The Market Value of R&D: theory and empirics

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London
The context

- Valuing or pricing innovation at the firm level
  - Possible input measures: R&D, patent counts, patents weighted by citations
  - Possible output measures: patents, profits, revenue productivity
- But, innovation returns are intertemporal and also uncertain
  - Forward-looking measure - the market value of the firm
  - Griliches 1981, followed by a long list of others
Large Literature

- Economics of innovation - US
  - Ben-Zion 84, Jaffe 86, Cockburn & Griliches 87
  - Griliches, Pakes, & Hall 87, Hall 93a,b
  - Megna & Klock 93, Thompson 93, Hunt 96
  - Darby et al 04

- Economics of innovation – Europe & Australia
  - Blundell et al 95, Bosworth & Rogers 01
  - Toivanen et al 02, Hall & Oriani 04, Greenhalgh & Rogers 04

- Accounting for intangibles
  - Connolly et al 86, Connolly & Hirschey 88, 90
  - Chauvin & Hirschey 93, 97, Johnson & Pazderka 93
  - Hirschey et al 98, Lev 02
Outline

- Brief overview of previous work
- A theoretical model to aid interpretation
- New results on European data
  - Hall and Oriani (2004)
What have we learned?

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

- What functional form should we use for the market value equation?
- What variables belong on the right hand side?
  - What about unobservable firm effects?
- How should we interpret the variations in the shadow value of R&D over time?
  - Most likely cause is ex post obsolescence, but how to measure this
- Reduced form? Or correct for endogeneity?
Functional Form

Next two slides – Kernel regression of
- Log Q on K/A
- Log Q on Log (K/A)
where Q = V/A
V = total market value of the firm
K = R&D stock of the firm (nominal)
A = Tangible assets of the firm (nominal)

Conclusions:
over the central range of the data, log linear is a reasonable approximation
In the tails (K/A<.01 or K/A>1) relationship is flatter
Theory – model profit-maximizing firm with 2 assets
Kernel regression - semilog

Figure B1
Kernel regression for log Q on K/A (year means removed)
Kernel regression – log-log

Figure B2
Kernel Regression of LogQ on Log(K/A)
“Theory”

**Ideal:** model investment in tangible and knowledge (intangible) assets under uncertainty using a dynamic program for the firm. Obtain a value function of the assets (state variables) of the firm.

**Common practice:** use a first order approximation to the value of the assets
Usual hedonic regression for market value

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

Non linear:  \[ \log V_{it} - \log A_{it} = \log Q_{it} = \log b_t + \log(1+\gamma_t K_{it}/A_{it}) \]

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

Interpretation:
- \( Q_{it} = V_{it}/A_{it} \) is Tobin’s \( q \)
- \( b_t = \) overall market level (approximately one).
- \( \gamma_t = \) Relative shadow value of \( K \) assets
  - \( (\gamma = 1 \text{ if depreciation correct, investment strategy optimal, and no adjustment costs } \Rightarrow \text{ no rents}). \)
Theoretical Q model (1)

- Tobin’s original Q = 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 (dV/dA) equal to average (V/A)

  - developed the theory with more than one capital
Theoretical Q model (2)

- Using the capital aggregator approach of Hayashi-Inoue, can show that

\[ V_t(\tilde{A}_t, \tilde{K}_t; s_t) = p_t^l (1 - \delta_t) \tilde{A}_t + p_t^R (1 - \delta_R) \tilde{K}_t + Q(s_t) \Phi(\tilde{K}_t, \tilde{A}_t) \]

- \( p_t^l (1 - \delta_t) \tilde{A}_t \) and \( p_t^R (1 - \delta_R) \tilde{K}_t \) are the end of period replacement values of the two assets A and K.

- \( \Phi(K_t, A_t) \) is the capital aggregator index under constant returns, constructed using the costs of the two capitals.

- \( s_t \) is the exogenous shock process (a vector of prices, demand, the macro economy, etc.)

- \( Q(s_t) \) is an index that summarizes the shocks (=0 in equilibrium)
Theoretical Q Model (3)

\[ V_t(\tilde{A}_t, \tilde{K}_t; s_t) = \rho_t' (1 - \delta_t) \tilde{A}_t + \rho_t^R (1 - \delta_R) \tilde{K}_t + Q(s_t) \Phi(\tilde{K}_t, \tilde{A}_t) \]

use \( \Phi(\tilde{K}_t, \tilde{A}_t) = \phi(\tilde{K}_t / \tilde{A}_t) \tilde{A}_t \)

\[ \Rightarrow Q_t = \frac{V_t}{\rho_t' \tilde{A}_t} = 1 - \delta_t + \frac{(1 - \delta_R) \rho_t^R \tilde{K}_t}{\rho_t' \tilde{A}_t} + \frac{Q(s_t)}{\rho_t'} \phi(\tilde{K}_t / \tilde{A}_t) \]

If the capital aggregator is approximately linear in \( \tilde{K} / \tilde{A} \):

\[ Q_t = 1 + \phi_0 \frac{Q(s_t)}{\rho_t'} + \left[ 1 - \delta_R + \frac{\phi_1 Q(s_t)}{\rho_t^R} \right] \frac{\rho_t^R \tilde{K}_t}{\rho_t' \tilde{A}_t} \]

or \( Q_t = q_t + \gamma_t \frac{K_t}{A_t} \)
Phi(K/A) vs (K/A)
US Manufacturing 1981-2001

Kernel regression
Linear regression
Implications

- End of period capital should incorporate depreciation
- Both intercept and slope contain a term due to supranormal rents
- The slope of K/A contains three terms:
  - $1$ (equilibrium value)
  - Depreciation $\delta$ (negative)
  - Rents $\phi_1 Q(s)/p^R$ (positive)
- Cannot be identified separately unless
  - $\phi$ is nonlinear in K/A OR
  - add more information (for example, current R&D)
# Results – US Manufacturing

9900 observations; 1500 firms

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K/A only</td>
<td>K/A</td>
<td>Phi(K/A)</td>
</tr>
<tr>
<td>1981-1985</td>
<td>1.58 (.13)</td>
<td>1.31 (.03)</td>
<td>-.86 (.10)</td>
</tr>
<tr>
<td>1986-1990</td>
<td>1.04 (.09)</td>
<td>1.12 (.05)</td>
<td>-.60 (.15)</td>
</tr>
<tr>
<td>1991-1995</td>
<td>0.78 (.06)</td>
<td>1.03 (.03)</td>
<td>-.65 (.04)</td>
</tr>
<tr>
<td>1996-2000</td>
<td>0.87 (.06)</td>
<td>0.97 (.03)</td>
<td>-.44 (.04)</td>
</tr>
</tbody>
</table>
Hall-Oriani (2004)

- No previous studies of the market value of innovation for many countries in the European Union (e.g., France, Germany, and Italy)
- Capital markets in these countries are different from those of Anglo-Saxon countries
  - looser discipline exerted by public stock markets
  - much lower share of institutional ownership
  - higher propensity for long-term investments?
- => Related data problems for these countries
  - lower number of publicly traded firms
  - no accounting requirement for R&D disclosure
Our empirical approach

- New database of firm-level data for a panel of manufacturing firms publicly-traded in France, Germany and Italy
- Data on comparable samples for the UK and US
- Hedonic valuation model based on prior work
  - Market value (price) of firm as a function of its assets (characteristics)
- Explore some econometric issues in estimation
  - Sample selection estimation to correct for selection biases
  - Possible presence of firm-specific effects
Findings

- **Econometrics:**
  - Sample selection matters very little
    - Process generating R&D reporting ignorable
  - Firm effects not correlated for Germany, France, and Italy
    - Low power because of small sample size?

- **Substantive:**
  - R&D capital valued positively by the market with a coefficient of about 0.3/0.4 in France, Germany, US
    - higher in UK; lower in Italy?
  - For non-R&D firms, majority control earns a premium in France and Italy (around 15-30%) but not in Germany
  - For R&D firms in France and Italy, R&D is discounted substantially (to about zero) if majority controlled
    - Lesser discount for Germany
New panel of publicly traded firms from 1989 to 1998, with and without data on R&D

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Firms</th>
<th>Share of Industrial R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>127</td>
<td>50.6%</td>
</tr>
<tr>
<td>Germany</td>
<td>283</td>
<td>63.6%</td>
</tr>
<tr>
<td>Italy</td>
<td>86</td>
<td>71.2%</td>
</tr>
<tr>
<td>UK</td>
<td>592</td>
<td>92.2%</td>
</tr>
<tr>
<td>US</td>
<td>1366</td>
<td>57.8%</td>
</tr>
</tbody>
</table>
Variables in our model

- **Dependent variable Q = V/A**
  - V = Market value of equity + outstanding debt
  - A = Book value of physical capital and inventories

- **R&D capital K**
  - Perpetual inventory of the past and present annual R&D expenditures with a constant depreciation rate (15%) and alternative initial growth rates

- **Control variables**
  - I = Other intangible assets
  - log sales (size proxy) – could use log assets
  - year dummies
### OLS and NLLS results:

#### Coefficients of R&D capital (K)

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>UK</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OLS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>.28***</td>
<td>.33***</td>
<td>.01</td>
<td>.88***</td>
<td>.33***</td>
</tr>
<tr>
<td><strong>NLLS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>.41***</td>
<td>.36***</td>
<td>-.14</td>
<td>1.94***</td>
<td>.80***</td>
</tr>
<tr>
<td><strong>Avg. Slope (S.D.)</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>.28 (.06)</td>
<td>.44 (.07)</td>
<td>.14 (.01)</td>
<td>1.45 (.27)</td>
<td>.46 (.11)</td>
</tr>
</tbody>
</table>

The average slope is the derivative of logQ wrt K/A for the nonlinear model, averaged over the data.

No relevant differences appear when K is calculated using alternative initial growth rates.
**Majority shareholder effect**

- Control = majority shareholder with >33% of ownership of firm

<table>
<thead>
<tr>
<th>Country</th>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Share of R&amp;D firms</td>
<td>57%</td>
<td>47%</td>
<td>55%</td>
</tr>
<tr>
<td>Premium for control</td>
<td>.42***</td>
<td>.11</td>
<td>.32***</td>
</tr>
<tr>
<td>Baseline R&amp;D coeff. (no control)</td>
<td>.66***</td>
<td>.56***</td>
<td>.94***</td>
</tr>
<tr>
<td>R&amp;D discount for control</td>
<td>-.56**</td>
<td>-.37***</td>
<td>-1.00***</td>
</tr>
</tbody>
</table>
Estimation issues

- Some continental European firms do R&D but do not report it.
  - Build a model of selection into the sample and estimate jointly with the valuation equation
- Permanent differences across firms that are correlated with R&D (so shadow value $\gamma$ may be mismeasured)
  - Use panel data methods
Sample selection

- Censored regression model (generalized tobit) with a stochastic threshold (Maddala, 1983; Hall 1987 for firm size and growth)
  - Regression equation for observed data
  - Probit equation for selection into sample
  - Disturbances allowed to be correlated
  - Test for normality using OLS regression with Heckman terms (lambda, lambda*P, ….)
Explaining R&D reporting

- Lack of R&D data for US or UK firms means
  - The firm did not do “material” R&D
- Lack of R&D data for continental firms - either
  - the firm did not do R&D or
  - it did not report R&D
- Predictor variables used:
  - Debt (D) to assets ratio (leverage)
  - Log sales (size)
  - Industry R&D intensity
  - Industry growth
  - Whether the majority owner had >50% of the firm
  - Year dummies
### Sample selection: Probit for reporting R&D

<table>
<thead>
<tr>
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<th>UK</th>
<th>US</th>
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</thead>
<tbody>
<tr>
<td><strong>D/A</strong></td>
<td>.092*</td>
<td>.050***</td>
<td>-.059</td>
<td>-.037</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td>(.051)</td>
<td>(.022)</td>
<td>(.081)</td>
<td>(.047)</td>
<td>(.009)</td>
</tr>
<tr>
<td><strong>Log Sales</strong></td>
<td>.081***</td>
<td>.052***</td>
<td>.112***</td>
<td>.084***</td>
<td>.050***</td>
</tr>
<tr>
<td></td>
<td>(.008)</td>
<td>(.003)</td>
<td>(.011)</td>
<td>(.004)</td>
<td>(.003)</td>
</tr>
<tr>
<td><strong>Industry R&amp;D intensity</strong></td>
<td>1.46***</td>
<td>1.58***</td>
<td>4.28***</td>
<td>4.61***</td>
<td>3.19***</td>
</tr>
<tr>
<td></td>
<td>(.32)</td>
<td>(.13)</td>
<td>(.91)</td>
<td>(.41)</td>
<td>(.12)</td>
</tr>
<tr>
<td><strong>Industry growth rate</strong></td>
<td>-.04</td>
<td>.34***</td>
<td>.41</td>
<td>.75***</td>
<td>.72***</td>
</tr>
<tr>
<td></td>
<td>(.38)</td>
<td>(.11)</td>
<td>(.27)</td>
<td>(.14)</td>
<td>(.10)</td>
</tr>
<tr>
<td><strong>D (control)</strong></td>
<td>.01</td>
<td>-.02**</td>
<td>-.09***</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>(.03)</td>
<td>(.01)</td>
<td>(.03)</td>
<td>--</td>
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</tr>
<tr>
<td><strong>Total obs.</strong></td>
<td>1145</td>
<td>2688</td>
<td>685</td>
<td>4723</td>
<td>10892</td>
</tr>
<tr>
<td><strong>Positive obs.</strong></td>
<td>308</td>
<td>337</td>
<td>239</td>
<td>2010</td>
<td>6995</td>
</tr>
<tr>
<td><strong>Pseudo R-squared</strong></td>
<td>.18</td>
<td>.25</td>
<td>.30</td>
<td>.23</td>
<td>.14</td>
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</table>
Sample selection: Coefficients of R&D capital (K)

<table>
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<tr>
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<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>K/A</td>
<td>.68***</td>
<td>.38***</td>
<td>.73***</td>
<td>.90***</td>
<td>.28***</td>
</tr>
<tr>
<td></td>
<td>(.19)</td>
<td>(.03)</td>
<td>(.26)</td>
<td>(.11)</td>
<td>(.02)</td>
</tr>
<tr>
<td>Control*(K/A)</td>
<td>-0.49**</td>
<td>-0.17</td>
<td>-0.89***</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>(.20)</td>
<td>(.10)</td>
<td>(.21)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>I/A</td>
<td>.69***</td>
<td>.94***</td>
<td>1.17***</td>
<td>.59***</td>
<td>.60***</td>
</tr>
<tr>
<td></td>
<td>(.14)</td>
<td>(.14)</td>
<td>(.28)</td>
<td>(.08)</td>
<td>(.04)</td>
</tr>
<tr>
<td>Control</td>
<td>.49***</td>
<td>-.04</td>
<td>.23***</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>(.11)</td>
<td>(.07)</td>
<td>(.07)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>Estimated rho</td>
<td>.53</td>
<td>.00</td>
<td>.05</td>
<td>.08</td>
<td>-.05</td>
</tr>
<tr>
<td></td>
<td>(.37)</td>
<td>(.20)</td>
<td>(.14)</td>
<td>(.16)</td>
<td>(.06)</td>
</tr>
</tbody>
</table>

Other variables in equation: log sales, year dummies
Panel data estimation

- **Random effects** – differences across firms that introduce serial correlation within firm, but are not related to R&D-value relation

- **Fixed effects** - differences across firms that are correlated with R&D
  - Within (LSDV) – inconsistent if R&D not strictly exogenous with respect to market value
  - First differences
    - possibly more downward biased if measurement error (Griliches & Hausman, 1986)
    - need to use GMM for estimation, but hard to find valid instruments – unsuccessful for market value equation
Panel results:
Coefficients of R&D capital (K)

<table>
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</tr>
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<tbody>
<tr>
<td>OLS</td>
<td>.56***</td>
<td>.38***</td>
<td>.71</td>
<td>.88***</td>
<td>.33***</td>
</tr>
<tr>
<td>First differences</td>
<td>-.61</td>
<td>.26***</td>
<td>-.16</td>
<td>.16</td>
<td>.31***</td>
</tr>
<tr>
<td>Within (F. E.)</td>
<td>.26</td>
<td>.27***</td>
<td>.74</td>
<td>-.01</td>
<td>.15***</td>
</tr>
<tr>
<td>Random effects</td>
<td>.38***</td>
<td>.30***</td>
<td>.65</td>
<td>.50***</td>
<td>.22***</td>
</tr>
</tbody>
</table>

Non-correlation  | Accepted| Accepted| Accepted| Rejected| Rejected|

Other variables in regression: I/A, log sales, control, control*(K/A), year dummies
Conclusions

- Germany and France, but not Italy
  - R&D capital for firms reporting it is valued positively by the stock market with a coefficient of about .3/.4
  - Not affected by selection or left-out firm effects

- Italy and France
  - Majority control earns a premium (around 15-30%)
  - But R&D in majority controlled firms is discounted substantially (to about zero)
  - R&D in non-controlled firms has coefficient of about .6/.7

- Similar to UK and US, except
  - The OLS coefficient for the UK sample is quite a bit higher
  - confirmed by evidence on R&D productivity in UK firms (Bond, Harhoff, Van Reenen 2003)
Discussion

- European financial markets value R&D in a similar way as the US and UK, but with variations due to ownership structure
- Market valuation of R&D expenditures in all countries except UK is lower than predicted by simple theory
  - (also decreased in all the countries over time, not shown)
- Possible explanations:
  - Non-optimal R&D investments (too high)
  - Higher R&D depreciation rate
  - Lower R&D effectiveness (realized return<expected)
  - Public incentives for R&D investments
  - R&D accounting regime/intangibles
  - Short-termism of the stock market
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
  - 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 R&D stock

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

where \( K_t \) = knowledge stock at end of period \( t \)

\( R_t \) = flow of R&D during \( t \)

\( \delta \) = depreciation rate of \( K \), usually = 15%

(Varied the definition of presample growth rates)

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

\[ K_t \approx R_t / (\delta + g) \]

Example: \( K_t \approx R_t / (0.15 + 0.05) = 5R_t \)

\[ \Rightarrow \] Low coefficient on \( K \) or \( R \) may imply \( \delta \gg 0.15 \)