Measuring the returns to innovation (1)

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Why is this an interesting problem?

- Economists
  - Models of innovation and growth
- Managers
  - Allocation of resources for invention
  - Measure results of innovation
- Accountants
  - Accurate reporting of intangible value in company accounts
- Policy makers
  - How much to spend on innovation? What policy instrument to use? How to choose the level of subsidy?
  - Evaluation of results

Framework for analysis

Investment in innovation (R&D, training, licenses) creates an asset that pays off in the future

- Enterprise level: asset tends to become less productive over time (it depreciates)
- Industry/country/world level: investments in innovation by many agents create aggregate “knowledge” asset
  - depreciates more slowly - when private firms no longer earn returns from an innovation, the knowledge they have created remains useful

Framework for analysis

Innovation investment $R_t$ at time $t = R_t$

Knowledge asset $K_t = f(R_{t-1}, R_{t-2}, ...)$

Gross rate of return $\rho = \frac{\partial PDV(K_t, X_t)}{\partial K_t} / \frac{\partial f(R_t, R_{t-1}, R_{t-2}, ...)}{\partial R_t}$

Net rate of return $\rho - \delta$

where $PDV =$ present discounted value

$X =$ other inputs

$\delta =$ depreciation of innovation assets

$\pi(K) =$ profits or welfare produced by $K$

Map of innovation inputs and outputs

- Demand pull (taste, market size)
- Tech. opportunity (science base)
- Market structure and industry; appropriability environment; Government institutions
- Firm size and market share; diversification, tech transfer and experience
- Economy-wide knowledge
- R&D and other innovation investments
- Innovation output
- Knowledge firm-level capital created by innovation investments
- Innovative sales
- Outcomes: Productivity, Profitability, Value, and Economic Growth
- Physical capital; Worker skills
Input measures
- R&D spending
  - within firm
  - alliance and joint venture participation
- Purchase of new capital equipment
- Technology purchases/licensing
- Marketing related to new products
- Training and education of workers
- Spillover variables
  - Based on geography or technology
- Innovation survey variables
  - Whether a firm is "innovative"
  - Sources of knowledge – suppliers, partners, consumers, internal

Intermediate inputs/outputs
- Patent counts
  - Raw
  - Weighted by citations received
- Innovation/new product counts
  - From news journals
  - From surveys
- Innovation surveys – shares of sales that is
  - New to market (radical?)
  - New to firm (incremental?)

Output measures
- Individual innovations
  - Licensing fees
  - Patent renewals as a function of fee schedule (Schanckerman-Pakes)
  - Surveys (Harhoff, Scherer, PATVAL)
- Firm level
  - Profits or revenue productivity
  - Stock or financial market value – covers a broad range of technology & industry, but requires active stock market (Griliches, Hall, etc.)
- Economy level (social returns)
  - Consumer willingness-to-pay (Trajtenberg)
  - Aggregate productivity growth

Relating inputs and outputs
1. Production function approach – private and/or social returns
2. Market value approach – private returns
3. Patents as indicators of innovation activity
4. Using innovation surveys

1. Production function framework
- Cobb-Douglas production
  - first order log approximation to production function
  - general tool to relate quant measures of output to input
- Line of business, firm, industry, or country level
- Variety of estimating equations:
  - Conventional production function
  - Partial or total factor productivity function
  - R&D intensity formulation
  - Semi-reduced form (add variable factor demand equations)

Conceptual issues
- What is output?
  - usual measures exclude benefit of government spending on R&D – defense, environment, health
  - Unmeasured quality change and new goods
  - Revenue or output?
- What is knowledge capital?
  - Varying lags in producing knowledge
  - Depreciation is endogenous at the firm level
  - Own capital depends on the efforts of others as well as the firm itself (spillovers)
Productivity approach (1)

\[ Y = AL^\alpha C^\beta K^\gamma e^\delta \]

- \( L \) = labor
- \( C \) = capital
- \( u \) = random shock
- \( K \) = research or knowledge capital, constructed from investments \( R \):
  \[ K_t = (1 - \delta)K_{t-1} + R_t \]

Differencing to remove firm effect:

\[ \Delta y = \Delta \lambda + \alpha \Delta L + \beta \Delta C + \gamma \Delta K + \Delta U \]

R&D intensity version:

\[ \Delta \lambda = \frac{R_t - \delta K_{t-1}}{K_{t-1}} = \frac{R_t}{K_t} - \delta \frac{K_{t-1}}{K_t} \]

\[ \gamma K_t = \rho \left( \frac{R_t}{K_t} \right) \]

where \( \rho = \frac{\partial Y}{\partial K} \), the gross rate of return to R&D capital

Alternative formulations

Partial or total factor productivity version:

Partial: \( \Delta y = \Delta L + \alpha \Delta L + \beta \Delta C + \gamma \Delta K + \Delta U \)

Total: \( \Delta y = \beta \Delta C + \gamma \Delta K + \Delta U \)

- \( \alpha \) and \( \beta \) may be estimated using factor shares at the firm level (when available).
- Often combined with the R&D intensity approach.
- Note change in the assumptions on \( \rho \) required for consistent parameter estimates.

Sources of endogeneity:

- Inputs and output chosen simultaneously - favorable productivity/profits experience leads to increased R&D effort in the future
- Firm knows its efficiency level (fixed effect) when choosing inputs
- Inputs measured with error

Solutions

- Difference to remove fixed effect, exacerbates measurement error bias
- Total or partial productivity moves some inputs to left hand side
- Instrumental variables, GMM for panel data

Simultaneity
French Firms 1981-1989

<table>
<thead>
<tr>
<th>Sales vs Value added</th>
<th>Log S</th>
<th>Log VA</th>
<th>(1-.74)*VA Coeff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep var</td>
<td>Log C</td>
<td>Log K</td>
<td>Log L</td>
</tr>
<tr>
<td>Total</td>
<td>0.257</td>
<td>0.984</td>
<td>0.995</td>
</tr>
<tr>
<td>Sum</td>
<td>0.183</td>
<td>0.024</td>
<td>0.050</td>
</tr>
<tr>
<td>R^2</td>
<td>0.303</td>
<td>0.926</td>
<td></td>
</tr>
<tr>
<td>s.e.</td>
<td>0.113</td>
<td>0.349</td>
<td></td>
</tr>
</tbody>
</table>

Source: Mairesse and Hall 1999

197 French firms 1980-1987

<table>
<thead>
<tr>
<th>Pooled OLS estimates</th>
<th>Double counting</th>
<th>Partial Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unadjusted</td>
<td>Adjusted</td>
</tr>
<tr>
<td></td>
<td>Labor share</td>
<td>Labor share estimated</td>
</tr>
<tr>
<td>Log(C/L)</td>
<td>0.21 (0.04)</td>
<td>0.11 (0.01)</td>
</tr>
<tr>
<td>Log(K/L)</td>
<td>0.18 (0.03)</td>
<td>0.22 (0.01)</td>
</tr>
<tr>
<td>Log L</td>
<td>0.03 (0.01)</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>Log K</td>
<td>0.02 (0.00)</td>
<td>0.01 (0.00)</td>
</tr>
<tr>
<td>R^2</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.11</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Source: Hall and Mairesse 1995

French Firms 1981-1989

<table>
<thead>
<tr>
<th>Approximate gross rate of return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large R&amp;D-doing manufacturing firms</td>
</tr>
<tr>
<td>Y</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>France (1981-1989)</td>
</tr>
<tr>
<td>UK (1988-1996)</td>
</tr>
<tr>
<td>Germany (1988-96)</td>
</tr>
<tr>
<td>US (1990-1998)</td>
</tr>
<tr>
<td>Chile (1998)</td>
</tr>
</tbody>
</table>

Output deflation at the firm level

Interpreting productivity growth regressions at the firm level:

(1) \( \Delta Y = \Delta Y_r + \alpha \Delta L + \beta \Delta C + \gamma \Delta K + \Delta u \)

versus

(2) \( \Delta S = \Delta Y_r + \Delta \rho = \Delta Y + \alpha \Delta L + \beta \Delta C + \gamma \Delta K + \Delta u \)

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

\( \gamma = \gamma_r + \gamma_p \)

The **true** productivity of R&D is the sum of:

- direct productivity of R&D
- the effect R&D has on the prices at which goods are sold (due to quality improvements, product differentiation, and cost

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 pecuniary externalities
  - benefits received by downstream producers and consumers in the form of lower prices
  - in some cases, these can be large
Illustration

- Some deflators at the industry level are hedonic (in the US and some OECD data)
  - e.g., for the computer industry and the communications equipment industry
- Deflate firm sales by 2-digit deflators instead of one overall deflator
  - true productivity is substantially higher than revenue productivity, because of price declines in these R&D-intensive industries
- Innovation investments largely directed at product improvement (~2/3 of R&D)

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Hedonic Price Deflator for Computers

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

<table>
<thead>
<tr>
<th>Period</th>
<th>Dep. Var = Log Sales (S)</th>
<th>Dep. Var = Log Sales, 2-digit deflators (Y)</th>
<th>Difference (&quot;price effect&quot;) (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974-1980</td>
<td>-.003 (.025)</td>
<td>.102 (.035)</td>
<td>-.099</td>
</tr>
<tr>
<td>1983-1989</td>
<td>.035 (.030)</td>
<td>.131 (.049)</td>
<td>-.096</td>
</tr>
<tr>
<td>1992-1998</td>
<td>.118 (.031)</td>
<td>.283 (.041)</td>
<td>-.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.

\[
\gamma_S = \gamma_I + \gamma_P
\]

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Firm stock market value

Measurement of private returns to investment in innovation

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Why market value?

- Returns to innovation are the profits earned in the future from investments made today
- Forward looking measure, allows intertemporal production of innovations
  - Under an efficient markets assumption, equal to the expected value of the discounted cash flows that will be received in the future from the assets of the firm
- Observable for a wide range of firms and countries (although not as wide as we would like)
- Measuring intangible assets a present-day problem for economists and accountants
- Exploring this methodology helps our understanding of how to measure innovation assets

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Theoretical framework

- Measured market value = value function associated with firm’s profit-maximizing dynamic program

References

- Hayashi (Econometrica 1982) – conditions under which marginal = average Q (including taxes)
- Wildasin (IJER 1985) – same thing for multiple capitals
- Hayashi & Inoue (Handbook of R&D) – same model with capital aggregator function
Theoretical Q model

- Tobin's original $Q = \frac{V}{A}$ where $V$ is the market value of a firm and $A$ is the replacement cost.
- $Q > 1$ => invest to create more of the asset
- $Q < 1$ => divest to reduce asset
- $Q = 1$ in equilibrium
- Hayashi (1982) - the asset is indivisible
  - derived $Q$ from dynamic programming
  - gathered conditions under which marginal $Q$ is equal to average $\frac{V}{A}$
  - developed the theory with more than one capital

Practice: hedonic regression

\[ V(A, K_0, K_1) = b_0 + b_1 K_0 + b_2 K_1 \]

Linear approx: $\log V = \log b_0 + \log(b_1 + b_2 K_0 / A)$

Non-linear: $\log Q_0 = \log b_1 + \log(1 + K_0 / A)$

$Q_0 = V / A$ is Tobin's $q$

$K_0 / A$ is ratio of intangible innovation assets to tangible

$\delta = \text{relative shadow value of K assets}$

+$Q = 1$ if depreciation correct, investment strategy optimal, and no adjustment costs.

Typical firm's balance sheet

<table>
<thead>
<tr>
<th>Assets (denominator)</th>
<th>Liabilities (numerator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property, plant, &amp; equipment</td>
<td>Common stock</td>
</tr>
<tr>
<td>Inventories</td>
<td>Preferred stock</td>
</tr>
<tr>
<td>Investments in other firms</td>
<td>Long term debt; bonds</td>
</tr>
<tr>
<td>Short term financial assets; cash; receivables</td>
<td>Short term debt; bank loans; payables</td>
</tr>
<tr>
<td>Good will; booked investment in intangibles</td>
<td>Subordinated debt; other financial claims</td>
</tr>
<tr>
<td>Intangible not on balance sheet</td>
<td>Owner's equity (residue)</td>
</tr>
</tbody>
</table>

What belongs in the value eq?

Only the assets (resource base) of the firm
- Physical capital ($A$)
- Knowledge capital ($K$), including IT capital such as software
- Purchased intangibles ($I$)
- Reputational capital, brand name value (stock of advertising)
- Human capital, to the extent that it is not captured in wages
- Other infrastructural capital, such as the existence of a distribution network

Not such things as growth in sales or profitability unless they are used as proxies for left-out types of capitals (similarly for fixed effects)

Constructing innovation stocks

\[ K_t = (1 + \delta) K_{t-1} + R_t \]

where $K_t$ = knowledge stock at end of period $t$

$R_t$ = flow of innovation investment during $t$

$\delta$ = depreciation rate of $K_t$ usually $= 15$

If $R$ grows at a constant rate $g$ over time, then

\[ K_t = R_t (1 + g) \delta \]

<table>
<thead>
<tr>
<th></th>
<th>Used</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g$</td>
<td>5%</td>
<td>15%</td>
</tr>
<tr>
<td>$\delta$</td>
<td>5%</td>
<td>15%</td>
</tr>
<tr>
<td>$\gamma K_t$</td>
<td>5%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Empirical evidence

- Industry aggregates - industries with high $Q$ have high R&D intensity
- Firm-level
  - Functional form?
  - Changes over time
Log of Tobin’s Q

\[ \log Q = 0.58 + 0.40 \log(K/A) \]

Median Q versus Median K/A by Industry

LogQ = 0.58 + 0.40 log(K/A)

Median Q and K/A for selected industries in US

<table>
<thead>
<tr>
<th>Industry</th>
<th>K/A</th>
<th>Q/V/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pharmaceuticals</td>
<td>3.99</td>
<td>8.92</td>
</tr>
<tr>
<td>Computer software</td>
<td>2.92</td>
<td>8.61</td>
</tr>
<tr>
<td>Computing equipment</td>
<td>1.44</td>
<td>3.68</td>
</tr>
<tr>
<td>Medical instruments</td>
<td>0.96</td>
<td>3.81</td>
</tr>
<tr>
<td>Autos</td>
<td>0.18</td>
<td>1.65</td>
</tr>
<tr>
<td>Printing &amp; publishing</td>
<td>0.15</td>
<td>2.08</td>
</tr>
<tr>
<td>Rubber &amp; plastics</td>
<td>0.15</td>
<td>1.81</td>
</tr>
<tr>
<td>Telecommunication services</td>
<td>0.12</td>
<td>2.27</td>
</tr>
<tr>
<td>Food &amp; tobacco</td>
<td>0.09</td>
<td>2.16</td>
</tr>
<tr>
<td>Primary metals</td>
<td>0.06</td>
<td>1.28</td>
</tr>
<tr>
<td>Lumber &amp; wood</td>
<td>0.04</td>
<td>1.14</td>
</tr>
</tbody>
</table>

A Puzzle?

- Compare changes 1972-1999
  1. Market value of R&D capital using hedonic model
  2. Revenue productivity of R&D capital
  3. Average R&D to sales ratio

Results

1. Market value declines during 1980s from 1 to around .2
2. R&D productivity increases steadily from .02 to .10
3. Firms investment rate jumps during 1980s from .02 to .04.

Why?

- Relationship between firm-level (revenue) productivity and aggregate productivity
- R&D is cumulative, creates “knowledge”
- Decay of useful knowledge not the same as decay of private returns from that knowledge
- How to measure and account for this fact in our models?