Advanced Industrial Organization I
Spillovers from Research & Development: Empirics

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1 Introduction

- New technology is a key driver of growth.

- Creating new technology requires research and development (R&D). Typically, in OECD countries, several percent of GDP is spent on R&D.

- Technology is **nonrival**, in the sense that it can be "shared" amongst producers.

- This is **good news** for countries who are not at the technological frontier, in the sense that they may be able to adopt new technologies without incurring the full cost associated with the underlying R&D.

- This is **bad news** for those that have to bear the R&D costs, because they don't get the full return on their investment. This plausibly diminishes the incentives for investing in R&D, and consequently slows technological progress.

- This lecture focuses on such **spillover effects** from R&D. I will concentrate on the following two papers:

- Keller, W. (2002) "Geographic Localization of International Technology Diffusion" American Economic Review 92(1): pp. 120-142.

- Griffith, Rachel, Rupert Harrison and John Van Reenen (2006). "How special is the special relationship: Using the impact of U.S. R&D spillovers on UK firms as a test of technology sourcing," American Economic Review 96(5), 1859-1875.

- Read the papers without focusing too much on the technical details. If you know the lecture notes you know a lot.

2 Technology Diffusion and Geography

Reference: Keller, W. (2002) "Geographic Localization of International Technology Diffusion" American Economic Review 92(1): pp. 120-142.

2.1 Motivation and Goal of the paper

- **Diffusion**: someone has an idea, say, on how to improve productivity; this idea spreads to other companies who also benefit from it.

- R&D spillovers suggest a diffusion-like process: the greater the spillover, the more rapid is the diffusion of technological advances.

- If spillovers are important, then there should be **income convergence** across countries

- What's the scope for technological spillovers?

- **Global spillovers**: Geography, notably distance, does not matter (very much) for the pace of knowledge spillovers. Innovations in Germany benefit firms in Australia no less than firms in Belgium.

  - If true, income convergence should be **fast**.

- **Local spillovers**: Spillovers are geographically limited in scope. To benefit from technological advances, you need to be located close to the place where these originate. Firms located in Australia will benefit much less from innovations in Germany than firms in Belgium.

- If true, can lead to **economic clusters** with persistently different levels of output. Slow, or no, convergence.

- A common view: technology knowledge is global, because of economic integration, efficient telecommunications, Internet etc. There is a global pool of technology, to which people in all countries have common access.

- Goal of Keller's paper: Investigate whether knowledge spillovers are mainly global or mainly local.

- How? Check if the **geographical distance** between countries affects the size of productivity gains from each others' R&D spending.

- Under the null hypothesis that there is a global pool of technology knowledge: distance should not matter.

- Why important to know the answer? The issue of convergence. Also:

  – Matters for macro policies aimed at increasing the rate of technological progress. If spillovers are local, then the own country reaps the rewards of its own R&D spending. If they are global, then there will be an incentive for other countries to free ride - and countries can't climb in the income ranking by investing in R&D.

  – Matters for the pattern of comparative advantage - if spillovers are local and your country is located close to a country that invests a lot in R&D, then that country - and your country - are likely to have a comparative advantage in the production of high-tech products. And so that, in turn, will influence trade patterns.

Three questions.

- Does the size of the **productivity effects** from G5 country R&D depend on the **distance** between the sender country and the recipient country? Note G5 = France, Germany, Japan, UK, the U.S.

- Does language matter?

- How, if at all, have the localization effects changed over time?

2.2 Empirical Setting

- Data: 12 manufacturing industries in 14 OECD countries for the years 1970-1995.

- Five countries - France, Germany, Japan, UK and the US - account for more than 92% of all the R&D in the sample. These "G5 countries" are treated in the analysis as the only **sources** of foreign technology. The **effects** of R&D will be analyzed focusing on the nine non-G5 countries.

- Relative location: The distance data is kilometers between the capital cities of the countries. More on this later.

- [Table 1: summary statistics]

TABLE 1—DESCRIPTIVE STATISTICS

Country	Symbol	Size in Terms of GDP*	Relative Size (Percent)	Size in Terms of R&D***	Relative Size (Percent)	R&D Growth******
Australia	AUS	54745	8.31	280	0.35	5.11
Canada	CAN	72945	11.07	973	1.21	7.68
Denmark	DEN	20827	3.16	179	0.22	7.48
Finland	FIN	20878	3.17	211	0.26	8.89
Italy	ITA	270236	41.00	1835	2.28	9.75
Netherlands	NL	39096	5.93	1049	1.30	4.87
Norway	NOR	17792	2.70	162	0.20	7.24
Spain	SPA	130753	19.84	389	0.48	9.42
Sweden	SWE	31886	4.84	876	1.09	6.65
Sum of 9 countries		659158		5953		
France	FRA	298530		5102	6.34	6.29
Germany	GER	350658		8962	11.13	10.22
Japan	JP	332562		11662	14.49	8.65
United Kingdom	UK	212000		6129	7.61	3.14
United States	USA	778406		42690	53.03	5.39
Sum of G-5 countries		1972156		74544		
Share of 9 countries*****			25.05		7.40	

Industry	ISIC	Size in Terms of GDP**	Relative Size (Percent)	Size in Terms of R&D****	Relative Size (Percent)	R&D Growth******
Food	31	96019	15.03	215	3.78	7.50
Textiles	32	77154	12.08	23	0.41	5.37
Wood	33	37767	5.91	21	0.36	8.84
Paper	34	60232	9.43	123	2.16	5.58
Chemicals	351/2	48945	7.66	1255	22.02	7.93
Rubber	355/6	22361	3.50	146	2.57	6.66
Non-metallic minerals	36	43257	6.77	64	1.13	5.63
Basic metals	37	35949	5.63	272	4.76	6.54
Metal products	381	54648	8.56	128	2.25	8.38
Non-electrical machinery and instruments	382/5	71180	11.14	715	12.55	8.93
Electrical machinery	383	37358	5.85	1527	26.78	7.71
Transportation	384	53819	8.43	1211	21.24	7.31

* All manufacturing value added 1980, in million $ U.S. 1990.
** Sum over 9 countries 1980, in million $ U.S. 1990.
*** All manufacturing R&D expenditures 1980, in million $ U.S. PPP.
**** Sum over 9 countries R&D expenditures 1980, in million $ U.S. PPP.
***** Sum of 9 countries over sum of all 14 countries.
****** Average annual growth of $ U.S. 1990 (PPP) R&D stocks, 1970–1995; depreciation rate = 0.1.

Calculating total factor productivity.

1. Start from the production function, in logs:

$$\ln Z_{cit} = \ln F_{cit} + \bar{\sigma}_{cit} \ln L_{cit} + (1 - \bar{\sigma}_{cit}) \ln K_{cit},$$

   where c, i, t denote country, industry and time, respectively; Z is value-added; F is total factor productivity (TFP); L is labour; K is capital; and $\bar{\sigma}_{cit}$ is a weight.

2. Move TFP to the left-hand side, and subtract off average (weighted) values across countries (without loss of generality, assume the average of log TFP is zero - this is fine, provided there is a constant in the model):

$$\begin{aligned} \ln F_{cit} &= \left(\ln Z_{cit} - \overline{\ln Z_{it}}\right) - \bar{\sigma}_{cit} \ln \left(L_{cit} - \overline{L_{it}}\right) \\ &\quad - (1 - \bar{\sigma}_{cit}) \left(\ln K_{cit} - \overline{\ln K_{it}}\right). \end{aligned}$$

Define $\bar{\sigma}_{cit}$ is an average of labour cost shares:

$$\bar{\sigma}_{cit} = 0.5\left(\alpha_{cit} + \bar{\alpha}_{it}\right),$$

where α_{cit} equals the wage bill (wage x labour) divided by total costs, e.g.

$$\alpha_{cit} = \frac{wage_{cit} \times L_{cit}}{Cost_{cit}},$$

and $\bar{\alpha}_{it}$ is the average of the α_{cit} across countries for a particular industry i at a particular time t. Thus we can compute α_{cit}, $\bar{\alpha}_{it}$ and hence $\bar{\sigma}_{cit}$ from the data, which can be justified by appealing to first-order conditions for cost minimization (how?). Once we've got $\bar{\sigma}_{cit}$, we can calculate TFP using the formula above.

2.3 Empirical Setting

- Basic ideas:
  - Productivity is positively related to domestic & foreign R&D.
  - The effectiveness of foreign R&D is negatively related to the distance from the foreign economy. In other words, international technology diffusion may be related to geographic distance.

- Basic model:

$$\ln F_{cit} = \beta \ln \left[S_{cit} + \gamma \left(\sum_{g \in G5} S_{git} \exp\left(-\delta D_{cg}\right) \right) \right] + \alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

where S is cumulative R&D spending; g is an index for the G5 countries; and D_{cg} is the distance between the recipient country c and the technology sender g.

- The key parameters are β, γ, and δ; α_{ci} is a country-industry fixed effect, and α_t is a time effect assumed common to all countries & industries (e.g. capturing the global business cycle).

- The parameter β determines the effect of R&D - combining own R&D S_{cit} and foreign R&D (provided $\gamma > 0$; if $\gamma = 0$ then β only measures the effect of own R&D).

- The parameter γ determines the strength of foreign R&D on productivity (the 'sender effect'). If $\gamma > 0$ then there are spillover effects; if $\gamma = 0$ then there are no spillover effects.

- Think about δ - the distance parameter. What does it mean?

- Suppose one of the G5 countries records R&D equal to S_{git} and suppose $\gamma > 0$ so that there are spillover effects from foreign R&D. How does this spillover effect depend on distance between the recipient country and the sender? Looking at the basic model, and especially the term

$$\gamma \left(\sum_{g \in G5} S_{git} \exp\left(-\delta D_{cg}\right) \right),$$

it is clear that, if $\delta > 0$, being located **far** from the technology sender g will **reduce** the effect of the sender's R&D on the recipient's technology.

- So the larger is δ, the stronger is the (negative) distance effect - in other words, the less "global" and more "local" are R&D spillovers.

- Under H_0 that distance doesn't matter (=spillovers are global), we have $\delta = 0$.

2.4 Results

- The basic model:

$$\ln F_{cit} = \beta \ln \left[S_{cit} + \gamma \left(\sum_{g \in G5} S_{git} \exp\left(-\delta D_{cg}\right) \right) \right] + \alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

- This can't be estimated by OLS since the model is nonlinear in the variables. Therefore the model is estimated using **nonlinear least squares**. If you don't know what that is don't worry; just think of it as a generalization of OLS that can be used for nonlinear models.

- The distance variable is a continuous variable coded in the data so as to increase by 1 for every additional 235 kilometers (this, in fact, is the distance between Germany and the Netherlands). Keep this in mind when interpreting the estimates of δ.

- [Discuss numerical illustration and results]

Interpreting the key parameters: A numerical illustration

$$\ln F_{cit} = \beta \ln \left[S_{cit} + \gamma \left(\sum_{g \in G5} S_{git} \exp\left(-\delta D_{cg}\right) \right) \right] + \alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

		Bonn	Washington	Paris	London	Japan
Amsterdam	kilometers	235	6188	427	357	9286
	distance units (km/235)	1.00	26.33	1.82	1.52	39.51
δ	**1.005**					
γ	**0.843**					
Remaining foreign R&D		31%	0%	14%	18%	0%
(=γ*exp(-δ*distance))						
δ	**0.5**					
γ	**0.843**					
Remaining foreign R&D		51%	0%	34%	39%	0%
(=γ*exp(-δ*distance))						

Benchmark Results

TABLE 2—GEOGRAPHIC LOCALIZATION: BENCHMARK RESULTS

	(2.1)	(2.2)	(2.3)	(2.4)
β	0.078	0.077	0.078	0.069
	(0.013)	(0.013)	(0.016)	(0.023)
δ	1.005	0.981	1.037	
	(0.239)	(0.196)	(0.262)	
χ				0.090
				(0.012)
γ	0.843			
	(0.059)			
γ_J		1.0		
		(set)		
γ_{US}		1.081		
		(0.059)		
γ_{UK}		0.616		
		(0.060)		
γ_G		1.188		
		(0.060)		
γ_F		0.944		
		(0.060)		
n	2808	2808	2808	2808
R^2	0.702	0.702	0.702	0.696
AIC	−4.233	−4.232	−4.234	−4.214

Notes: Standard errors are in parentheses; β measures the effect of domestic R&D; γ (and γ_g) measure the relative effect from G-5 country R&D; δ as well as χ determine the distance effects ($\delta > 0$ and $\chi > 0$, respectively, are consistent with localization); AIC = Akaike's Information Criterion, as defined in the text.

- Col 2.1: The estimated productivity effect from domestic & foreign R&D is 0.078, & significant.
- The "potency" of distance deflated foreign R&D: γ = 0.84 (significant)
- The distance parameter: δ = 1.01 (significant). Thus, effective R&D from G5 countries **falls** with distance.
- Supports localization hypothesis: countries far away from the G5 countries have lower productivity **because** the geographical distance hampers technology diffusion.
- Col 2.2 – different distance effects across the G5 countries. Col 2.3, γ is assumed to be 1. Same basic insights as above. Col 2.4 different specification (you may ignore) – same qualitative result.

Specification:

$$\ln F_{cit} = \beta \ln \left[S_{cit} + \gamma \left(\sum_{g \in G5} S_{git} \exp\left(-\delta D_{cg}\right) \right) \right] + \alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

- One way of quantifying the results above is to compute the **geographic half-life** of technology: At what distance from the technology sender does only half of the technology sent out remain? Solve for D^*_{cg}:

$$\begin{aligned} S_{git} \exp\left(-\delta D^*_{cg}\right) &= 0.5 S_{git} \\ D^*_{cg} &= -\frac{\ln(0.5)}{\delta}, \end{aligned}$$

  which gives $D^*_{cg} = 0.69$. Remember that one unit of D is equal to 235 kilometers, this means half of the technology sent out is lost already after

$$0.69 \times 235 = 162$$

  kilometers. This is a large effect! Too large to be plausible? Judge for yourself.

- Now return to the three questions with which we began:

1. Does the size of the productivity effects from G5 country R&D depend on the distance between the sender country and the recipient country? Note G5 = France, Germany, Japan, UK, the U.S.

2. Do language skills matter?

3. How, if at all, have the localization effects changed over time?

- The first of these has now been answered; how about questions (2) and (3)?

Do language skills matter?

- It's plausible to hypothesize that language determines spillover strength; in particular, if the recipient and sender share the same language, then you might expect the spillover effects to be stronger.

- To investigate, Keller generalizes his basic model to allow the distance effect to depend on whether the sender and recipient countries share the same language:

$$\ln F_{cit} = \beta \ln \left[S_{cit} + \gamma \left(\sum_{g \in G5} \left(1 + \eta I_{cg}^{sl}\right) S_{git} \exp\left(-\delta D_{cg}\right) \right) \right] + \alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

where I_{cg}^{sl} is a dummy variable equal to 1 if countries c and g share the same language, and zero otherwise. If the new parameter η is different from zero, this implies language plays a role for technology diffusion.

- The estimate of η is positive and significant, thus speaking the same language as the technology sender means you (the recipient country) will **benefit more** from the sender's R&D.

- The distance effect remains strong.

- [Results in Table 4; focus on column 4.1]

Does language matter for spillovers? Key findings in Table 4

	Exponential (4.1)
β	0.077
	(0.013)
δ	1.044
	(0.230)
χ	
γ	0.832
	(0.059)
η	0.565
	(0.060)
ς	
λ	
n	2808
R^2	0.702
AIC	−4.235

Significantly different from zero.

$$\ln F_{cit} = \beta \ln \left[S_{cit} + \gamma \left(\sum_{g \in G5} \left(1 + \eta I_{cg}^{sl}\right) S_{git} \exp\left(-\delta D_{cg}\right) \right) \right] + \alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

Changes to the localization effects over time?

- Generalized model:

$$\ln F_{cit} =$$

$$\beta \ln \left[S_{cit} + \left(\sum_{g \in G5} \gamma_g \left(1 + \psi_F I_t\right) S_{git} \exp\left(-\delta \left(1 + \psi_D I_t\right) D_{cg}\right) \right) \right]$$
$$+\alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

where I_t is a dummy equal to one for the latter half of the sample period (1983-1995). (Detail: we now allow for sender-specific coefficients γ_g - not important).

- Two new parameters. Key parameter: ψ_D

- If ψ_D is **negative**, this implies a **weaker** localization effect in the more recent period covered in the data (provided $\gamma > 0$, $\delta > 0$ and ψ_F not a large negative).

- [Results in Table 5; focus on column 5.1]

How has technology localization changed over time? Key results from Table 5

	Exponential (5.1)
β	0.096
	(0.010)
δ	0.384
	(0.043)
χ	
γ_J	1.0
	(set)
γ_{US}	1.031
	(0.059)
γ_{UK}	0.863
	(0.060)
γ_G	1.157
	(0.060)
γ_F	1.011
	(0.060)
ψ_D	−0.784
	(0.068)
ψ_F	0.061
	(0.108)
n	2808
R^2	0.724
AIC	−4.304

- The parameter ψ_D is -0.78 and significantly different from zero, indicating that technology flows from the G5 countries have a less geographically localized effect over time.

- Also, the estimated distance effect parameter is much lower than previously: δ=0.384 in col 5.1, Table 5.

- What's the distance effect in 1983-1995?

$$\ln F_{cit} =$$

$$\beta \ln \left[S_{cit} + \left(\sum_{g \in G5} \gamma_g \left(1 + \psi_F I_t\right) S_{git} \exp\left(-\delta \left(1 + \psi_D I_t\right) D_{cg}\right) \right) \right]$$

$$+\alpha_{ci} + \alpha_t + \varepsilon_{cit},$$

2.5 Conclusions

- The size of the productivity effects from G5 country R&D depends on the distance between the sender country and the recipient country

- Language skills matter.

- Localization effects have become weaker over time.

- On balance the evidence suggests spillovers are quite strong (represented by the parameter γ). This may lead to inefficiently low R&D because of free-riding mechanisms.

3 Firm-Level Evidence on Technology Sourcing

Reference: Griffith, Rachel, Rupert Harrison and John Van Reenen (2006). "How special is the special relationship: Using the impact of U.S. R&D spillovers on UK firms as a test of technology sourcing," American Economic Review 96(5), 1859-1875

3.1 Motivation and Goal of the paper

Point of departure: As we have seen above, the transfer of ideas from technologically leading countries to those behind the frontier are important for economic growth.

- However, the mechanisms underlying technology transfer are not well understood, and little empirical evidence exists on this issue.

- This paper focuses on **technology sourcing** as a method of gaining access to foreign knowledge. Firms in a country behind the frontier can tap into leading-edge knowledge by setting up R&D labs abroad - basically in order to "listen in" on new ideas.

- The paper investigates whether the R&D stock in the US had a stronger impact on the TFP of UK firms that had more of their inventors located in the US than other UK firms.

- In other words, the paper is asking the question: "Do UK firms benefit more from US R&D if they themselves locate some of their R&D in the

US?". The idea is that by locating some of their R&D activities in the US, the UK firms "listen in" on technological advances made in the US.

- Notice that this idea is consistent with the results in Keller's (2002) paper indicating that technology is, to a substantial degree, local rather than global.

- [Figure 1: If US R&D grows rapidly, then the **difference** in growth rates between UK firms with **high** inventor presence in the US and UK firms with **low** inventor presence in the US is **large**]

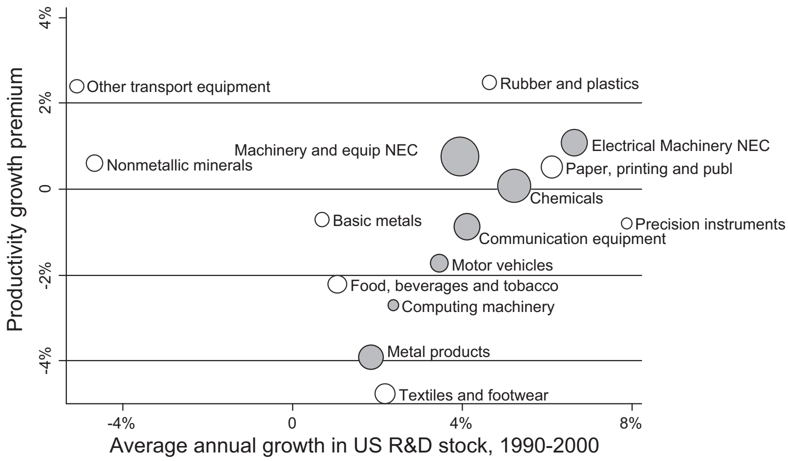

Figure 1. US R&D Growth and "Productivity Growth Premium" for UK Firms with a High Proportion of US Inventors

Notes: The vertical axis is the "productivity premium" for UK firms with strong inventor presence in the US between 1990 and 2000 (i.e., the differential in annual average labor productivity growth for our UK firms with above-median US inventor presence, versus those with below-median US inventor presence). The horizontal axis is average annual growth in US R&D stock. Shaded industries are those with largest US-UK TFP gap over the period (i.e., where UK firms had the "most to learn"). Industry points are weighted by number of firms in our sample. There is a positive relationship across all industries, and it is strongest in the "high-gap" sector.

We illustrate our identification strategy in Figure 1. The horizontal axis shows the average annual growth of the US R&D stock by industry between 1990 and 2000. On the vertical axis, we plot the mean "productivity premium" for UK firms that had a substantial proportion of inventors located in the US (i.e., the difference in productivity growth between UK firms with a high proportion of their inventors located in the US prior to 1990 and UK firms with zero or low US inventor presence). It is clear that the productivity premium is larger in those industries where the US had faster R&D growth. Furthermore, the shaded industries are those where the US already had a substantial technological lead over the UK in 1990 and where, presumably, UK firms had the most to learn. For these "high-gap" sectors, the upward-sloping relationship is particularly striking.

Figure 1 does not control for many other confounding influences, and the paper uses a variety of econometric methods to deal with input endogeneity, unobserved heterogeneity, and selectivity. Even after controlling for these, we find that UK firms that had more of their inventive activity located in the US *prior* to 1990 benefited disproportionately from the growth in US R&D in the 1990s. According to our estimates, US R&D during the 1990s was associated with 5-percent-higher TFP for UK manufacturing firms in 2000 (about $13 billion), with the majority of the benefits accruing to firms with an innovative presence in the US.[6]

Needless to say, our estimates present a lower bound on the full benefits of US R&D to the rest of the world. They provide, however, a salutary warning to policymakers who seek to boost

Business Expenditure on Research and Development (BERD) data) rose significantly during the early 1980s, fell back in the early 1990s, and rebounded strongly from 1994 onward. Much of the early 1980s increase was due, however, to defence-related R&D, which fell back rapidly after 1988. The growth in civil R&D intensity was strongest during the 1990s (civil R&D is likely to have greater international spillover potential than military R&D).

[6] Value added in UK manufacturing was £154 billion in 2000, about $250 billion at prevailing exchange rates.

- **Key result in paper:**
  - US R&D during the 1990s was associated with 5-percent-higher TFP for UK manufacturing firms.
  - UK firms with high inventor presence in the US benefited **disproportionately** from US R&D during the 1990s. Thus, US R&D may generate large spillover benefits for the rest of the world, but foreign firms must actually invest in innovative activity **in the US**, in order to reap the full returns.
- Hence: "When it comes to international technology spillovers, it seems there is no such thing as a completely free lunch" (p. 1874).
- Quite possibly, such effects will be even bigger for other recipient countries, that are less advanced than the UK.

- Some policy makers want to make European multinationals to repatriate US R&D back to Europe - given the results in this paper, that might be a very bad idea.

3.2 Empirical Approach

We start by writing down the production function, this time as:

$$Y_{it} = A_{it} L_{it}^{\alpha_l} K_{it}^{\alpha_k} R_{it}^{\alpha_r} (DOM)_{jt}^{\gamma_{i1}} (FOR)_{jt}^{\gamma_{i2}},$$

where i, j, t denote firm, industry and time, respectively; Y is value added; A is total factor productivity (TFP); L is employment; K is physical capital; R is the firm's own R&D stock; DOM and FOR are the R&D stocks in the firm's industry in the UK and the US, respectively; and Greek letters denote unknown parameters.

- Main interest: Does the **effect** of foreign R&D - i.e. the parameter γ_{i2} - depend on the geographic location of the UK firm's innovative activity?

- To answer this question, assume the following specification for γ_{i2}:

$$\gamma_{i2} = \phi_1 + \phi_2 W_i^{US},$$

where W_i^{US} is the share of firm i's innovative activity in the US. Hence, if ϕ_2 is positive, one would conclude that the effect of US R&D on UK firm productivity depends on presence of the UK firm in the US.

- The authors use a similar specification for γ_{i1}, the effect of domestic R&D on UK firm-level productivity:

$$\gamma_{i1} = \theta_1 + \theta_2 W_i^{UK}.$$

- Finally, they specify TFP as

$$\ln A_{it} = \phi_3 W_i^{US} + \theta_3 W_i^{UK} + \delta' z_{it} + \varepsilon_{it},$$

where z_{it} is a vector of control variables (e.g. demand shocks) and ε_{it} is a stochastic error term, interpretable as a shock to productivity.

- Using lower-case letters to denote natural logarithms (i.e. $x = \ln X$), the specification of the empirical model is as follows:

$$\begin{aligned} y_{it} &= \alpha_l l_{it} + \alpha_k k_{it} + \alpha_r r_{it} \\ &+\theta_1 \times dom_{jt} + \phi_1 \times for_{jt} \\ &+\theta_2 \left(W_i^{UK} \times dom_{jt} \right) + \phi_2 \left(W_i^{US} \times for_{jt} \right) \\ &+\phi_3 W_i^{US} + \theta_3 W_i^{UK} + \delta' z_{it} + \varepsilon_{it}. \end{aligned}$$

This is the model that they are going to estimate. What are the key parameters, and how should they be interpreted?

3.2.1 Econometric Issues

As you know, the estimation of production functions is not entirely straightforward. The basic problem is that the firm's productivity shock is likely to be correlated with the firm's input choices (capital, labour, R&D), in which case the inputs are endogenous. Why?

The authors tackle this problem in three ways:

- Allow for time invariant unobserved heterogeneity through firm fixed effects

- Instrumental variables, using lagged values of the inputs as instruments for current values.("System Generalized Method of Moments - SYS-GMM)

- The Olley-Pakes approach (see lecture by Florin Maican).

I want to discuss the econometrics as briefly as possible here. Since OLS gives results that are similar to those obtained with the more sophisticated estimators, I will focus on the OLS results. What's important is that you see why the authors adopted a different approach than OLS.

- Other concerns:
  - The coefficients on the R&D spillover terms may reflect other shocks correlated with demand or supply (omitted variables). Fix: Industry fixed effects and other industry variables; use lags of the spillover terms (less affected by contemporaneous shocks).

– The variables W_i^{US} and W_i^{UK} are chosen by the firms, and so potentially endogenous (correlated with the error term). Fix: use **presample** information to construct these variables - specifically, patents **before** 1990.

3.3 Data

- Panel of 188 manufacturing firms listed on the LSE in 1985. Account for a large proportion of UK R&D (about 70% in 1996). Runs from 1990 to 2000.

- Match with data on all patents taken out by these firms at the US Patent and Trademark Office (USPTO) since 1975. Firms in sample had 38,160 patents. Of these patents (which are thus taken out by UK firms):

  - About 37% had the lead inventor located in the UK

  - About 39% had the lead inventor located in the US

- So the US is an important location for inventive activity of UK firms (See Table 1 in paper for more details).

- Basic definition of W_i^{US}

$$\frac{\text{Patents of firm } i \text{ for which lead inventor is based in US}}{\text{All patents of firm } i},$$

  during the 1975-1989 period (i.e. presample).

- W_i^{UK} constructed in the same way.

- Some alternative definitions considered too - see paper for details

- If no patents, then $W_i = 0$.

- Notice: the inventive activity variables W_i^{US}, W_i^{UK} are time invariant - i.e. they do not change over time.

- [Table 2: Descriptive statistics. Table 3: Result]

TABLE 2—DESCRIPTIVE STATISTICS

	Mean	Median	Standard deviation
Firm-level variables			
Employees	11,256	1,795	29,167
Value added (£m)	390	50.4	960
Capital stock (£m)	549	51.1	1477
R&D stock (£m)	152	1.8	627
R&D stock/value added	0.160	0.047	0.276
W_i^{US} location measure	0.351	0.213	0.382
W_i^{US} location & citation	0.317	0.194	0.351
W_i^{US} loc. & cit. within 3 yrs.	0.121	0.016	0.172
W_i^{UK} location measure	0.272	0.019	0.350
W_i^{UK} location & citation	0.064	0.000	0.132
W_i^{UK} loc. & cit. within 3 yrs.	0.014	0.000	0.046
Industry-level variables			
ln(UK R&D stock)	7.264	7.674	1.381
ln(US R&D stock)	9.798	9.572	1.241

Notes: Sample includes 188 firms, 1990–2000; all monetary amounts are in 1995 currency, deflated using OECD two-digit industry price deflator; firm-level value added is constructed as the sum of total employment costs, operating profit, depreciation, and interest payments; capital stocks and R&D stock are constructed using a perpetual inventory method.

tional measure with different propensities to patent across industries.

In order to show that our measure of inventor location is capturing what we want, we consider refining it in two ways. We focus on patents that can be seen to be drawing on: (a) US-based R&D, and (b) very recent technological developments. A key theme in the literature is that technology sourcing is not the only motivation for firms to locate innovative activity abroad. In particular, firms may conduct R&D overseas in order to adapt existing technologies to new markets. Our empirical approach to this issue is to use data on citations to focus on patents that are most likely to represent technology sourcing behavior. Consider two extreme cases for a patent owned by a UK firm but invented in the US. The first is where the patent cites only other patents owned by the same parent firm and whose inventors were located in the UK. This patent is more likely to represent activity associated with adapting an existing technology to the US market. The other extreme is where the patent cites many other patents not owned by the parent firm and whose inventors were located in the US. This patent is more likely to represent technology sourcing behavior. We want to investigate whether there is evidence for technology sourcing behavior in productivity outcomes, so we focus on the latter.

To implement this approach, our second measure of W_i^{UK} and W_i^{US} (denoted location & citation in Table 2) uses only patents that cite other patents whose lead inventors were located in the same country and were not owned within the same parent firm. This measure of W_i^{US} is thus equal to the proportion of the firm's patents where: (a) the lead inventor is located in the US, and (b) the patent cites at least one other patent whose lead inventor was located in the US and which was not owned by the same parent firm.

Our third, and most refined, measure of W_i^{UK} and W_i^{US} (denoted location & citation within 3 years in Table 2) is the same as the second measure, except it also uses information on the time lag between the citing and cited patent. Technology-sourcing behavior is likely to be associated with gaining access to pools of "tacit" knowledge. Given that knowledge created recently is more likely to have tacit characteristics, we include only citations to patents whose application date is no more than three years prior to that of the citing patent. The third measure of W_i^{US} is thus equal to the proportion of the firm's total patents where: (a) the lead inventor is located in the US, and (b) the patent

Econometric Results

Table 3: R&D-Augmented Production Functions (selected results)

	(1)	(2)	(3)
Estimation method	OLS	OLS	GMM
Dependent variable	$\ln(Y)_{it}$	$\ln(Y/K)_{it}$	$\ln(Y/K)_{it}$
Location weight: W_i	—	Location	Location
$\ln(L/K)_{it}$	—	0.658	0.649
labour-capital		(0.046)	(0.063)
$\ln(L)_{it}$	0.620	—	—
labour	(0.057)		
$\ln(K)_{it}$	0.343	—	—
capital	(0.042)		
$\ln(R\&D)_{it}$	0.029	0.012	0.023
firm R&D stock	(0.008)	(0.007)	(0.012)
$W_i^{US} * \ln(US\ R\&D)_{jt}$	—	0.076	0.068
% inventors in US * ln(US industry R&D stock)		(0.024)	(0.037)
$W_i^{UK} * \ln(UK\ R\&D)_{jt}$	—	0.035	0.028
% inventors in UK * ln(UK industry R&D stock)		(0.022)	(0.030)
$\ln(US\ R\&D)_{jt}$	—	0.050	0.061
US industry R&D stock		(0.118)	(0.069)
$\ln(UK\ R\&D)_{jt}$	—	0.273	0.263
UK industry R&D stock		(0.165)	(0.104)
W_i^{US}	—	−0.696	−0.622
% inventors in US		(0.240)	(0.360)
W_i^{UK}	—	−0.296	−0.261
% inventors in UK		(0.156)	(0.197)
Firms	188	188	188
Observations	1794	1794	1794

Col. 1-3 in Table 3 show the key results.

- Col. 1 does not impose constant returns to scale; col. 2-3 do (why?).
- Labour coef. is about 0.65.
- Positive & significant return to own R&D. Implied rate of return: 14% (why?).
- Coef. on interaction term between US inventor location and US R&D stock is positive and significant at 5% level (except in col. 3)

➢ Hence technology sourcing: UK firms with strong inventor presence in the US benefit the most from US R&D spillover.

- Linear UK R&D positive & significant, suggesting domestic spillovers.

- Based on the results, what is the predicted effect of an increase in US R&D by 10% on the TFP of a UK firm with all of its inventor activity located in a) the US; b) the UK?

Quick summary of the authors' "Further investigations".

- Separate out the industries that have "most to learn" - defined as those for whom the TFP gap with the US is larger than the median - and check if the above effect is present for this sub-sample. It is (Table 4).

- Use absolute number of patents rather than the ratio. This works too but there is evidence that the ratio definition used above is better.

- Measures of the location of **sales** are insignificant when added to the baseline regression. This suggests you really need to locate **innovative activity** in the US in order to benefit disproportionately from US R&D. Just exporting goods to the US is not sufficient.

- Other robustness checks too - see Table 4.

3.4 Summary & Conclusions

- "Strong evidence for the existence of knowledge spillovers associated with technology sourcing".

- Effect of US R&D on UK firm-level productivity is especially high for those UK firms with strong inventor presence in the US. Thus, firms may invest in R&D activity in a technologically advanced country in order to gain access to spillovers of new "tacit" knowledge.

- Policy: Member states of the EU have agreed on a target to raise the level of R&D within the Union to 3% of GDP. The results in this paper suggest that relocating R&D efforts away from the US and toward Europe may be counterproductive.