Measuring the returns to innovation (1)

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Globelics Academy
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Outline

Today
1. Overview – measuring the returns to innovation
2. Measuring the returns to R&D using productivity regressions
3. Measuring the private returns to R&D using market value equations

Tomorrow
1. Measuring innovation using patent data
2. Innovation survey data
Why is this an interesting problem?

To economists
- Test models of innovation and growth, e.g., are there spillovers?
- Advise policy makers

To managers
- Allocation of resources for invention
- Measure results of innovation

To accountants
- Accurate reporting of intangible value in company accounts

To policy makers
- How to increase innovative activity?
- How much to spend; what policy instrument to use? How to choose the level of subsidy?
- Evaluation of results of policy
Framework

Investment in innovation (R&D, training, etc.) creates an asset which pays off in the future
- At the firm (enterprise) level, asset tends to become less productive over time (it depreciates)

At the industry/country/world level, individual investments in innovation create an aggregate “knowledge” asset
- Aggregate knowledge depreciates more slowly
- Even when private firms no longer earn returns from an innovation, the knowledge they have created remains useful
Overall framework

- Innovation investment \( R \) at time \( t = R_t \)
- Innovation asset \( K_t = f(R_t, R_{t-1}, R_{t-2}, \ldots) \)

Gross rate of return \( \rho \equiv \frac{\partial PDV(\pi(K_t))}{\partial K_t} \frac{\partial f(R_t, R_{t-1}, R_{t-2}, \ldots)}{\partial R_t} \)

Net rate of return \( \equiv \rho - \delta \)

where \( PDV = \) present discounted value
\( \delta = \) depreciation of innovation assets
\( \pi(K) = \) profits or welfare given \( K \)
Map of innovation inputs and outputs

Market structure and industry; appropriability environment; Government institutions

Demand pull (taste, market size) Tech. opportunity (science base)

Firm size and market share, diversification, and experience

R&D and other innovation investments

Knowledge firm-level capital created by innovation investment

Economy-wide knowledge

Economy-wide knowledge

Innovation output

Innovative sales

Outcomes: Productivity, Profitability, Value, and Economic Growth

Patents, other IPR

Physical capital Worker skills

Diffusion process
Input measures

- **R&D spending**
  - within firm
  - alliance and joint venture participation

- **Purchase of new capital equipment**
  - important for small firm innovation

- **Technology purchases/licensing**

- **Marketing related to new products**

- **Training and education of workers**

- **Spillover variables**
  - Based on geography or technology

- **CIS 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

- CIS – 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 (Schankerman-Pakes)
- Surveys (Harhoff, Scherer, Vopel)

Firm level
- Profits or revenue productivity (not intertemporal)
- 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 (Griliches, etc.)
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)
- 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?
- Conventional measures exclude much of the benefit of government R&D – space, 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)

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

where \( L = \) labor
\( C = \) capital
\( K = \) research or knowledge capital
\( u = \) random shock

\[ K_t = (1 - \delta)K_{t-1} + R_t \]
Productivity approach (2)

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

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

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

Econometrics:

The error $u$ may possibly be correlated with the current (and future) input levels.

The firm effect $\eta$ may also be correlated with input levels.
Alternative formulations

Differencing 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 version:

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

\[ \Rightarrow \gamma \Delta k_{it} \approx \left( \gamma \frac{Y_{it}}{K_{it}} \right) \frac{R_{it}}{Y_{it}} = \rho \frac{R_{it}}{Y_{it}} \]

where \( \rho = \frac{\partial Y_{it}}{\partial K_{it}} \), the gross rate of return to R&D capital
Alternative formulations

Partial or total factor productivity:

Partial: \( \Delta y_{it} - \hat{\alpha} \Delta l_{it} = \Delta \lambda_t + \beta \Delta c_{it} + \gamma \Delta k_{it} + \Delta u_{it} \)

Total: \( \Delta y_{it} - \hat{\alpha} \Delta l_{it} - \hat{\beta} \Delta c_{it} = \Delta \lambda_t + \gamma \Delta k_{it} + \Delta u_{it} \)

Where \( \alpha \) and \( \beta \) may be estimated using factor shares at the firm level (when available).

This approach often combined with the R&D intensity approach.

Note the change in the assumptions on \( u \) required for consistency.
Some measurement issues

- Often we have only sales, and not value added nor materials
  - Assume materials share constant across time for each firm
  - Result is that coefficients are inflated by (1-share of materials) – confirmed in practice
- Double counting of R&D (Schankerman 1981)
  - R&D expenditure is also in labor and capital
  - Under simple assumptions, elasticity is downward biased by share of R&D in growth of labor/capital
- Effects of choice of deflators (input and output)
Simultaneity

Sources of endogeneity:

- Inputs and output chosen simultaneously; favorable productivity 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, in particular GMM for panel data
### French Firms 1981-1989

#### Sales vs Value added

<table>
<thead>
<tr>
<th>Dep var</th>
<th>Log S</th>
<th>Log VA</th>
<th>(1-.74)*VA Coeff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log C</td>
<td>0.043 (.002)</td>
<td>0.193 (.008)</td>
<td>0.050</td>
</tr>
<tr>
<td>Log K</td>
<td>0.024 (.001)</td>
<td>0.092 (.004)</td>
<td>0.024</td>
</tr>
<tr>
<td>Log L</td>
<td>0.193 (.005)</td>
<td>0.699 (.012)</td>
<td>0.183</td>
</tr>
<tr>
<td>Log M</td>
<td>0.735 (.004)</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>0.995</td>
<td>0.984</td>
<td>0.257</td>
</tr>
</tbody>
</table>

**R²** | .993 | .926 |
**s.e.** | .115 | .349 |

*Source: Mairesse and Hall 1999*
197 French firms 1980-1987

Pooled OLS estimates

<table>
<thead>
<tr>
<th></th>
<th>Double counting</th>
<th>Partial Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unadjusted</td>
<td>Adjusted</td>
</tr>
<tr>
<td>Log(C/L)</td>
<td>.21 (.01)</td>
<td>.20 (.01)</td>
</tr>
<tr>
<td>Log(K/L)</td>
<td>.18 (.01)</td>
<td>.25 (.01)</td>
</tr>
<tr>
<td>logL</td>
<td>-.03 (.01)</td>
<td>-.04 (.01)</td>
</tr>
<tr>
<td>R²</td>
<td>.996</td>
<td>.996</td>
</tr>
<tr>
<td>s.e.</td>
<td>.336</td>
<td>.344</td>
</tr>
</tbody>
</table>

Source: Hall and Mairesse 1995
## French Firms 1981-1989

<table>
<thead>
<tr>
<th></th>
<th>Dep Var = log(Y/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Log C/L</td>
<td>.20 (.01)</td>
</tr>
<tr>
<td>Log K/L</td>
<td>.25 (.01)</td>
</tr>
<tr>
<td>Log L</td>
<td>-.04 (.01)</td>
</tr>
<tr>
<td>R²</td>
<td>.996</td>
</tr>
<tr>
<td>s.e.</td>
<td>.344</td>
</tr>
</tbody>
</table>

**Source:** Hall and Mairesse 1995

**Note:** all estimates are inconsistent if RHS vars not strictly exogenous; within are probably least biased.
Approximate rate of return

\[ \frac{\partial Y}{\partial R} = \gamma \frac{Y}{R} \]

Large R&D-doing manufacturing firms

<table>
<thead>
<tr>
<th>Country</th>
<th>Measure</th>
<th>Y</th>
<th>R/Y</th>
<th>γ</th>
<th>dY/dR</th>
</tr>
</thead>
<tbody>
<tr>
<td>France (1981-1989)</td>
<td>VA</td>
<td>4%</td>
<td></td>
<td>.069</td>
<td>1.72</td>
</tr>
<tr>
<td>UK (1988-1996)</td>
<td>Sales</td>
<td>2.42%</td>
<td></td>
<td>.065</td>
<td>3.30</td>
</tr>
<tr>
<td>Germany (1988-96)</td>
<td>Sales</td>
<td>5.84%</td>
<td></td>
<td>.079</td>
<td>1.35</td>
</tr>
<tr>
<td>US (1990-1998)</td>
<td>Sales</td>
<td>8.00%</td>
<td></td>
<td>.118</td>
<td>1.48</td>
</tr>
<tr>
<td>Chile (1998)</td>
<td>VA</td>
<td>1.5%</td>
<td></td>
<td>.131</td>
<td>8.7</td>
</tr>
</tbody>
</table>
Output deflation at the firm level

Interpreting productivity growth regressions at the firm level:

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

versus

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

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

\[ \gamma_S = \gamma_Y + \gamma_P \]
Firm stock market value

Measurement of *private* returns to investment in innovation
Why market value?

- Returns to innovation are the profits earned in the future from investments made today.
- Firm value on financial markets is a 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.
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 (AER 1982) – same thing for multiple capitals
- Hayashi & Inoue (Econometrica 1991) – same model with capital aggregator function
Theoretical Q model

- Tobin’s original $Q = \frac{V}{A}$ = ratio of the market value $V$ of a (unique) asset to its replacement cost $A$
  - $Q>1$ => invest to create more of the asset
  - $Q<1$ => disinvest to reduce asset
  - $Q=1$ in equilibrium

- Hayashi (1982) - the asset is a firm
  - derived $Q$ from the firm’s dynamic program
  - gave conditions under which marginal $Q$ ($\frac{dV}{dA}$) equal to average ($\frac{V}{A}$)

  - developed the theory with more than one capital
  - See Hall 2004 for application here
**Practice: hedonic regression**

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

*Linear approx:*

\[ \log V_{it} - \log A_{it} = \log Q_{it} = \log b_t + \gamma K_{it}/A_{it} \]

*Non linear:*

\[ \log Q_{it} = \log b_t + \log(1+\gamma_t K_{it}/A_{it}) \]

\( Q_{it} = V_{it}/A_{it} \) is Tobin’s \( q \)

\( b_t \) = overall market level (approximately one)

\( K_{it}/A_{it} \) = ratio of intangible innovation assets to tangible

\( \gamma_t \) = relative shadow value of \( K \) assets

(\( \gamma = 1 \) 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>Intangibles not on balance sheet</td>
<td>Owner’s equity (residual)</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?*).  

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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 \( K \), usually = 15%

If \( R \) grows at a constant rate \( g \) over time, then

\[ K_t \approx \frac{R_t}{(\delta+g)} \]

\[ \Rightarrow \text{Low coefficient on } K \text{ or } R \text{ may imply } \delta \gg 0.15 \]
Empirical evidence

- Industry aggregates - industries with high Q have high R&D intensity
- Firm-level
  - Functional form?
  - Changes over time
Median Q versus Median K/A by Industry

LogQ = 0.58 + 0.40 log(K/A)

Pharmaceuticals
Computer software
# Median Q and K/A for selected industries

<table>
<thead>
<tr>
<th>Industry</th>
<th>K/A</th>
<th>V/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pharmaceuticals</td>
<td>3.39</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 and publishing</td>
<td>0.15</td>
<td>2.08</td>
</tr>
<tr>
<td>Rubber &amp; plastics</td>
<td>0.15</td>
<td>1.61</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>
Relative Market Value of R&D Stock - U. S. Manufacturing Sector

Year

K/A Coefficient
0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40

Loose trim (.1<q<10; KA<5)  Tight trim (.2<q<5; KA<1)
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?
U. S. Trends in R&D Productivity

R&D in U.S. Manufacturing

Year

Coefficient or ratio


R&D Productivity
Average R&D Intensity
Market Value of R&D
Some open questions

- Relationship between firm-level (revenue) productivity and aggregate productivity

- Puzzles
  - Has the productivity of R&D declined?
  - How do we reconcile
    - R&D intensity and R&D growth versions of production function?
    - Market value and productivity versions of rate of return computation?
    - Firm and industry results?

- R&D Stock computation
  - 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?