How Special is the Special Relationship?

Using the impact of US R&D spillovers on UK firms as a test of technology sourcing

John Van Reenen

London School of Economics and Centre for Economic Performance

Rachel Griffith and Rupert Harrison

IFS and UCL

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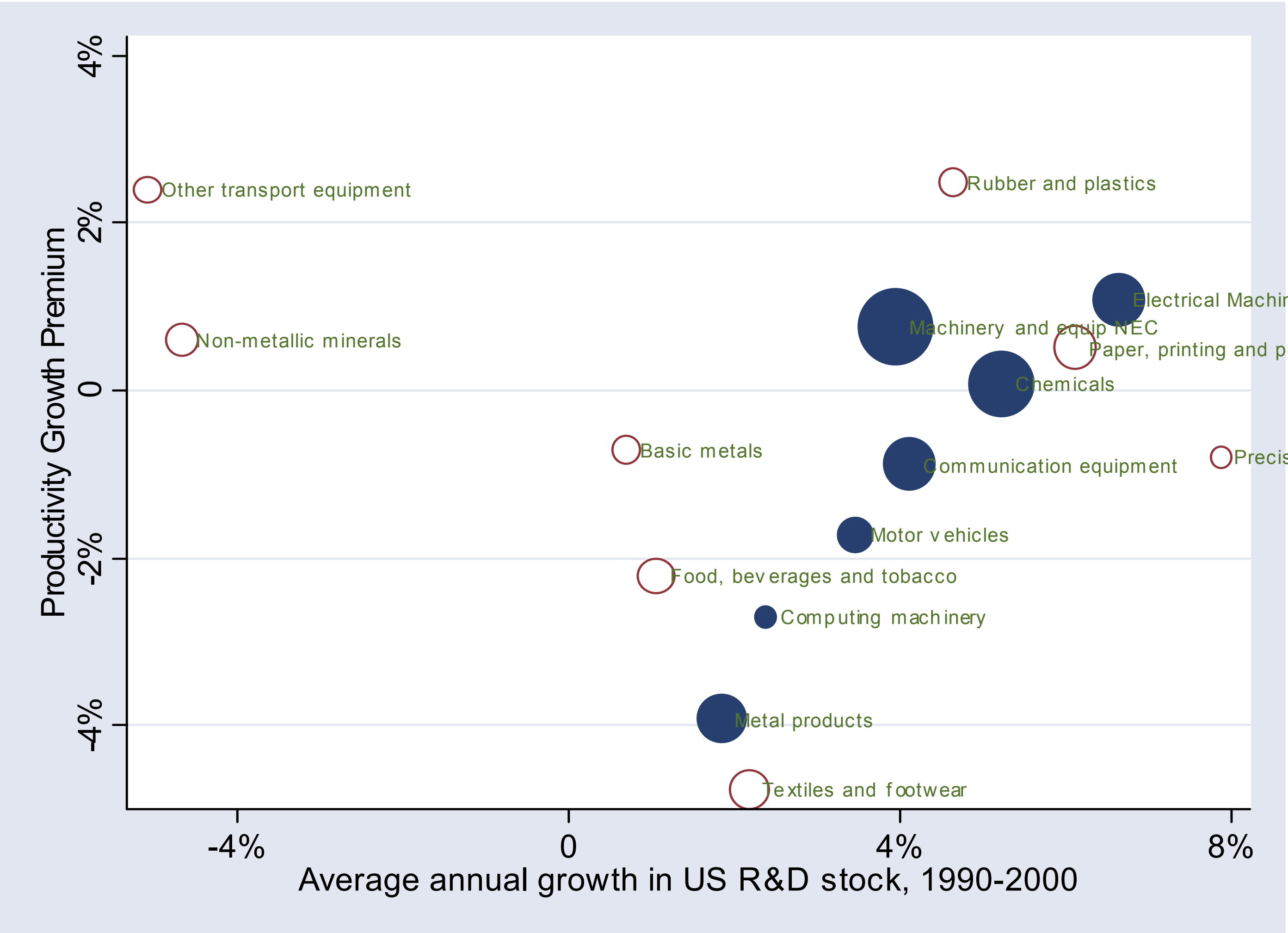
I. Introduction

- International technology transfer at the centre of economic growth but how does it occur? Micro-econometric evidence is thin
- One important mechanism is *"technology sourcing*" hypothesis – firms obtain international R&D spillovers by locating their inventors/R&D labs close to leading edge research
- *Our test:* Do UK firms with stronger inventor presence in the US benefit disproportionately from US R&D efforts? Use patent inventor for geographical location.
- *Experiment:* did UK firms with high inventor presence in the US (by 1990) benefit disproportionately from the 1990-2000 burst in US R&D?
- UK good test case for tech sourcing hypothesis
  - behind the frontier – UK about 40% lower labour productivity than US
  - But a lot of historical linkages: much inter-firm variation in UK FDI in USA
- We also perform same exercise on US firms – do they benefit from tech sourcing in the UK?

Summary

- Find evidence that UK firms benefit more from US R&D spillovers if they have strong US inventor presence
- UK manufacturing TFP (total factor productivity) would be 5% lower in 2000 without 1990s growth in US R&D
- US firms do not benefit from UK spillovers very much (i.e. statistical and economic significance is low)
- Policy relevance – EU policy makers attempted to “repatriate” R&D labs away from US (Lisbon Agenda)

Figure 1: Productivity growth premium (Difference in labour productivity growth for UK firms with high % of US inventors) and R&D growth in US industries



Note: 'High TFP gap' industries shaded

Literature on international spillover mechanisms

- **Geographical closeness.** Home bias of innovative activity (e.g. Jaffe et al, 1993 QJE; Jaffe and Trajtenberg, 2002) . But little evidence *within* firms *across* countries.
- **International trade.** Learning from importing (e.g. Coe and Helpman, 1995) or exporting (e.g. MacGavie, 2004)
- **FDI.** Mainly inward FDI (e.g. Keller and Yeaple, 2003). But we look at "outward" FDI of specific kind
- Technological sourcing evidence from patent *citations* – Bransetter (2004) on US affiliates of Japanese firms. We look at international citations *and* productivity

II. A simple model

Consider the firm level R&D augmented production Function (Griliches, 1979, 1998)

$$Y = F(X, DOMESTIC, FOREIGN)$$

Y = value added
X = firm inputs: capital, labour, R&D, etc.
DOMESTIC = domestic external knowledge pool (domestic R&D spillovers)
FOREIGN = foreign external knowledge pool (international R&D spillovers)

Foreign Spillovers $$\frac{\partial Y}{\partial FOREIGN} > 0$$

Tech sourcing: Are foreign spillovers stronger when the firm has a greater inventor presence (e.g. R&D lab) in the US (W^F)? $$\frac{\partial^2 Y}{(\partial FOREIGN)(\partial W^F)} > 0$$

Cobb Douglas Production function for firm *i* in industry *j* at time *t* in UK

Value added $$Y_{it} = A_{it} L^{\alpha_l}{}_{it} K^{\alpha_k}{}_{it} R^{\beta}{}_{it} DOMESTIC^{\gamma_{1i}}{}_{jt} FOREIGN^{\gamma_{2i}}{}_{jt}$$

labour (L), capital (K), Own R&D capital (R), UK external R&D ($DOMESTIC$), US external R&D ($FOREIGN$)

Elasticities with respect to UK and US knowledge stocks are functions of location variables:

$$\gamma_{1i} = \theta_1 + \theta_2 W_{i0}^{UK}$$

$$\gamma_{2i} = \phi_1 + \phi_2 W_{i0}^{US}$$

Proxies for proportion of R&D in US (W_{i0}^{US})

Key empirical production function

(Lower case letters are logs)

$$y_{it} = \alpha_l l_{it} + \alpha_k k_{it} + \beta r_{it} + \theta_3 W_{i0}^{UK} + \phi_3 W_{i0}^{US} + a_{it}$$
$$+ \theta_1 domestic_{jt} + \phi_1 foreign_{jt}$$
$$+ \theta_2 (W_{i0}^{UK} * domestic_{jt}) + \phi_2 (W_{i0}^{US} * foreign_{jt})$$

Test for technology sourcing – does US R&D have larger effect when greater US presence

Also do a symmetrical estimation for US firms

Direct spillover measure: Citation Equation

- Count of number of cites from patent *p* of UK firm *i* at time *t* to US inventor

$$CITES^{US}_{pit} = h(W^{US}_{i0}, W^{UK}_{i0}, x_{pit})$$

Do UK firms with strong US inventive presence disproportionately cite US inventors?

All other variables
From production
Function,
TOTALCITES,
Etc.

III. Econometrics of production functions with firm panel data

- Generic Issues
  - Endogeneity of inputs
  - Unobserved heterogeneity
  - Selection bias
  - Compare OLS, GMM (Blundell-Bond 2000) and extension of Olley Pakes (1996) for R&D (Buettner, 2004)
- Problems specific to our application
  - Endogeneity of inventor location
  - Correlation of inventor location with unobserved trends

System GMM

Equation of interest

$$y_{it} = \alpha x_{it} + a_{it}; a_{it} = \tau_t + \eta_i + u_{it}$$

1) Difference equation eliminates firm fixed effects

Moment conditions allow use of suitably lagged levels of the variables as instruments for the first differences (assuming levels error term serially uncorrelated, see Arellano and Bond, 1991)

$$E[x_{i,t-s}\Delta u_{it}] = 0$$

for $s > 1$ when $u_{it} \sim MA(0)$, and for $s > 2$ when $u_{it} \sim MA(1)$, etc.

Test assumptions using autocorrelation test and Sargan

Problem of weak instruments with persistence series…..

System GMM

2) Use lagged differences as instruments in the **levels equation**
additional moment conditions (Arellano and Bover, 1998; Blundell and Bond, 2000):

$$E[\Delta x_{i,t-s}(\eta_i + u_{it})] = 0$$

for s = 1 when u_{it} ~ MA(0), and for s = 2 when u_{it} ~ MA(1)

Requires first moments of x to be time-invariant, conditional on common year dummies

Can test the validity of the additional moment conditions

We combine both sets of moments for difference and levels equations to construct "System GMM" estimator

We assume all firm level variables are endogenous, while industry level variables are exogenous in main specifications (relax in some specifications)

Olley and Pakes (1996)

- Semi-parametric approach
- Structural model of firm behaviour. State variables are capital (deterministic) and unobserved productivity (stochastic), ω.
- Control variables are labour and investment
- Model generates an investment policy function that is strictly increasing in unobserved productivity conditional on capital. Hence invertible.
- Invertibility of investment function allows us to control non-parametrically for unobserved productivity shock. This generates a two step algorithm for estimating parameters of production function (labour's coefficient then capital)
- Buettner (2004) extend OP structural model to allow for choice of R&D (this stochastically affects the unobserved productivity state next period)
- The first step of OP algorithm still goes through, but the second step needs to be modified to allow for a second quasi-fixed input (R&D)

OP Algorithm stage 1 (labour coefficient)

$$y_{it} = \alpha_0 + \alpha_l l_{it} + \alpha_k k_{it} + \omega_{it} + \eta_{it}$$

Serially correlated productivity state

Using the invertibility of the investment function

$$y_{it} = \alpha_0 + \alpha_l l_{it} + \alpha_k k_{it} + \tilde{\omega}(i_{it}, k_{it}) + \eta_{it}$$

$$= \alpha_l l_{it} + \phi(i_{it}, k_{it}) + \eta_{it}$$

$$where\, \phi(i_{it}, k_{it}) = \phi_t = \alpha_0 + \tilde{\omega}(i_{it}, k_{it})$$

Use a series estimator to control for the unknown function and obtain consistent estimate of the labour coefficient (via OLS).

OP Algorithm stage 2 (estimate of capital coefficient)

Using the stage 1 labour coefficient

$$y_{it}^* = y_{it} - \alpha_l l_{it} = \alpha_k k_{it} + \omega_{it} + \eta_{it}$$

Using the Markov assumption on the productivity term (and Assumption that capital does not immediately adjust to productivity Innovation. Conditional on survival

$$\omega_{it} |_{\chi_{it}=1} = E[\omega_{it} | \psi_{it}, \chi_{it} = 1] + \xi_{it}$$

Productivity innovation

This is an index which determines the distribution of current productivity states.
In OP it depends only on the lagged productivity state (and shock).
Under Buettner (2004) it will also depend on past R&D decisions.

OP Stage 2-cont.

Substituting the expectation into the equation for output net of labour

$$y_{it}* = \alpha_k k_{it} + E[\omega_{it} \mid \psi_{it}, \chi_{it} = 1] + \xi_{it} + \eta_{it}$$

Using the invertibility of the R&D policy rule (*r*) we substitute out the Expectation of the unobserved current productivity state

$$y_{it}* = \alpha_k k_{it} + g(r^{-1}(r_{it-1}, \omega_{it-1})) + \xi_{it} + \eta_{it}$$

$$y_{it}* = \alpha_k k_{it} + \tilde{g}(r_{it-1}, \phi_{t-1} - \alpha_k k_{it-1}) + \xi_{it} + \eta_{it}$$

We use a series estimator to control for the unknown function g(.) to obtain Consistent estimates of the capital coefficient by NLLS

Other econometric issues

- Endogeneity of inventor location – firm with higher TFP choose to locate in US?
- Use *pre-sample* locational decisions (1975-1989) so not affected by within sample shocks.
- Also include other trends (UK R&D, UK value added, US value added,…)

IV. Data

- In order to implement our empirical strategy we need measures of:

1. The geographical location of firms' innovative activity
2. Firms' productivity performance
3. Domestic and foreign knowledge pools available to firms

Patent Data

- Patent data provides key information on the location of innovative activity
- 2 ½ million patents registered at the US Patent Office
- Manually matched to a large sample of UK parent firms
- We use all patents applied for since 1975
- Key information for our purposes is the country of the main *inventor*

Patent Citations

- We also use data on patent citations to refine our measures of the location of firms' innovative activity. We distinguish between two motivations for locating R&D abroad:
- Technology sourcing
- Adapting existing products to new markets
- We assume a patent owned by a UK firm but invented by an inventor located in the USA is more likely to be associated with technology sourcing behaviour if it cites other patents that were
  – not owned by the same firm (i.e. not self citation),
  – invented in the USA,
  – and (possibly) invented recently – more likely to be tacit

Location measures: W^{UK}, W^{US}

- **Basic location weight:**
  - The proportion of a firm's total patents where the inventor is located in the USA
- **Location and citation:**

The proportion of the firm's total patents where:

the inventor is located in the USA

the patent cites at least one other patent whose inventor was both located in the USA and did not work for the same parent firm

- **Location and citation within 3 years:**

The proportion of the firm's total patents where:

- the inventor is located in the USA
- the patent cites at least one other patent *that was applied for within the last three years* and whose inventor was both located in the USA and did not work for the same parent firm

Country of Inventor (Table 1)

Country of Inventor	(1) Number of Patents matched to our UK firms	(2) % Share of patents matched to our UK firms	(3) % Share of patents matched to our US firms	(4) % Share of all USPTO patents
UK	19,745	31.0	1.1	3.0
USA	28,731	45.1	92.3	55.7
Japan	4,411	6.9	1.5	18.8
Germany	2,481	3.9	1.3	7.9
France	1,457	2.3	0.9	3.0
Other	6,908	10.8	2.9	11.6
Total	63,733	100	100	100

Location Weight for UK firms (Table A3)

	Mean	Median	Standard Deviation	Min	Max
Total patent applications	240	40.5	657	1	5820
UK Location Weight	0.354	0.274	0.363	0	1
UK Location + Citation Weight	0.082	0.017	0.145	0	1
UK Location + Citation Within 3 Years	0.019	0.000	0.054	0	0.5
USA Location Weight	0.462	0.425	0.379	0	1
USA Location + Citation Weight	0.417	0.368	0.349	0	1
USA Location + Citation Within 3 Years	0.162	0.134	0.184	0	1

Firm Accounts Data: UK

- Firms listed on the London Stock Exchange (Datastream)
- Data covers 1968 – 2000, but R&D not regularly reported prior to 1989 – estimation 1990-2000
- "UK Firms", but data represents global activity
- Capital, labour, R&D, value added
- After conditioning on manufacturing firms performing R&D with at least five consecutive observations over 1990 – 2000, we are left with 1794 observations on 188 firms

Firm Accounts Data: US

- Compustat (all publicly listed firms)
- Hall et al (2000) match by name using subsidiaries
- Construct patent data in the same way as UK. Estimate on 1990-2000 period
- Capital, labour, R&D, sales
- 5,446 observations on 570 R&D and patenting performing firms

Spillover Pool Data

- Basic issue is constructing appropriate knowledge weighting matrix
- OECD 'ANBERD' dataset on total R&D expenditure by 2-digit manufacturing industry (ISIC Rev 3)
- We focus on manufacturing industries
- Advantages:
  - based on geographical location of R&D, allowing identification of geographical aspects of spillovers
  - covers all R&D performed in the industry, not just that of sampled firms
- Disadvantages:
  - 2-digit industries may not be a good indicator of technological proximity
  - Also some firms operate in more than one 2-digit industry
- OECD 'STAN' dataset provides aggregate value added for the same 2-digit industries

V. Results

- Table 3: OLS, GMM, OP
- Coefficient sensible on labour/capital
- Average private return to R&D c.16%
- Diagnostics OK
- Key interaction significant across all specifications
- Evidence for domestic spillovers, but not significantly greater for firms with high UK presence

Production Functions for UK firms (Table 3)

	(1)	(2)	(3)	(4)	(5)	(6)
Estimation Method	**OLS**	**OLS**	**GMM**	**GMM**	**GMM**	**Olley-Pakes**
Dependent variable	**ln (Y)** $_{it}$	**ln (Y/K)** $_{it}$	**ln (Y/K)** $_{it}$	**ln (Y/K)** $_{it}$	**ln (Y/K)** $_{it}$	**ln (Y)** $_{it}$
Company listed in:	**UK**	**UK**	**UK**	**UK**	**UK**	**UK**
Location Weight, W	Location	Location	Location	Location & Citation	Location & Citation within 3 years	Location & Citation within 3 years
ln (L/K) $_{it}$ **labour-capital**	-	0.657 (0.046)	0.648 (0.065)	0.647 (0.065)	0.642 (0.067)	-
ln (L) $_{it}$ **labour**	0.620 (0.057)	-	-	-	-	0.555 (0.039)
Ln(K) $_{it}$ **capital**	0.343 (0.042)	-	-	-	-	0.385 (0.041)
ln (R&D) $_{it,}$ **firm R&D stock**	0.029 (0.008)	0.012 (0.007)	0.026 (0.011)	0.025 (0.010)	0.022 (0.010)	0.015 (0.005)
W^{US}* ln (US R&D) $_{jt}$	-	**0.076 (0.024)**	**0.066 (0.035)**	**0.084 (0.031)**	**0.173 (0.054)**	**0.165 (0.062)**
W^{UK}* ln (UK R&D) $_{jt}$	-	0.035 (0.022)	0.026 (0.028)	0.092 (0.095)	0.400 (0.291)	-0.488 (0.557)
ln (US R&D) $_{jt}$ **US industry R&D stock**	-	0.050 (0.118)	0.065 (0.067)	0.059 (0.065)	0.063 (0.066)	-0.054 (0.038)
ln (UK R&D) $_{jt}$ **UK industry R&D stock**	-	0.273 (0.165)	0.221 (0.101)	0.219 (0.101)	0.206 (0.096)	0.250 (0.083)

Economic Magnitudes

– The increase in US R&D stock over 1990-2000 means that TFP in our UK firms was 5% higher by 2000

– This compares with an average 6.5% higher level of TFP associated with the increase in their own R&D stocks

Results for US firms (Table 4)

- Sensible capital and labour coefficients
- Evidence of domestic spillovers like UK
- UK interaction is positive but statistically insignificant (and small in economic magnitude)

US firms (Table 4)

	(1)			
Estimation method	**GMM**			
Dependent variable	**ln (Y) $_{it}$**			
Company listed in	**USA**			
Sample	USA			
Location weight:	Location			
	-			
ln (L/K) $_{it}$				
ln (L) $_{it}$	0.620 (0.571)			
ln (K) $_{it}$	0.343 (0.042)			
ln (R&D) $_{it}$	0.049 (0.035)			
W^{US} *** ln (US R&D) $_{jt}$**	0.002 (0.02)			
W^{UK} *** ln (UK R&D) $_{jt}$**	0.151 (0.131)			
ln (US R&D) $_{jt}$	0.247 (0.078)			
ln (UK R&D) $_{jt}$	-0.063 (0.046)			

Economic Magnitudes

UK firms at the mean

	Elasticity	Rate of return
Own R&D	.026	.163
R&D in the UK	.230	.058
R&D in the US	.095	.002

US firms at the mean

Variable	Elasticity	Rate of return
Own R&D	.049	.204
R&D in the UK	n.s. (-.06)	n.s.
R&D in the US	.249	.041

Further investigations

- *Industry heterogeneity?* Relationship stronger in industries with high TFP gap (columns 3 and 4)
- *Does W^{US} just proxy for more overseas production?* Condition on sample with no/very lower overseas production (column 2 of table 4)
- *Absorptive capacity?* Interact firm patents (and firm R&D) with US R&D.
- *Technological closeness to US?* Compare with Jaffe method
- *Unobserved heterogeneity?* Citations equation and pre-sample firm TFP

Further Investigations on production function (table 4)

	(1)	(2)	(3)	(4)
Estimation method	**GMM**	**GMM**	**GMM**	**GMM**
Dependent variable	**ln (Y) $_{it}$**	**Log(Y/K) $_{it}$**	**Log(Y/K) $_{it}$**	**Log(Y/K) $_{it}$**
Company listed in	**USA**	**UK**	**UK**	**UK**
Sample	Usa	**High TFP Gap with USA**	**Low Gap with the USA**	**“Domestic”**
Location weight:	Location	Location & Citation within 3 years	Location & Citation within 3 years	Location & Citation within 3 years
	-			
ln (L/K) $_{it}$		0.757 (0.076)	0.518 (0.087)	0.610 (0.072
ln (L) $_{it}$	0.706 (0.078)			
ln (K) $_{it}$	0.220 (0.052)			
ln (R&D) $_{it}$	0.049 (0.035)	0.029 (0.013)	0.005 (0.014)	0.029 (0.014)
W^{US} * ln (US R&D) $_{jt}$	0.002 (0.02)	0.277 (0.130)	0.123 (0.093)	0.212 (0.063
W^{UK} * ln (UK R&D) $_{jt}$	0.151 (0.131)	0.434 (0.267)	-0.826 (1.072)	-0.672 (0.408
ln (US R&D) $_{jt}$	0.247 (0.078)	0.353 (0.171)	0.035 (0.070)	0.116 (0.096
ln (UK R&D) $_{jt}$	-0.063 (0.046)	0.404 (0.152)	-0.041 (0.121)	0.211 (0.135

Count data models of citations from UK firms to US firms (table 5)

	(1)	(2)
Estimation method	**Negative Binomial**	**Negative Binomial**
Dependent variable	$CITES_{pit}^{US}$	$CITES_{pit}^{US}$
W_i^{US}	0.631	0.104
	(0.267)	(0.198)
W_i^{UK}	0.197	0.054
	(0.205)	(0.199)
US_{pit}	-	0.684
		(0.158)
UK_{pit}	-	0.037
		(0.107)
$TOTALCITES_{pit}$	0.013	0.012
	(0.001)	(0.001)
Dispersion (delta)	1.050	0.999
	(0.069)	(0.067)
Observations	14,161	14,161
Mean of dep. var.	0.695	0.695
Log Pseudo-L	-15,116.06	-14,996.25

Is patent Inventor US? → US_{pit}

- Corroborates production Function
- No evidence that some other unobserved variable correlated with location is Generating US spillovers result

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VI. Conclusions and Extensions

- Evidence that R&D spillovers from US greater when UK firms locate inventors in the US
- Policy implications – subsidies to repatriate European R&D from the US could be self defeating (Lisbon Agenda)
- Extensions
  - Other countries: (a) spillovers from outside USA; (b) other firm data (e.g. German EPO)
  - Modelling and testing determination of R&D location (e.g. tax credits)

Back up slides

Table 2: UK firms

	Mean	Median	Standard Deviation
Employees	10,711	1,750	27,564
Value added (£m)	372	48	914
Capital stock per worker (£)	38,700	30,000	31,900
Value added per employee (£)	31,404	50,201	12,438
R&D expenditure/value added	0.029	0.010	0.044
R&D stock/value added	0.158	0.046	0.272

- These are large firms, but slightly smaller than US
- US firms have higher R&D intensity
- In aggregate data US market sector 40% more output per hour, 20% higher TFP (higher capital intensity).

US Firms (Table A4)

	Mean	Median	Standard Deviation
Employees	13,760	3,528	38,640
Capital per employee ($)	59,407	34,607	81,630
Real sales per employee ($m)	193.736	162.843	128.641
R&D expenditure/value added	0.059	0.029	.198
R&D stock/value added	0.237	0.113	0.567

Economic Magnitudes

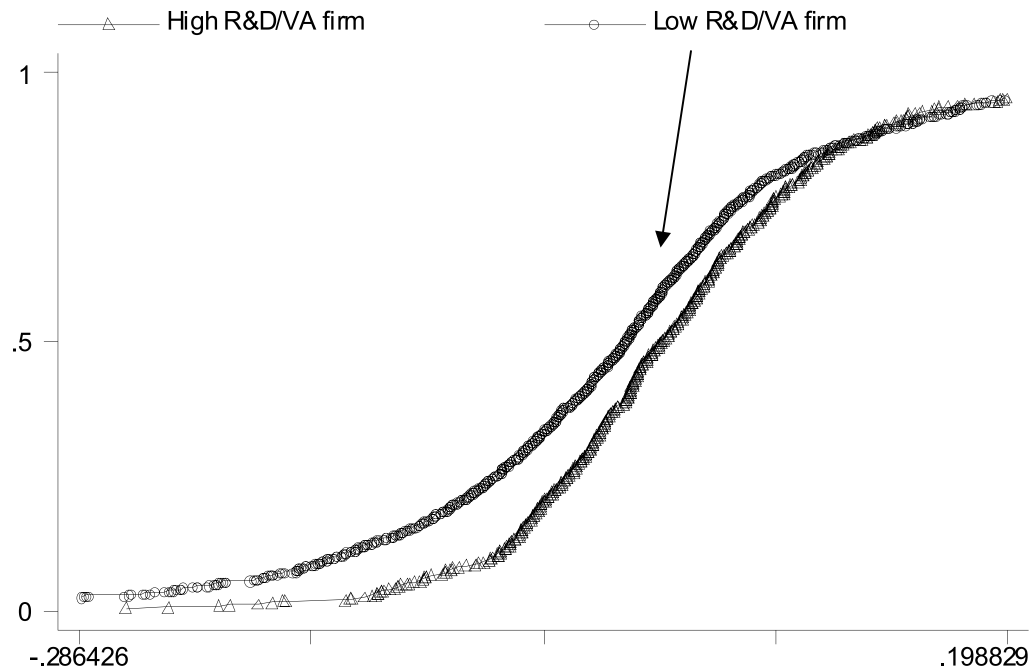
UK firms at the mean
(column 3, Table 3)

	Elasticity	Rate of return
Own R&D	.026	.163
R&D in the UK	.230	.058
R&D in the US	.095	.002

Elasticity of US R&D spillovers w.r.t. UK firm productivity (associated with Increase in US presence by 50%)

	(1)	(2)	(3)
Weight definition	Weight = 10%	Weight =60%	Change (2)-(1)
Location	.072	.105	.033
Location & citation within 3 years	.080	.167	.087

OP estimation for UK firms – CDF of change in omega: distribution of high R&D intensity firm stochastically dominates low R&D intensity firms



Cummulative distribution of productivity increment

	(1)	(2)		
Estimation method	**GMM**	**OP**		
Dependent variable	**ln (Y)** $_{it}$	**ln (Y)** $_{it}$		
Company listed in	**USA**	**USA**		
Sample	USA	USA		
Location weight:	Location	Location		
ln (L) $_{it}$	0.706 (0.078)	0.567 (0.026)		
ln (K) $_{it}$	0.220 (0.052)	0.214 (0.029)		
ln (R&D) $_{it}$	0.049 (0.035)	0.039 (0.011)		
W^{US} *** ln (US R&D)** $_{jt}$	0.002 (0.02)	0.002(0.055)		
W^{UK} *** ln (UK R&D)** $_{jt}$	0.151 (0.131)	0.158(0.175)		
ln (US R&D) $_{jt}$	0.247 (0.078)	0.104(0.072)		
ln (UK R&D) $_{jt}$	-0.063	[illegible]		

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