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

R&D in US Manufacturing - Unbalanced Panel
(controlling for 2-digit industry)
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.)

\[ Y = A L^\alpha C^\beta K^\gamma e^u \]

where \( L = \text{labor} \)

\[ C = \text{capital} \]

\[ K = \text{research or knowledge capital} \]

\[ u = \text{random shock} \]
Productivity framework (cont.)

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

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

\[ i = 1, \ldots, N \quad t = 1, \ldots, T \]

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

**Correlated firm effects:** \( \eta \) 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 ($\delta$ assumed = 15%)
  \[ K_t = (1 - \delta_K)K_{t-1} + R_t \]
  \[
  \Rightarrow K_t \approx R_t / (\delta_K + g_R)
  \]
- 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.
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

Shipments Deflators for U.S. Manufacturing
NBER Bartlesman-Gray Productivity Database

Index number

Year

Computers & electronics
Instruments & Comm. Equip.
Other manufacturing
## Estimated R&D Elasticity – U.S. Manufacturing Firms

<table>
<thead>
<tr>
<th>Period</th>
<th>Dep. Var = Log Sales</th>
<th>Dep. Var = Log Sales, 2-digit deflators</th>
<th>Difference (&quot;price effect&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974-1980</td>
<td>-.003 (.025)</td>
<td>.102 (.035)</td>
<td>0.099</td>
</tr>
<tr>
<td>1983-1989</td>
<td>.035 (.030)</td>
<td>.131 (.049)</td>
<td>0.096</td>
</tr>
<tr>
<td>1992-1998</td>
<td>.118 (.031)</td>
<td>.283 (.041)</td>
<td>0.165</td>
</tr>
</tbody>
</table>

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:

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

\[
\Rightarrow \gamma \Delta k_{it} \approx \rho \frac{R_{it}}{Y_{it}}
\]

where \( \rho \) is the gross rate of return to R&D capital
Two methods

(1) estimate \( \gamma \) and derive \( \rho \) (\( \Delta k \))

(2) estimate \( \rho \) directly (\( R/Y \))

Net rate of return is \( \rho - \delta \) (minus a possible capital gain or loss)

Regardless of method, result depends on choice of \( \delta \) in several ways

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

Resulting estimates of \( \delta \) 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, \( \delta_K = \) depreciation, \( g_R = \) growth of R&D, \( \sim = \) “true”

Profit maximization implies

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

Interest rate close to growth rate => \( \delta \) 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: \( \log(V_{it}/A_{it}) = \log Q_{it} = \log b_{t} + \log(1+\gamma_{t} K_{it}/A_{it}) \)

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).
\( \gamma_{t} \) = relative shadow value of K assets
\( (\gamma = 1 \text{ if depreciation correct, investment strategy optimal, and no adjustment costs } \Rightarrow \text{ no rents}) \).
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

$$\Rightarrow \hat{\delta}_{it} = \frac{(0.15 + g_{it})}{\hat{\gamma}_t} - g_{it}$$
## Market value estimates – US manufacturing sector

<table>
<thead>
<tr>
<th>Period</th>
<th>K/A Coefficient</th>
<th>(s.e.)</th>
<th>Median depreciation</th>
<th>(s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974-1978</td>
<td>0.398</td>
<td>0.028</td>
<td>42.8%</td>
<td>9.2%</td>
</tr>
<tr>
<td>1979-1983</td>
<td>0.573</td>
<td>0.028</td>
<td>30.3%</td>
<td>4.9%</td>
</tr>
<tr>
<td>1984-1988</td>
<td>0.362</td>
<td>0.029</td>
<td>54.0%</td>
<td>9.0%</td>
</tr>
<tr>
<td>1989-1993</td>
<td>0.352</td>
<td>0.033</td>
<td>55.3%</td>
<td>7.8%</td>
</tr>
<tr>
<td>1994-1998</td>
<td>0.507</td>
<td>0.040</td>
<td>37.8%</td>
<td>5.5%</td>
</tr>
<tr>
<td>1999-2003</td>
<td>0.745</td>
<td>0.044</td>
<td>21.8%</td>
<td>2.9%</td>
</tr>
</tbody>
</table>
## Estimated depreciation of R&D for selected sectors

<table>
<thead>
<tr>
<th>Period</th>
<th>Drugs &amp; medical instruments</th>
<th>Computers &amp; electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974-1978</td>
<td>9.9% (4.2%)</td>
<td>31.9% (8.1%)</td>
</tr>
<tr>
<td>1979-1983</td>
<td>19.6% (7.9%)</td>
<td>50.1% (14.5%)</td>
</tr>
<tr>
<td>1984-1988</td>
<td>5.8% (3.1%)</td>
<td>88.1% (27.6%)</td>
</tr>
<tr>
<td>1989-1993</td>
<td>20.6% (6.6%)</td>
<td>51.3% (8.6%)</td>
</tr>
<tr>
<td>1994-1998</td>
<td>18.8% (5.6%)</td>
<td>51.2% (11.6%)</td>
</tr>
<tr>
<td>1999-2003</td>
<td>18.9% (5.6%)</td>
<td>25.2% (5.3%)</td>
</tr>
</tbody>
</table>
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