The Market Value of R&D: theory and empirics

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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)

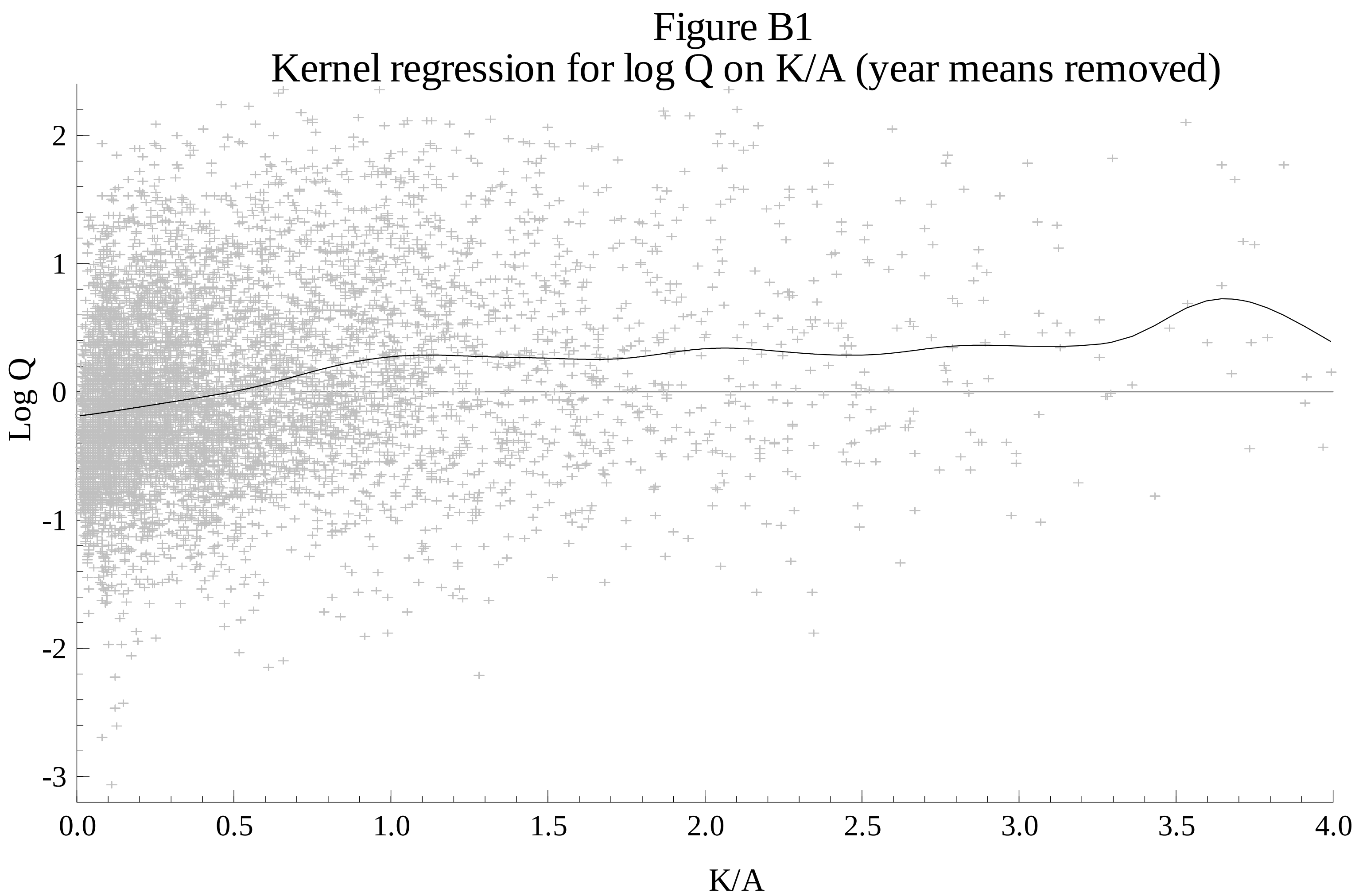
Conclusions:

over the central range of the data, log linear is a reasonable approximation

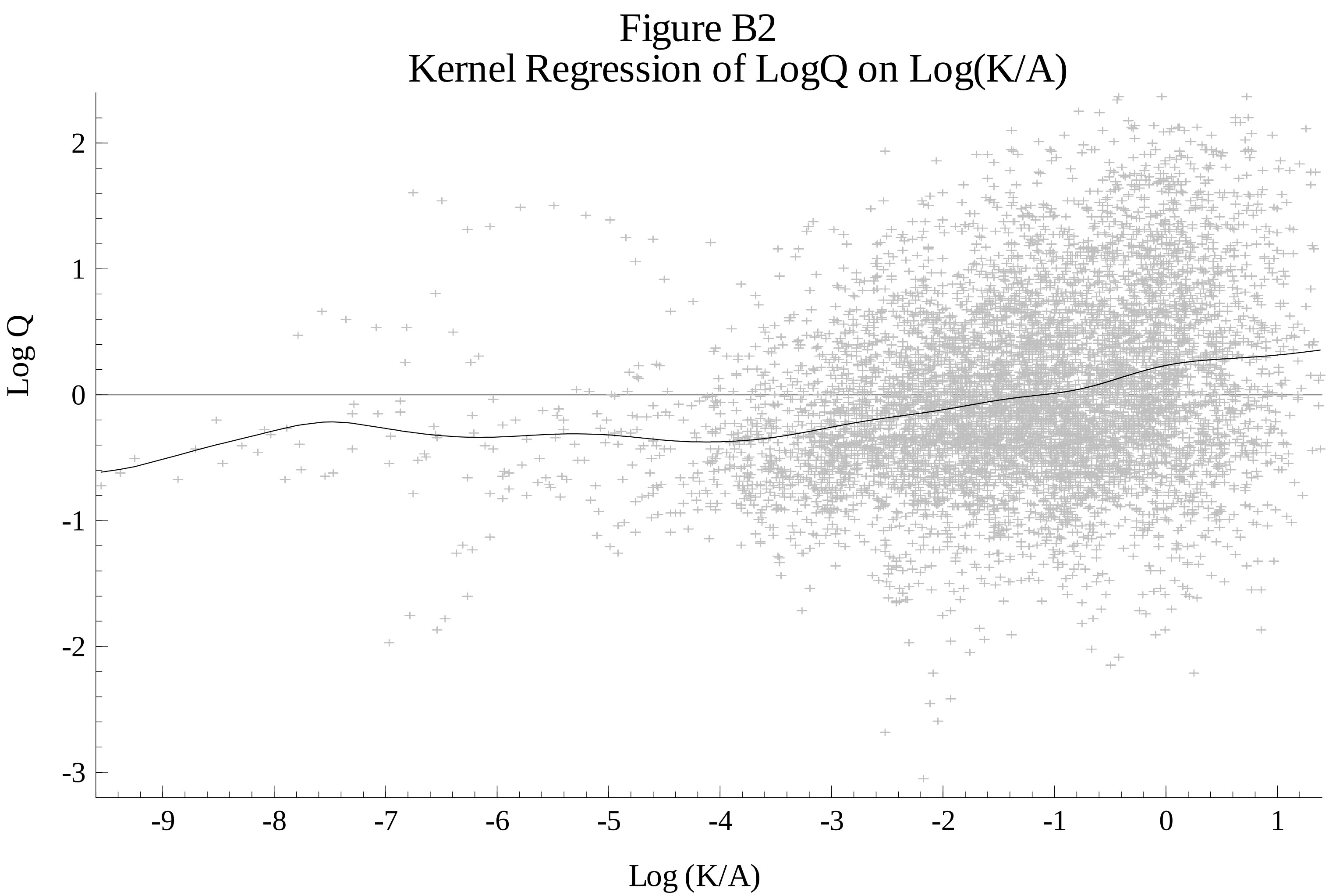
In the tails (K/A<.01 or K/A>1) relationship is flatter

Theory – model profit-maximizing firm with 2 assets

Kernel regression - semilog



Kernel regression – log-log



"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).

γ_t = Relative shadow value of K assets

(γ = 1 if depreciation correct, investment strategy optimal, and no adjustment costs => 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)
- Hayashi-Inoue (1991) and Wildasin (1984)
  - developed the theory with more than one capital

Theoretical Q model (2)

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

$$V_t(\tilde{A}_t, \tilde{K}_t; s_t) = p_t^I(1-\delta_I)\tilde{A}_t + p_t^R(1-\delta_R)\tilde{K}_t + Q(s_t)\Phi\left(\tilde{K}_t, \tilde{A}_t\right)$$

- $p_t^I(1-\delta_I)\tilde{A}_t$ 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)

$$V_t(\tilde{A}_t, \tilde{K}_t; s_t) = p_t^I(1-\delta_I)\tilde{A}_t + p_t^R(1-\delta_R)\tilde{K}_t + Q(s_t)\Phi\left(\tilde{K}_t, \tilde{A}_t\right)$$

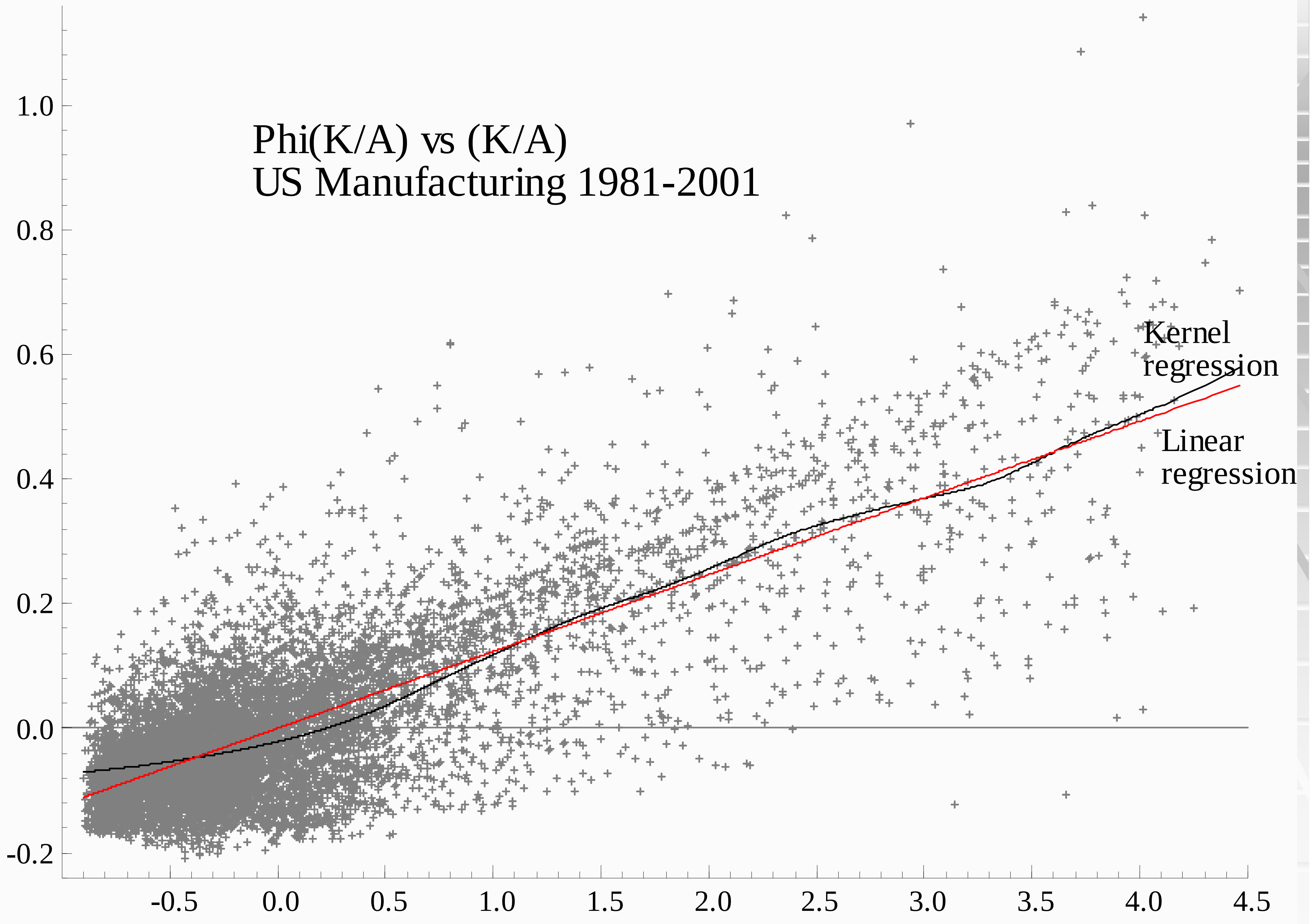
$$use \quad \Phi\left(\tilde{K}_t, \tilde{A}_t\right) = \phi\left(\tilde{K}_t / \tilde{A}_t\right)\tilde{A}_t$$

$$\Rightarrow Q_t = \frac{V_t}{p_t^I \tilde{A}_t} = 1 - \delta_I + \frac{(1-\delta_R)p_t^R \tilde{K}_t}{p_t^I \tilde{A}_t} + \frac{Q(s_t)}{p_t^I}\phi\left(\tilde{K}_t / \tilde{A}_t\right)$$

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

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

$$or \quad Q_t = q_t + \gamma_t \frac{K_t}{A_t}$$


Phi(K/A) vs (K/A)
US Manufacturing 1981-2001
Kernel regression
Linear regression
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

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 δ (negative)
  - Rents $\varphi_1 Q(s)/p^R$ (positive)
- Cannot be identified separately unless
  - φ is nonlinear in K/A *OR*
  - add more information (for example, current R&D)

Results – US Manufacturing
9900 observations; 1500 firms

	(1)	(2)		(3)	
	K/A only	K/A	Phi(K/A)	K/A	R&D/A innov.
1981-1985	1.58 (.13)	1.31 (.03)	-.86 (.10)	2.19 (.17)	7.33 (.88)
1986-1990	1.04 (.09)	1.12(.05)	-.60 (.15)	1.09 (.09)	3.46 (.41)
1991-1995	0.78 (.06)	1.03 (03)	-.65 (.04)	0.78 (.07)	2.43 (.37)
1996-2000	0.87 (.06)	0.97 (.03)	-.44 (.04)	0.81 (.06)	2.62 (.27)

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

Data

New panel of publicly traded firms from 1989 to 1998, with and without data on R&D

Country	Number of Firms	Share of Industrial R&D
France	127	50.6%
Germany	283	63.6%
Italy	86	71.2%
UK	592	92.2%
US	1366	57.8%

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)

	France	Germany	Italy	UK	US
OLS	.28***	.33***	.01	.88***	.33***
NLLS	.41***	.36***	-.14	1.94***	.80***
Avg. Slope	.28	.44	.14	1.45	.46
(S.D.)	(.06)	(.07)	(.01)	(.27)	(.11)

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

NLLS Coefficient Estimate for K/A			
Country	France	Germany	Italy
Share of R&D firms	57%	47%	55%
Premium for control	.42***	.11	.32***
Baseline R&D coeff. (no control)	.66***	.56***	.94***
R&D discount for control	-.56**	-.37***	-1.00***

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 γ 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

	France	Germany	Italy	UK	US
D/A	.092* (.051)	.050*** (.022)	-.059 (.081)	-.037 (.047)	.002 (.009)
Log Sales	.081*** (.008)	.052*** (.003)	.112*** (.011)	.084*** (.004)	.050*** (.003)
Industry R&D intensity	1.46*** (.32)	1.58*** (.13)	4.28*** (.91)	4.61*** (.41)	3.19*** (.12)
Industry growth rate	-.04 (.38)	.34*** (.11)	.41 (.27)	.75*** (.14)	.72*** (.10)
D (control)	.01 (.03)	-.02** (.01)	-.09*** (.03)	--	--
Total obs.	*1145*	*2688*	*685*	*4723*	*10892*
Positive obs.	*308*	*337*	*239*	*2010*	*6995*
Pseudo R-squared	*.18*	*.25*	*.30*	*.23*	*.14*

Sample selection: Coefficients of R&D capital (K)

	France	Germany	Italy	UK	US
K/A	.68*** (.19)	.38*** (.03)	.73*** (.26)	.90*** (.11)	.28*** (.02)
Control*(K/A)	-.49** (.20)	-.17 (.10)	-.89*** (.21)	--	--
I/A	.69*** (.14)	.94*** (.14)	1.17*** (.28)	.59*** (.08)	.60*** (.04)
Control	.49*** (.11)	-.04 (.07)	.23*** (.07)	--	--
Estimated rho	.53 (.37)	.00 (.20)	.05 (.14)	.08 (.16)	-.05 (.06)

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 – unsuccesful for market value equation

Panel results: Coefficients of R&D capital (K)

	France	Germany	Italy	UK	US
OLS	$.56^{***}$	$.38^{***}$	.71	$.88^{***}$	$.33^{***}$
First differences	-.61	$.26^{***}$	-.16	.16	$.31^{***}$
Within (F. E.)	.26	$.27^{***}$	.74	-.01	$.15^{***}$
Random effects	$.38^{***}$	$.30^{***}$	.65	$.50^{***}$	$.22^{***}$
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

δ = 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 $\delta >> 0.15$