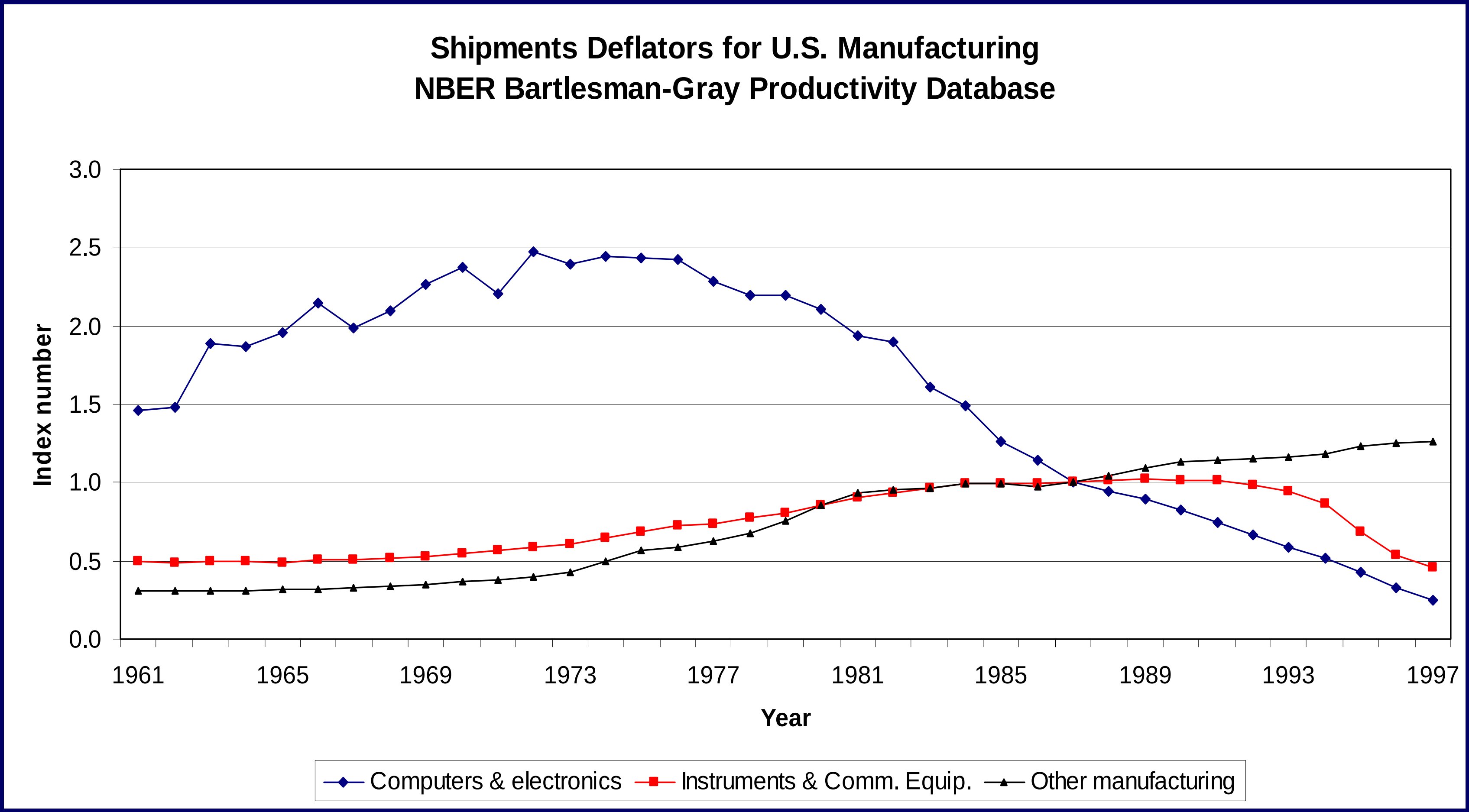
Interpretation

- Revenue productivity is a determinant of private returns
- True productivity (more constant quality output for a given set of inputs) is relevant for social returns
- The difference represents
  - Negative - pecuniary externalities
  - Positive – output "stealing" or market power increases due to R&D

Illustration

- Some U.S. deflators at the industry level are hedonic, notably those for the computer industry and now the communications equipment industry (see next slide)
- Deflate firm sales by 2-digit deflators instead of one overall deflator
- Result: true productivity is substantially higher than revenue productivity, because of hedonic price declines in these R&D-intensive industries.

Hedonic Price Deflator for Computers



Estimated R&D Elasticity – U.S. Manufacturing Firms

Period	Dep. Var = Log Sales	Dep. Var = Log Sales, 2-digit deflators	Difference ("price effect")
1974-1980	-.003 (.025)	.102 (.035)	0.099
1983-1989	.035 (.030)	.131 (.049)	0.096
1992-1998	.118 (.031)	.283 (.041)	0.165

Method of estimation is GMM-system with lag 3 and 4 instruments.
Sample sizes for the three subperiods are 7156, 6507, and 6457.

Estimating returns

Difference to remove firm effect:

$$\Delta y_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma\Delta k_{it} + \Delta u_{it}$$

R&D intensity:

$$\Delta k_{it} = \frac{R_{it} - \delta K_{i,t-1}}{K_{i,t-1}} \cong \frac{R_{it}}{K_{i,t-1}} \quad \text{if depreciation } \delta \text{ is near zero}$$

$$\Rightarrow \gamma\Delta k_{it} \cong \rho \frac{R_{it}}{Y_{it}}$$

where ρ is the gross rate of return to R&D capital

Two methods

(1) estimate *γ* and derive *ρ (Δk)*

(2) estimate *ρ* directly (*R/Y*)

Net rate of return is ρ-δ (minus a possible capital gain or loss)

Regardless of method, result depends on choice of δ in several ways

Using $K \cong R/(\delta + g)$, can derive δ from estimates.

Resulting estimates of δ are typically inconsistent, imprecise, and too low (negative?) – why?

Estimating depreciation

Simple neoclassical framework:

$$c_K = r + \delta_K$$

c_J = cost of capital J, r = required rate of return, δ_K = depreciation, g_R = growth of R&D, ~ = "true"

Profit maximization implies

$$\frac{\gamma}{\beta} = \frac{c_K \tilde{K}}{c_A A} = \frac{(r + \delta_K)}{c_A} \frac{(0.15 + g_R)}{(\delta_K + g_R)} \frac{K}{A}$$

Interest rate close to growth rate => δ hard to identify even if we assume a normal rate of return

Market value model

- Assumes market efficiency
- Two versions
  - Theoretical – value function from firm's dynamic program as a function of state variables (capital, R&D, etc.)
  - Hedonic – value of a set of goods that have a lower-dimensional vector of characteristics – yields a measure of current shadow value of the assets (not stable over time)

Hedonic regression for market value

$$V_{it}(A_{it}, K_{it}) = b_t \, [A_{it} + \gamma K_{it}]$$

Non linear: $log(V_{it}/A_{it}) = logQ_{it} = log\ b_t + log(1+\gamma_t K_{it}/A_{it})$

Linear approx.: $log\ Q_{it} = log\ b_t + \gamma_t\ K_{it}/A_{it}$

Interpretation:

$Q_{it} = V_{it}/A_{it}$ is Tobin's *q* for firm *i* in year *t*

b_t = overall market level (approximately one).

γ_t = relative shadow value of K assets

(γ = 1 if depreciation correct, investment strategy optimal, and no adjustment costs => no rents).

Summary of past results

- Market value positively related to R&D
- Range of estimates for shadow value
  - R&D expenditure coefficient: ~1.5 to 8 or 9
  - R&D stock coefficient: 0.2 to 2
- Wide variability over time and industry
- Substantial variability in specification, making comparisons difficult
  - Intangibles, patents, trademarks
  - Leverage, sales growth, market share

Extracting depreciation rate

- Strong assumptions:
  - Equilibrium in R&D
  - Market efficiency
  - Negligible adjustment costs
  - Only mismeasurement in *K* is using wrong depreciation rate to construct it

$$\Rightarrow \hat{\delta}_{it} = \frac{(.15 + g_{it})}{\hat{\gamma}_t} - g_{it}$$

Market value estimates – US manufacturing sector

Period	K/A Coefficient	(s.e.)	Median depreciation	(s.e.)
1974-1978	0.398	0.028	42.8%	9.2%
1979-1983	0.573	0.028	30.3%	4.9%
1984-1988	0.362	0.029	54.0%	9.0%
1989-1993	0.352	0.033	55.3%	7.8%
1994-1998	0.507	0.040	37.8%	5.5%
1999-2003	0.745	0.044	21.8%	2.9%

Estimated depreciation of R&D for selected sectors

Period	Drugs & medical instruments	Computers & electronics
1974-1978	*9.9% (4.2%)*	*31.9% (8.1%)*
1979-1983	*19.6% (7.9%)*	*50.1% (14.5%)*
1984-1988	5.8% (3.1%)	*88.1% (27.6%)*
1989-1993	*20.6% (6.6%)*	*51.3% (8.6%)*
1994-1998	*18.8% (5.6%)*	*51.2% (11.6%)*
1999-2003	*18.9% (5.6%)*	*25.2% (5.3%)*

Conclusion

- Still a puzzle?
  - Market value gives more reasonable estimates of depreciation, but required assumptions very strong
  - R&D has become more revenue-productive, as suggested by its higher share; suggests
    - Either convergence to equilibrium
    - Or increased depreciation