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**GEOGRAPHIC AND TECHNOLOGICAL
R&D SPILLOVERS WITHIN THE TRIAD:
MICRO EVIDENCE FROM US PATENTS**

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GEOGRAPHIC AND TECHNOLOGICAL R&D SPILLOVERS WITHIN THE TRIAD: MICRO EVIDENCE FROM US PATENTS

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Abstract

This paper aims at assessing the magnitude of R&D spillover effects on large international R&D companies' productivity growth. In particular, we investigate the extent to which R&D spillover effects are intensified by both geographic and technological proximities between spillover generating and receiving firms. We also control for the firm's ability to identify, assimilate and absorb the external knowledge stock. The results estimated by means of panel data econometric methods (system GMM) indicate a positive and significant impact of both types of R&D spillovers and of absorptive capacity on productivity performance.

Keywords: Geographic and technological R&D spillovers, absorptive capacity, firms' productivity growth

JEL codes: O33, O47

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1. Introduction

One of the most important developments in the new growth and international trade theories has been the recognition of the significant role of knowledge flows between economic agents from different regions or economic areas. According to Grossman and Helpman (1991), for instance, growth rates are faster when technological change readily flows across international borders. For Romer (1990), the non-rival and partially non-excludable feature of the knowledge good does not allow inventors to fully prevent other firms from using their inventions. More generally, knowledge spillovers may be driven by a variety of channels such as the mobility of workers, the exchange of information at technical conferences, or knowledge available in the scientific and technological literature including patent documents. These knowledge externalities or R&D spillovers can benefit to competitors' R&D by lowering the costs of their own R&D activities and in turn may contribute to their productivity performance. However, new products and processes can also render existing ones obsolete or less competitive and firms that encounter difficulties to stay in the R&D race may suffer from rivals' R&D. In this case, R&D externalities are associated with competitive pressures which will translate into negative effects on firms' performance.

The specific type of knowledge flows that economists have most been interested in concerns pure knowledge spillovers¹. Economists have often investigated the patterns of these knowledge flows from a geographic or a technological perspective, i.e. in terms of geographic proximity or technological linkages between the unit generating these flows and the recipients. Over the last decade, several studies in the literature that examines the spatial dimension of innovative activities have found that knowledge spillovers tend to be locally concentrated (Jaffe, 1989; Jaffe et al., 1993). At the same time, other studies have shown evidence of a positive relationship between the R&D of 'technological neighbours' and the firm's R&D productivity (as measured by patenting). In terms of productivity performance, the effects of R&D spillovers also appear to be mainly technologically localised (Jaffe, 1986, 1988).

While very important for economic growth, the two types of geography and technology based R&D externalities have rarely been investigated together (Orlando, 2000). A first contribution of this paper is to analyse the impact of these spillover phenomena on firms' productivity in a unified framework. To this end, we implement two methodologies to analyse knowledge flows among firms. We construct the R&D spillover stock by considering a technological as well as a geographic proximity measure. The approach for modelling the technology based R&D spillover variable builds on the methodology that was first empirically implemented by Jaffe (1986). This method rests on the construction of technological proximities between firms in a technological space. The firms' positions in the technological space are characterized by the distribution of their patents over patent classes. Localization R&D spillovers are performed on the basis of geographic distances between firms which use the latitude and longitude coordinates of corporate headquarters (Orlando, 2000).

In order for R&D spillovers to be effective, firms must be able to identify, assimilate and exploit the external knowledge stock. The degree of absorptive capacity will depend on the firms' own R&D activities. A second contribution of the study is to analyse the role of absorptive capacity in enhancing the firms' ability to benefit from geographic and technological based R&D spillovers. Following Cohen and Levinthal (1989), the firm's own

¹ Griliches (1979) operates a distinction between pure knowledge spillovers and rent spillovers. The latter arise because new goods and services are purchased at less than their full quality-adjusted prices.

R&D is used to measure the level of knowledge accumulation internal to the firm and the importance of absorptive capacity.

We use an extended production function to estimate the impact of R&D spillover components and absorptive capacity besides traditional inputs and own R&D stock (Griliches, 1979). The dataset consists of a representative sample composed of 808 worldwide R&D-intensive manufacturing firms over the period 1988-1997. This information is matched to the USPTO dataset of Hall et al. (2001). The results estimated by means of panel data econometric methods indicate a positive and significant impact of R&D spillovers on productivity performance. On the whole, the elasticity associated with the geographic (resp. technological) R&D spillover pool is two times (resp. four times) the one of the firm's own R&D stock. Furthermore, US and Japanese firms are mainly sensitive to spillover effects generated by domestic firms while European firms appear to mainly benefit from the international R&D spillover stock.

The paper is organized as follows. In section 2, we describe the dataset constructed for the purposes of the study. Then, we discuss the different methodologies used to measure the spillover stocks as well as the econometric framework. Section 3 presents the main empirical findings. A concluding section briefly summarises the empirical findings and points out some directions for future research.

2. Data and econometric framework

2.1. Data sources and matching procedure

The dataset has been constructed with the view of setting up a representative sample of the largest firms at the international level that reported R&D expenditures. The information on company profiles and financial statements comes from the *Worldscope/Disclosure* database². The dataset consists of a balanced panel of 808 firms over the 1988-1997 period (Appendix 4). For each firm, information is available for net sales (S), the number of employees (L), the net property, plant and equipment (C), annual R&D expenditures (R) and main industry sectors according to the Standard Industrial Classification (SIC – 4 digits). The database of Hall et al. (2001) on US patents is the second source of information used in this study. This database, which is available on the NBER website, contains all the patents registered at the US Patent & Trademark Office (USPTO) over the period from January 1, 1963 to December 30, 1999. The database contains a huge set of information among which the technological fields corresponding to the claimed invention. In Appendix 4, we show the number of patents used in the database, by country and economic area. The third source of information concerns the geographic coordinates of firms, i.e. the latitude and the longitude. This information has been retrieved on the basis of firms' headquarters addresses and is used to compute geographic distances between firms.

A major task in assembling the dataset has been the matching of patents from the Hall et al. (2001) data with firms in the *Worldscope* database. Two difficulties have been encountered. First, patents are assigned to firms on the basis of their names which can vary from one data sources to the other, e.g. 'Co' instead of 'Corporation', 'Incorporated' or 'Inc' and other such changes or abbreviations. Second, many large firms have several R&D performing subsidiaries in several countries and it is not obvious to link the patents applied by these

² See Cincera (1998) for more details as regards the content of this database.

subsidiaries to the parent company. Ideally, one has to have a ‘mapping’ of the main firms company to their subsidiaries and affiliates. However, it is not easy to construct an accurate mapping, since it changes over time through the process of merger and acquisition.

Taking into account these issues, the matching procedure consisted of two steps. In a first step, patents were assigned to firms on the basis of their generic names. For instance, when searching for the word “*Fiat*” we retrieved 435 patent documents. Examining more in detail the firm’s full names reported in these documents, it appeared that 391 patents were assigned to “*Fiat S.p.A.*”, 26 patents to “*Fiat Products INC.*”, 14 patents to “*Fiat Français*” and 4 patents to “*Fiat Products LTD*”. These last companies are clearly foreign subsidiaries of the European parent company. Hence, the patents granted to these firms have been consolidated with the ones of “*Fiat*”. In a second step, this procedure has been repeated for each firm of the sample. For about 80% of the sample there was only one firm name in the retrieved documents. For the rest, firm names which could be identified without any doubts as subsidiaries have been matched with generic names.

2.2. Variables’ construction

Given the presence of outliers, a cleaning procedure similar to the one in Capron and Cincera (1998) has been implemented in order to reject firms whose variables displayed very high and frequent variations. The process of merger and acquisition of firms over time is the most likely reason for the presence of such outliers.

All variables have been converted into constant 1995 dollars. Because of the non-availability of output deflators at the industry level for each country, net sales (S), net property, plant & equipment (C), R&D expenditures (R) have been deflated using the GDP deflators of respective countries. The stock of R&D capital has been built on the basis of the permanent inventory method with a depreciation rate equal to 15 percent and an initial stock of R&D capital calculated by assuming a growth rate of R&D expenditure equal to 5 percent.

A key issue in the empirical analysis on knowledge spillovers is the measurement of the pool of external knowledge. This stock is usually built as the amount of R&D conducted elsewhere weighted by some proximity measure which reflects the intensity of knowledge flows between the source and the recipient of spillovers³.

In this paper, we follow the methodology developed by Jaffe (1986) to compute the technological proximity. This procedure rests in the construction of a technological vector for each firm based on the distribution of its patents across technology classes⁴. These vectors allow one to locate firms into a multi-dimensional technological space where technological proximities between firms are performed as the uncentered correlation coefficient between the corresponding technology vectors:

³ Different proximity measures have been used in the literature. See Griliches (1992), Mohnen (1996) or Cincera and van Pottelsberghe (2001) for a review.

⁴ Thanks to the USPTO patent classification system, it is possible to identify the technological classes to which patents are assigned. In order to construct the technological proximity measures, we use the higher level classification proposed by Hall et al. (2001) which consists of 36 two-digit technological categories (see Appendix 1).

$$P_{ij} = \frac{\sum_{k=1}^K T_{ik} T_{jk}}{\sqrt{\sum_{k=1}^K T_{ik}^2 \sum_{k=1}^K T_{jk}^2}} \quad (1)$$

where: T_i is the technological vector of the firm i and
 P_{ij} is the technological proximity between firm i and j .

According to this procedure, the total weighted stock of R&D spillovers is performed as follows:

$$Ts_i = \sum_{i \neq j} P_{ij} K_j \quad (2)$$

where: K_j is the R&D capital stock of firm j .

Table 1 illustrates some technological proximity measures for different firms in the dataset. As emphasised by Jaffe (1986), this technological distance index relies on the strong assumption that the appropriability conditions of knowledge are the same for all firms. The more the outcomes of R&D activities are appropriable, the less there will be knowledge flows between R&D performers and the potential users of this knowledge. Since these variables are not observable at the firm level, their direct assessment is hard to pick up. However, in a panel data context, one may assume that these firms specific unobserved effects are constant over the period considered.

Table 1. Technological proximities

	BASF	Bayer	Hitachi	IBM	Motorola
BASF	1.00				
Bayer	0.97	1.00			
Hitachi	0.13	0.08	1.00		
IBM	0.09	0.05	0.88	1.00	
Motorola	0.04	0.02	0.66	0.61	1.00

As for technological proximities, different measures have also been proposed in the literature to measure the geographic proximity between firms⁵. Following Orlando (2000), we use the latitude and the longitude coordinates of firms derived from the address of their headquarters. Assuming a spherical earth of actual earth volume, the arc distance in miles between any two firms i and j can be performed as:

$$d_{ij} = 2 * 3.959 * \arcsin \sqrt{\sin^2 \left(\frac{lat_j - lat_i}{2} \right) + \left(\frac{\cos(lat_j) + \cos(lat_i)}{2} \sin \left(\frac{lon_j - lon_i}{2} \right) \right)^2} \quad (3)$$

where: 3.959 is the radius of the earth in miles and latitude and longitude values are in radians.

⁵ See Orlando (2000) and Greunz (2003) for a review.

As stressed by Orlando (2000), the use of corporate headquarters to represent the firm location may be questionable for the purpose of spillover measurement. Quoting the author (2000: p.14), “One may argue that our true interest is in the location of innovation, not necessarily in the location of corporate headquarters. However, if firms view R&D as their most strategically important investment they are likely to locate this activity close to corporate headquarters. Furthermore, while R&D may be a reasonable proxy of the scale of a firm’s innovative activity, spillovers from this implied knowledge base may emerge from any of the locations that compose the firm; R&D facilities, production facilities, or corporate headquarters. Thus, corporate headquarters may be as good a proxy of firm location as we can hope to find⁶”.

Based on the geographic distances of firms and assuming that the spillovers’ stock is negatively correlated to the geographic distance d_{ij} , we implement a weighted sum of R&D capital stock. We cannot use the function $1/d$ to compute the proximity G_{ij} since for values of d_{ij} equal to zero, the function $1/d_{ij}$ is not definite. To solve this problem, we use the negative exponential function, $1/e^{d_{ij}}$, so if the distance is zero, the geographic proximity is 1, i.e. the maximum possible value:

$$G_{ij} = 1 / e^{d_{ij}} \quad (4)$$

Once we have computed the geographic proximity G_{ij} among firms, we can construct the geographic based R&D spillover stock for firm i as:

$$Tsg_i = \sum_{i \neq j} G_{ij} K_j \quad (5)$$

Table 2 reports the geographic proximities of the same five firms as in the previous example. Although the R&D spillovers based on the proximities in the technological or geographic space are likely to be less contaminated by pecuniary externalities and common industry effects, evidence of their impact on productivity may still be unrelated to knowledge spillovers, but rather the result of spatially correlated technological opportunities. Yet, as emphasised by Griliches (1992), if new opportunities exogenously arise in a technological area, firms active in that area will increase their R&D spending and improve their productivity.

Table 2. Geographic proximities

	BASF	Bayer	Hitachi	IBM	Motorola
Basf	1.00				
Bayer	0.91	1.00			
Hitachi	0.00	0.00	1.00		
IBM	0.04	0.04	0.03	1.00	
Motorola	0.02	0.02	0.06	0.48	1.00

⁶ Orlando (2000) consulted the Directory of American Research and Technology 1993 which reports the location of firms’ corporate headquarters as well as the location and composition of their R&D. It follows that about 87% of the companies of a representative sample carry out their R&D at the same place as their corporate headquarter location.

In order for R&D spillovers to be effective, firms must be able to ‘absorb’ the knowledge generated outside their walls. Yet, the empirical measurement of firms’ absorptive capacity, i.e. the ability of firms to identify, assimilate and exploit knowledge from the environment (Cohen and Levinthal, 1989) has proven to be difficult. The usual way retained to measure absorptive capacity is through R&D⁷. Indeed, as discussed by Cohen and Levinthal (1989), R&D activities are not only aimed at generating new knowledge but these activities also play an important role in building a firm’s absorptive capacity. In practice, it is difficult to disentangle between the two faces of this dual role of R&D. Kinoshita (2000) and Grunfeld (2004) consider the interaction term between the firm’s own R&D intensity and the R&D spillover variable to evaluate the firms’ absorptive capacity. In this study we consider the R&D stock as an alternative of the R&D intensity in order to capture the cumulative nature of the learning process which helps to build the absorptive capacity.

2.3. Econometric framework and summary statistics

Following Griliches (1979), the impact of technological and geographic R&D spillovers on firms’ productivity growth besides traditional inputs and the firm’s own R&D stock is estimated by means of an extended Cobb-Douglas production function:

$$Y = AL^{\beta_1}C^{\beta_2}K^{\beta_3}X^{\gamma} \quad (6)$$

This function can also be estimated by adding an interaction term between the firm’s own R&D capital and the R&D spillover stock by setting:

$$\gamma = \gamma_1 + \gamma_2 K \quad (7)$$

This allow us to test for the presence and the extent of absorptive capacity. Replacing (7) in (6), taking the logarithms and introducing a set of time dummies leads to:

$$\ln Y_{it} = \alpha_i + \lambda_t + \beta_1 \ln L_{it} + \beta_2 \ln C_{it} + \beta_3 \ln K_{it} + \gamma_1 \ln X_{it} + \gamma_2 K_{it} \ln X_{it} + \varepsilon_{it} \quad (8)$$

where: \ln is the natural logarithm;

i indices the firm and t indices the time;

Y_{it} is the value-added;

L_{it} is the employment;

C_{it} is the stock of physical capital;

K_{it} is the stock of R&D capital;

α_i is the firm’s fixed effect;

λ_t is a set of time dummies;

X_{it} is a vector of spillover components;

β and γ are vectors of parameters and

⁷ The framework developed by Griffith et al. (2003) is based on the interaction between Research employment and the gap between the level of total factor productivity (TFP) of a given industry and the industry with the highest TFP. Cassiman and Veugelers (2002) and Schmidt (2005) use direct measures of absorptive capacities from innovation surveys.

ε_{it} is the disturbance term.

Different R&D spillover components have been estimated:

Ts = total stock of technological spillovers;

Ns = national⁸ stock of technological spillovers;

Is = international stock of technological spillovers;

Tsg = total stock of geographic spillovers;

Nsg = national stock of geographic spillovers and

Isg = international stock of geographic spillovers.

Equation (8) is estimated by means of four econometric models for panel data: OLS first difference, within group, first difference and system IV-GMM. While all four models allow controlling for firms' permanent unobserved specific effects, only the latter allows one taking into account the possible endogeneity or simultaneity issue of the explanatory variables with the error term⁹. The more recent system GMM estimator combines the standard set of equations in first difference (GMM first difference) with suitably lagged levels as instruments, with an additional set of equations in levels with suitably lagged first differences as instruments¹⁰. The validity of these additional instruments, which consist of first difference lagged values of the regressors, can be tested through difference Sargan over-identification tests. The system GMM estimator can lead to considerable improvements in terms of efficiency as compared to the first difference GMM estimator¹¹.

Appendix 2, 4 and 5 present some descriptive statistics and Appendix 3 gives the representativeness of the dataset in terms of R&D expenditures. R&D expenditures of the 808 firms of the dataset amount to about 30 to 50% of the corresponding R&D aggregates for the EU, Japan and the US.

3. Empirical findings

This section presents the main empirical findings of the paper. Table 3 reports the estimates regarding the impact of traditional inputs, the firm's own R&D stock and the geographic based R&D spillover stock on productivity growth. The results appear to be different from one model to the other; the OLS first difference estimator underestimates the coefficients values, while the within group estimator tend to overestimate them. The differences between the first difference and the within estimates suggest the presence of measurement error in the left hand side variables (Griliches and Hausman, 1986). Simultaneity and endogeneity issues

⁸ By national, we mean the weighted sum of R&D stocks of firms from a same geographic block, i.e. Europe, Japan or the US.

⁹ See Griliches and Mairesse (1995) for a discussion.

¹⁰ See Blundell and Bond (1998) for a discussion about the instruments available for the first-differenced equations.

¹¹ This occurs when the lagged levels of the series are only weakly correlated with subsequent first differences, so that the instruments available for the first difference equations are weak. See Arellano and Bover (1995) and Blundell and Bond (1998).

are another source of bias between the GMM estimates and the first difference and within ones.

Given the reasons discussed before, our favourite estimates are given by the GMM system model. Yet, for the estimates based on the full sample, the Sargan test of overidentifying restrictions rejects the validity of the set of instruments at the 5% level of significance. This may be explained by differences in terms of endogeneity and simultaneity of some variables across the three economic blocs. If such differences are present, the choice of lagged values of the regressors as valid instruments will vary across regions. As a result, using the same lags for all of them may reject the validity of some instruments. Turning to the results by economic area seems to confirm this explanation as the Sargan tests are all statistically significant at the 5% level.

Table 3. Geographic based R&D spillover

OLS-FD	Within		GMM-F.D.	GMM-SYS		
TOTAL SAMPLE: 808 FIRMS X 10 YEARS						
$\Delta \ln L$	0.47* (0.022)	LnL 0.55* (0.011)	$\Delta \ln L$	0.51* (0.017)	$\Delta \ln L$	0.49* (0.016)
$\Delta \ln C$	0.15* (0.016)	LnC 0.19* (0.009)	$\Delta \ln C$	0.15* (0.012)	$\Delta \ln C$	0.14* (0.011)
$\Delta \ln K$	0.26* (0.011)	LnK 0.26* (0.011)	$\Delta \ln K$	0.28* (0.021)	$\Delta \ln K$	0.22* (0.013)
$\Delta \ln Tsg$	0.10* (0.018)	LnTsg 0.58* (0.017)	$\Delta \ln Tsg$	0.64* (0.032)	$\Delta \ln Tsg$	0.44* (0.024)
			X^2 (d.f.)	253.35 (98)	X^2 (d.f.)	360.75 (128)
US SAMPLE: 465 FIRMS X 10 YEARS						
$\Delta \ln L$	0.46* (0.027)	lnL 0.62* (0.013)	$\Delta \ln L$	0.44* (0.016)	$\Delta \ln L$	0.41* (0.016)
$\Delta \ln C$	0.16* (0.020)	lnC 0.17* (0.010)	$\Delta \ln C$	0.18* (0.014)	$\Delta \ln C$	0.18* (0.012)
$\Delta \ln K$	0.29* (0.016)	lnK 0.24* (0.014)	$\Delta \ln K$	0.26* (0.010)	$\Delta \ln K$	0.23* (0.014)
$\Delta \ln Tsg$	0.14* (0.029)	lnTsg 0.70* (0.021)	$\Delta \ln Tsg$	0.58* (0.036)	$\Delta \ln Tsg$	0.42* (0.027)
			X^2 (d.f.)	113.83** (98)	X^2 (d.f.)	145.66** (128)
JP SAMPLE: 227 FIRMS X 10 YEARS						
$\Delta \ln L$	0.44* (0.091)	LnL 0.31* (0.027)	$\Delta \ln L$	0.60* (0.041)	$\Delta \ln L$	0.54* (0.026)
$\Delta \ln C$	0.15* (0.033)	LnC 0.27* (0.021)	$\Delta \ln C$	0.21* (0.018)	$\Delta \ln C$	0.22* (0.013)
$\Delta \ln K$	0.28* (0.050)	LnK 0.24* (0.025)	$\Delta \ln K$	0.07* (0.029)	$\Delta \ln K$	0.29* (0.022)
$\Delta \ln Tsg$	0.05** (0.025)	LnTsg 0.43* (0.034)	$\Delta \ln Tsg$	0.63* (0.034)	$\Delta \ln Tsg$	0.36* (0.024)
			X^2 (d.f.)	113.33** (98)	X^2 (d.f.)	145.26** (128)
EU SAMPLE: 116 FIRMS X 10 YEARS						
$\Delta \ln L$	0.65* (0.056)	LnL 0.60* (0.029)	$\Delta \ln L$	0.66* (0.010)	$\Delta \ln L$	0.57* (0.009)
$\Delta \ln C$	0.07* (0.032)	LnC 0.14* (0.024)	$\Delta \ln C$	0.08* (0.005)	$\Delta \ln C$	0.14* (0.008)
$\Delta \ln K$	0.28* (0.071)	LnK 0.21* (0.032)	$\Delta \ln K$	0.20* (0.013)	$\Delta \ln K$	0.27* (0.017)
$\Delta \ln Tsg$	0.19* (0.035)	LnTsg 0.56* (0.045)	$\Delta \ln Tsg$	0.74* (0.022)	$\Delta \ln Tsg$	0.52* (0.013)
			X^2 (d.f.)	94.30** (76)	X^2 (d.f.)	95.81** (84)

Notes:

*(**)=statistically significant at the 5 (10)% level;

Heteroskedastic-consistent standard errors in brackets;

Two step estimates; instruments used: observations dated t-2 and t-3 for Europe and t-2, t-3, t-4 and t-5 for Japan and USA;

Chi² value of Sargan overidentification test and number of degrees of freedom in brackets.

The estimated elasticities associated with the labour variable vary between 0.41 for the US and 0.57 for Europe while for the physical capital variable the coefficients range from 0.14 for Europe to 0.22 for Japan. It should be noted that these estimates are somewhat low compared to the ones generally reported in the literature. As pointed out by Capron and Cincera (1998), this can be explained by the fact that we use net sales instead of value added for measuring the output in equation (6) and we do not include raw materials in this equation due to data

unavailability. Assuming constant returns to scale should bring an elasticity associated with the raw materials of about 0.3 to 0.4.

The results indicate a positive and significant impact of firms' own R&D capital on productivity performance. The magnitude of these coefficients, i.e. 0.23 for the US, 0.27 for Europe and 0.29 for Japan, are somewhat higher compared to the ones obtained in the related literature which can be explained by the high R&D intensity characterizing the firms of the dataset¹². Finally there appears to be a rather strong relationship between the growth of productivity and the geography based spillover R&D stock. The estimated elasticity associated with this variable is always significant and higher as compared to the firm's own R&D stock. In terms of the regressions performed for each geographic area, we observe a stronger elasticity for Europe (about 0.5 for the GMM system model) and somewhat lower values for the US and Japan (about 0.35-0.4). These findings, which are in line with the results of previous studies, indicate that the geographic distance between firms matter for R&D spillovers¹³.

Table 4. National/International Spillover effects (geographic proximity)

OLS-FD		Within		GMM-F.D.		GMM-SYS	
US SAMPLE: 465 FIRMS X 10 YEARS							
$\Delta \ln L$	0.49* (0.028)	$\ln L$	0.64* (0.013)	$\Delta \ln L$	0.51* (0.018)	$\Delta \ln L$	0.47* (0.017)
$\Delta \ln C$	0.15* (0.020)	$\ln C$	0.16* (0.010)	$\Delta \ln C$	0.16* (0.013)	$\Delta \ln C$	0.15* (0.013)
$\Delta \ln K$	0.23* (0.010)	$\ln K$	0.20* (0.014)	$\Delta \ln K$	0.18* (0.034)	$\Delta \ln K$	0.22* (0.015)
$\Delta \ln Nsg$	0.66* (0.050)	$\ln Nsg$	0.81* (0.025)	$\Delta \ln Nsg$	0.87* (0.042)	$\Delta \ln Nsg$	0.69* (0.034)
$\Delta \ln Isg$	-0.02* (0.008)	$\ln Isg$	-0.02** (0.014)	$\Delta \ln Isg$	-0.06* (0.009)	$\Delta \ln Isg$	-0.10* (0.012)
				X^2 (d.f.)	123.08** (109)	X^2 (d.f.)	164.88** (160)
JP SAMPLE: 227 FIRMS X 10 YEARS							
$\Delta \ln L$	0.52* (0.108)	$\ln L$	0.31* (0.028)	$\Delta \ln L$	0.46* (0.031)	$\Delta \ln L$	0.48* (0.031)
$\Delta \ln C$	0.17* (0.033)	$\ln C$	0.27* (0.021)	$\Delta \ln C$	0.21* (0.016)	$\Delta \ln C$	0.23* (0.014)
$\Delta \ln K$	0.27* (0.049)	$\ln K$	0.24* (0.026)	$\Delta \ln K$	0.13* (0.016)	$\Delta \ln K$	0.22* (0.013)
$\Delta \ln Nsg$	0.08* (0.018)	$\ln Nsg$	0.37* (0.053)	$\Delta \ln Nsg$	1.68* (0.034)	$\Delta \ln Nsg$	0.63* (0.052)
$\Delta \ln Isg$	-0.21* (0.071)	$\ln Isg$	0.05 (0.047)	$\Delta \ln Isg$	-0.78* (0.031)	$\Delta \ln Isg$	-0.21* (0.039)
				X^2 (d.f.)	121.16** (109)	X^2 (d.f.)	164.23** (160)
EU SAMPLE: 116 FIRMS X 10 YEARS							
$\Delta \ln L$	0.68* (0.055)	$\ln L$	0.66* (0.030)	$\Delta \ln L$	0.71* (0.007)	$\Delta \ln L$	0.71* (0.008)
$\Delta \ln C$	0.03 (0.033)	$\ln C$	0.08* (0.024)	$\Delta \ln C$	0.04* (0.003)	$\Delta \ln C$	0.03* (0.005)
$\Delta \ln K$	0.21* (0.077)	$\ln K$	0.13* (0.033)	$\Delta \ln K$	0.10* (0.010)	$\Delta \ln K$	0.10* (0.011)
$\Delta \ln Nsg$	0.69* (0.093)	$\ln Nsg$	0.79* (0.056)	$\Delta \ln Nsg$	0.84* (0.019)	$\Delta \ln Nsg$	0.89* (0.009)
$\Delta \ln Isg$	0.02* (0.006)	$\ln Isg$	0.02** (0.014)	$\Delta \ln Isg$	0.08* (0.002)	$\Delta \ln Isg$	0.02* (0.001)
				X^2 (d.f.)	96.86** (90)	X^2 (d.f.)	104.90** (98)

Notes:

*(**)=statistically significant at the 5 (10)% level;

Two step estimates; instruments used: observations dated t-2 and t-3 for Europe and t-2, t-3, t-4 and t-5 for Japan and USA;

Heteroskedastic-consistent standard errors in brackets;

Chi² value of Sargan overidentification test and number of degrees of freedom in brackets.

Table 4 confirms the role of localisation effects on knowledge flows across the three main pillars within the Triad. Following Jaffe *et al.* (1993), the geographic R&D spillover stock is split into two components, for each region. The first component refers to the R&D of firms within the national borders (national stock – Nsg) and the second to the foreign ones

¹² See Appendix 4.

¹³ See Jaffe *et al.* (1993), Jaffe and Trajtenberg (1996, 1999), Orlando (2000), Maurseth and Verspagen (2002) or Greunz (2004).

(international stock, I_{sg}). Interestingly, the national geographic based R&D spillover stock has a higher elasticity with respect to output growth as compared to the results in the previous table. As emphasised by Maurseth and Verspagen (2002) who refer to the concept of National Innovation Systems, factors such as institutional settings, national policies, language and history may explain the significant effect of country borders. The national component has a somewhat higher impact on firms' productivity growth in Europe (elasticity of about 0.9 for the GMM system estimates) compared to the US (0.7) and Japan (0.6). The international component appears to have a significant and negative impact for the US and Japan (-0.1 and -0.23 respectively). This negative effect of R&D carried out outside the national borders on productivity performance may be due to competition. Yet, a positive though very small effect is observed for European firms.

Table 5. Technology based R&D spillovers

OLS-FD	Within	GMM-F.D.	GMM-SYS
TOTAL SAMPLE: 808 FIRMS X 10 YEARS			
$\Delta \ln L$ 0.49* (0.024)	$\ln L$ 0.59* (0.011)	$\Delta \ln L$ 0.54* (0.018)	$\Delta \ln L$ 0.52* (0.017)
$\Delta \ln C$ 0.14* (0.016)	$\ln C$ 0.18* (0.009)	$\Delta \ln C$ 0.13* (0.012)	$\Delta \ln C$ 0.12* (0.012)
$\Delta \ln K$ 0.26* (0.016)	$\ln K$ 0.22* (0.012)	$\Delta \ln K$ 0.18* (0.030)	$\Delta \ln K$ 0.23* (0.014)
$\Delta \ln Ts$ 0.46* (0.044)	$\ln Ts$ 0.75* (0.020)	$\Delta \ln Ts$ 0.87* (0.040)	$\Delta \ln Ts$ 0.68* (0.033)
		X^2 (d.f.) 253.35 (98)	X^2 (d.f.) 360.75 (128)
US SAMPLE: 465 FIRMS X 10 YEARS			
$\Delta \ln L$ 0.48* (0.028)	$\ln L$ 0.64* (0.013)	$\Delta \ln L$ 0.50* (0.018)	$\Delta \ln L$ 0.46* (0.018)
$\Delta \ln C$ 0.15* (0.020)	$\ln C$ 0.17* (0.010)	$\Delta \ln C$ 0.17* (0.013)	$\Delta \ln C$ 0.16* (0.013)
$\Delta \ln K$ 0.26* (0.011)	$\ln K$ 0.21* (0.014)	$\Delta \ln K$ 0.24* (0.032)	$\Delta \ln K$ 0.27* (0.015)
$\Delta \ln Ts$ 0.62* (0.053)	$\ln Ts$ 0.85* (0.025)	$\Delta \ln Ts$ 0.81* (0.044)	$\Delta \ln Ts$ 0.60* (0.032)
		X^2 (d.f.) 114.15** (98)	X^2 (d.f.) 145.66** (128)
JP SAMPLE: 227 FIRMS X 10 YEARS			
$\Delta \ln L$ 0.28* (0.050)	$\ln L$ 0.32* (0.027)	$\Delta \ln L$ 0.62* (0.041)	$\Delta \ln L$ 0.56* (0.030)
$\Delta \ln C$ 0.15* (0.033)	$\ln C$ 0.23* (0.022)	$\Delta \ln C$ 0.16* (0.018)	$\Delta \ln C$ 0.15* (0.013)
$\Delta \ln K$ 0.23* (0.010)	$\ln K$ 0.20* (0.026)	$\Delta \ln K$ 0.05 (0.031)	$\Delta \ln K$ 0.22* (0.025)
$\Delta \ln Ts$ 0.07* (0.109)	$\ln Ts$ 0.63* (0.044)	$\Delta \ln Ts$ 0.81* (0.046)	$\Delta \ln Ts$ 0.64* (0.038)
		X^2 (d.f.) 114.99** (98)	X^2 (d.f.) 145.26** (128)
EU SAMPLE: 116 FIRMS X 10 YEARS			
$\Delta \ln L$ 0.68* (0.056)	$\ln L$ 0.66* (0.029)	$\Delta \ln L$ 0.71* (0.010)	$\Delta \ln L$ 0.70* (0.014)
$\Delta \ln C$ 0.03 (0.033)	$\ln C$ 0.08* (0.024)	$\Delta \ln C$ 0.04* (0.005)	$\Delta \ln C$ 0.03* (0.007)
$\Delta \ln K$ 0.17* (0.081)	$\ln K$ 0.11* (0.033)	$\Delta \ln K$ 0.04* (0.018)	$\Delta \ln K$ 0.08* (0.012)
$\Delta \ln Ts$ 0.83* (0.100)	$\ln Ts$ 0.87* (0.058)	$\Delta \ln Ts$ 1.01* (0.021)	$\Delta \ln Ts$ 1.00* (0.018)
		X^2 (d.f.) 94.30** (76)	X^2 (d.f.) 95.81** (84)

Notes:

**=statistically significant at the 5 (10)% level;

Heteroskedastic-consistent standard errors in brackets;

Two step estimates; instruments used: observations dated t-2 and t-3 for Europe and t-2, t-3, t-4 and t-5 for Japan and USA;

Chi² value of Sargan overidentification test and number of degrees of freedom in brackets.

If the geographic proximity and localisation effects represent an important determinant of R&D spillovers, other proximity measures may also be important for the diffusion of knowledge externalities. One of the proximity measures which has already been investigated in the literature (Jaffe, 1986) assumes that R&D spillovers are proportional to the intensity and similarity of firms' research activities¹⁴. Table 5 reports the results of the productivity

¹⁴ The third proximity measure which is not examined in this study rests on the amount of economic transactions between firms. See Cincera (2005) for a discussion.

equation augmented with the technology based R&D spillover stock. It is worth noting that except for a few cases, the estimated coefficients associated with traditional inputs and the firm's own R&D stock are not different from the ones for the geographic based R&D spillover stock. Interestingly, this conclusion does not hold for the spillover variable. Here the corresponding elasticities appear to be much higher (about 0.6 for the US and Japan and about 1 for European firms for the GMM system estimates). Given the methodologies implemented to construct the geographic and technological based R&D externalities, this would suggest that the technological proximity is more important for R&D spillovers than the geographic distance (about 50% for the US and Japan to 100% For Europe).

Table 6. National/International spillover effects (technological proximity)

OLS-FD	Within	GMM-F.D.	GMM-SYS
US SAMPLE: 465 FIRMS X 10 YEARS			
$\Delta \ln L$ 0.48* (0.028)	LnL 0.64* (0.013)	$\Delta \ln L$ 0.52* (0.018)	$\Delta \ln L$ 0.46* (0.017)
$\Delta \ln C$ 0.15* (0.020)	LnC 0.17* (0.010)	$\Delta \ln C$ 0.16* (0.013)	$\Delta \ln C$ 0.16* (0.014)
$\Delta \ln K$ 0.24* (0.010)	LnK 0.21* (0.014)	$\Delta \ln K$ 0.20* (0.032)	$\Delta \ln K$ 0.20* (0.016)
$\Delta \ln N_s$ 1.14* (0.133)	LnNs 0.70* (0.072)	$\Delta \ln N_s$ 1.31* (0.099)	$\Delta \ln N_s$ 1.95* (0.124)
$\Delta \ln I_s$ -0.46* (0.123)	LnIs 0.16* (0.070)	$\Delta \ln I_s$ -0.42* (0.089)	$\Delta \ln I_s$ -1.23* (0.108)
		X^2 (d.f.) 123.11** (109)	X^2 (d.f.) 164.88** (160)
JP SAMPLE: 227 FIRMS X 10 YEARS			
$\Delta \ln L$ 0.42* (0.102)	LnL 0.30* (0.027)	$\Delta \ln L$ 0.51* (0.035)	$\Delta \ln L$ 0.50* (0.031)
$\Delta \ln C$ 0.10* (0.032)	LnC 0.20* (0.021)	$\Delta \ln C$ 0.09* (0.015)	$\Delta \ln C$ 0.09* (0.013)
$\Delta \ln K$ 0.24* (0.049)	LnK 0.21* (0.025)	$\Delta \ln K$ 0.10* (0.033)	$\Delta \ln K$ 0.25* (0.025)
$\Delta \ln N_s$ 2.95 (0.219)	LnNs 1.55* (0.155)	$\Delta \ln N_s$ 1.88* (0.116)	$\Delta \ln N_s$ 1.74* (0.114)
$\Delta \ln I_s$ -2.93* (0.221)	LnIs -0.94* (0.160)	$\Delta \ln I_s$ -1.07* (0.116)	$\Delta \ln I_s$ -1.08* (0.124)
		X^2 (d.f.) 121.19** (109)	X^2 (d.f.) 164.23** (160)
EU SAMPLE: 116 FIRMS X 10 YEARS			
$\Delta \ln L$ 0.68* (0.056)	LnL 0.65* (0.029)	$\Delta \ln L$ 0.69* (0.059)	$\Delta \ln L$ 0.72* (0.007)
$\Delta \ln C$ 0.03 (0.033)	LnC 0.08* (0.024)	$\Delta \ln C$ 0.14* (0.004)	$\Delta \ln C$ 0.02* (0.005)
$\Delta \ln K$ 0.16* (0.083)	LnK 0.11* (0.033)	$\Delta \ln K$ 0.07* (0.010)	$\Delta \ln K$ 0.05* (0.012)
$\Delta \ln N_s$ -0.43* (0.208)	LnNs 0.07 (0.131)	$\Delta \ln N_s$ -0.04 (0.038)	$\Delta \ln N_s$ -1.11* (0.058)
$\Delta \ln I_s$ 1.25* (0.208)	LnIs 0.78* (0.130)	$\Delta \ln I_s$ 1.00* (0.035)	$\Delta \ln I_s$ 2.06* (0.062)
		X^2 (d.f.) 96.86** (90)	X^2 (d.f.) 104.05** (98)

Notes:

*(**)=statistically significant at the 5 (10)% level;

Heteroskedastic-consistent standard errors in brackets;

Two step estimates; instruments used: observations dated t-2 and t-3 for Europe and t-2, t-3, t-4 and t-5 for Japan and USA;

Chi² value of Sargan overidentification test and number of degrees of freedom in brackets.

In order to shed some further light on this question, we also split the technological based externalities into a national and an international component as we did for the geographic based R&D spillover stock. This allows us to investigate the extent to which both geographic and technological proximities matter for the diffusion of knowledge. The results shown in Table 6 are quite interesting. We observe a strong and positive impact of the national stock component for the US and Japan and a strong negative effect of the international component. A symmetric result is observed for Europe. European firms appear to benefit positively and to a large extent from the R&D spillovers generated by international firms while a negative impact is detected for the national R&D spillover stock. Comparing these results with the ones in Table 6, we may conclude for the US and Japan not only that the technological proximity is more important than the geographic one but also that both proximities need to be present in order for R&D externalities to be effective in explaining firms' productivity growth. For the firms that are distant in the geographic sense, technological proximity also

matters but in a negative way. In this case the R&D of rivals is detrimental to the firm's productivity performance. For Europe, the interpretation is more subtle. Geographic proximity is important for R&D spillovers. Yet, this proximity combined with the technological one lead to a negative competitive effect of the external knowledge stock. One possible interpretation is that European countries are not very well integrated in terms of their innovation systems and the competitive pressures of R&D activities seem to overcome the positive effects of pure knowledge spillovers. Then, the positive impact of the international stock seems to confirm the findings of Capron and Cincera (1998). The fact that Europe appears to only benefit from the international stock might indicate that the productivity performance of European firms seems to depend, to a large extent, on technologies developed by technological neighbours located outside the European borders.

Table 7. Absorptive capacity effect

GMM-SYS	
Technological proximity	Geographic Proximity
US SAMPLE: 465 FIRMS X 10 YEARS	
$\Delta \ln L$ 0.69* (0.025)	$\Delta \ln L$ 0.69* (0.025)
$\Delta \ln C$ 0.26* (0.014)	$\Delta \ln C$ 0.26* (0.014)
$\Delta \ln K$ 0.27* (0.016)	$\Delta \ln K$ 0.27* (0.016)
$\Delta K \ln Ts$ 0.79* (0.152)	$\Delta K \ln Ts_g$ 0.79* (0.157)
χ^2 (d.f.) 145.66** (128)	χ^2 (d.f.) 145.66** (128)
JP SAMPLE: 227 FIRMS X 10 YEARS	
$\Delta \ln L$ 0.48* (0.031)	$\Delta \ln L$ 0.48* (0.031)
$\Delta \ln C$ 0.33* (0.014)	$\Delta \ln C$ 0.33* (0.013)
$\Delta \ln K$ 0.26* (0.013)	$\Delta \ln K$ 0.26* (0.013)
$\Delta K \ln Ts$ 0.71* (0.110)	$\Delta K \ln Ts_g$ 0.73* (0.116)
χ^2 (d.f.) 145.26** (128)	χ^2 (d.f.) 145.26** (128)
EU SAMPLE: 116 FIRMS X 10 YEARS	
$\Delta \ln L$ 0.41* (0.011)	$\Delta \ln L$ 0.41* (0.010)
$\Delta \ln C$ 0.29 (0.009)	$\Delta \ln C$ 0.29* (0.009)
$\Delta \ln K$ 0.23* (0.013)	$\Delta \ln K$ 0.23* (0.015)
$\Delta K \ln Ts$ 0.56* (0.048)	$\Delta K \ln Ts_g$ 0.59* (0.047)
χ^2 (d.f.) 95.81** (84)	χ^2 (d.f.) 95.81** (84)

Notes:

**=statistically significant at the 5 (10)% level;

Heteroskedastic-consistent standard errors in brackets;

Two step estimates; instruments used: observations dated t-2 and t-3 for Europe and t-2, t-3, t-4 and t-5 for Japan and USA;

Chi² value of Sargan overidentification test and number of degrees of freedom in brackets.

Assuming that the stock of own R&D is a proxy of absorptive capacity, it is possible to analyse the extent to which this capacity interacts with both geographic and technological sources of R&D spillovers. The results reported in Table 7 indicate a positive impact of the interaction terms between firms' own R&D stock and both types of R&D spillover stocks. These findings suggest the presence of complementarities between these knowledge stocks. Furthermore, the results also suggest no any particular differences between the levels of absorptive capacities and their interaction with the geographic and technological R&D spillover variables. Yet, in terms of economic blocks, the ability of US and to a lesser extent of Japanese firms to exploit external knowledge and to turn it into productivity growth appear to be higher compared to European firms.

4. Conclusions

The purpose of this study has been to assess the impact, besides traditional inputs and the firm's own R&D stock, of two types of R&D externalities on large international R&D companies' productivity growth over the last decade. The first R&D spillover variable considered is formalized by weighting the R&D stocks of other firms according to their geographic proximity. As in previous studies in the literature on the geography of innovation, the idea has been to examine the extent to which localisation effects matter in the diffusion of R&D spillovers. The second type of R&D externality uses the distances of firms into a technological space constructed on the basis of the distribution of firms' patents across technological fields. Besides the physical proximity between the sender and the recipient of knowledge flows, technological 'closeness' is another dimension which can affect the scope and direction of R&D spillovers.

The main results of the paper can be summarised as follow. Both the geographic and technological based R&D spillovers stocks have an important and positive impact on the productivity growth of firms. The effects of the pure technological externalities on firms' economic performance appear to be higher as compared to the geographic spillovers. This finding suggests that the technological proximity is more important than the geographic one for the impact of R&D spillovers on firms' productivity growth. Differences are also present across economic blocks. While of a comparable magnitude in the US and in Japan, the elasticity of the R&D spillover stocks appears to be higher for European firms: 0.5 (respectively 1) in the EU against 0.4 (respectively 0.6) in the US and Japan for the geographic (respectively technologically)-based R&D spillover pool.

In order to further analyse the interplay between geographic and technological proximities for the diffusion of knowledge, both types of R&D spillover stocks have been split into a national and an international component. The main conclusions are that R&D spillovers tend to be spatially bounded at least at the level of the spatial aggregation considered in this study and that for the US and Japan the importance of geographic proximity for knowledge diffusion is dependent to technological proximity. Hence in order for R&D externalities to be fully effective in terms of productivity performance both proximities are needed. Geographic and technological proximities should therefore be viewed as complementary. This finding is however not confirmed for Europe. European firms seem to mostly benefit from the R&D results generated by their technological competitors located outside the European borders. When both geographic and technological proximities are present, a negative impact of R&D spillovers on productivity growth is observed. There are two possible interpretations for these findings. First, the fragmentation of the European Research Area or the lack of integration of the National Innovation Systems of its Member States prevents European firms from fully internalizing the outcomes of the R&D activities carried out by their neighbours. In this case, the negative effects of competitors' R&D seem to outweigh the positive outcomes of pure knowledge spillovers. The fact that the absorptive capacity has been found to be lower for European firms compared to US and Japanese ones seems to corroborate this conclusion. Second, the fact that European firms appear to mainly benefit from R&D spillovers generated by foreign firms may suggest that the former are lagging behind the ones close to the technological frontier.

In order to further explore these questions, further analyses are needed. Among the few suggestions for future work, we can mention the level of aggregation of spatial units. The level of observation retained in this study, i.e. the country and the European level, is probably too broad and it would be interesting to replicate the analysis at a more disaggregated spatial level such as the region. As it has already been done in previous studies, we plan to use

information on patent citations to construct a more direct measure for R&D spillovers. Backward citations for instance, i.e. references in patent documents to former patents, can be interpreted as evidence of spillover effects from the knowledge described in the cited patent to the knowledge of the citing patent. Finally, the analysis could be enriched by considering alternative measures of absorptive capacities and their impact on firm economic performance such as the level of education of the workforce.

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Appendix 1. Classification of Patent Classes into Technological Categories and Sub-Categories

Cat. Code	Category Name	Sub-Cat. Code	Sub-Category Name	Patent Classes
1	Chemical	11	Agriculture, Food, Textiles	8, 19, 71, 127, 442, 504
		12	Coating	106, 118, 401, 427
		13	Gas	48, 55, 95, 96
		14	Organic Compounds	534, 536, 540, 544, 546, 548, 549, 552, 554, 556, 558, 560, 562, 564, 568, 570
		15	Resins	520, 521, 522, 523, 524, 525, 526, 527, 528, 530
		19	Miscellaneous-chemical	23, 34, 44, 102, 117, 149, 156, 159, 162, 196, 201, 202, 203, 204, 205, 208, 210, 216, 222, 252, 260, 261, 349, 366, 416, 422, 423, 430, 436, 494, 501, 502, 510, 512, 516, 518, 585, 588
2	Computers & Communications	21	Communications	178, 333, 340, 342, 343, 358, 367, 370, 375, 379, 385, 455
		22	Computer Hardware & Software	341, 380, 382, 395, 700, 701, 702, 704, 705, 706, 707, 708, 709, 710, 712, 713, 714
		23	Computer Peripherals	345, 347
		24	Information Storage	360, 365, 369, 711
3	Drugs & Medical	31	Drugs	424, 514
		32	Surgery & Medical Instruments	128, 600, 601, 602, 604, 606, 607
		33	Biotechnology	435, 800
		39	Miscellaneous-Drug&Med	351, 433, 623
4	Electrical & Electronic	41	Electrical Devices	174, 200, 327, 329, 330, 331, 332, 334, 335, 336, 337, 338, 392, 439
		42	Electrical Lighting	313, 314, 315, 362, 372, 445
		43	Measuring & Testing	73, 324, 356, 374
		44	Nuclear & X-rays	250, 376, 378
		45	Power Systems	60, 136, 290, 310, 318, 320, 322, 323, 361, 363, 388, 429
		46	Semiconductor Devices	257, 326, 438, 505
	49	Miscellaneous-Elec.	191, 218, 219, 307, 346, 348, 377, 381, 386	
5	Mechanical	51	Materials Processing & andling	65, 82, 83, 125, 141, 142, 144, 173, 209, 221, 225, 226, 234, 241, 242, 264, 271, 407, 408, 409, 414, 425, 451, 493
		52	Metal Working	29, 72, 75, 76, 140, 147, 148, 163, 164, 228, 266, 270, 413, 419, 420
		53	Motors, Engines & Parts	91, 92, 123, 185, 188, 192, 251, 303, 415, 417, 418, 464, 474, 475, 476, 477
		54	Optics	352, 353, 355, 359, 396, 399
		55	Transportation	104, 105, 114, 152, 180, 187, 213, 238, 244, 246, 258, 280, 293, 295, 296, 298, 301, 305, 410, 440
		59	Miscellaneous-Mechanical	7, 16, 42, 49, 51, 74, 81, 86, 89, 100, 124, 157, 184, 193, 194, 198, 212, 227, 235, 239, 254, 267, 291, 294, 384, 400, 402, 406, 411, 453, 454, 470, 482, 483, 492, 508

Sources: Hall et al. (2001)

Appendix 1. Classification of Patent Classes into Technological Categories and Sub-Categories (con't)

Cat. Code	Category Name	Sub-Cat. Code	Sub-Category Name	Patent Classes
6	Others	61	Agriculture, Husbandry, Food	43, 47, 56, 99, 111, 119, 131, 426, 449, 452, 460
		62	Amusement Devices	273, 446, 463, 472, 473
		63	Apparel & Textile	2, 12, 24, 26, 28, 36, 38, 57, 66, 68, 69, 79, 87, 112, 139, 223, 450
		64	Earth Working & Wells	37, 166, 171, 172, 175, 299, 405, 507
		65	Furniture, House Fixtures	4, 5, 30, 70, 132, 182, 211, 256, 297, 312
		66	Heating	110, 122, 126, 165, 237, 373, 431, 432
		67	Pipes & Joints	138, 277, 285, 403
		68	Receptacles	53, 206, 215, 217, 220, 224, 229, 232, 383
		69	Miscellaneous- Others	1, 14, 15, 27, 33, 40, 52, 54, 59, 62, 63, 84, 101, 108, 109, 116, 134, 135, 137, 150, 160, 168, 169, 177, 181, 186, 190, 199, 231, 236, 245, 248, 249, 269, 276, 278, 279, 281, 283, 289, 292, 300, 368, 404, 412, 428, 434, 441, 462, 503

Sources: Hall et al. (2001)

Appendix 2. Summary statistics

Variable	Mean	Std. Dev.	Min	Max
Ln S	12.13	2.58	3.32	18.93
Ln C	12.25	2.02	6.06	18.03
Ln L	8.29	1.69	3.71	13.56
Ln K	11.82	1.93	6.07	17.61
Ln Ts	18.70	0.66	13.85	19.87
Ln Ns	17.66	0.74	13.05	19.03
Ln Is	18.22	0.69	12.05	19.50
Ln Tsg	19.04	0.24	18.01	20.02
Ln Nsg	18.85	0.37	17.68	19.65
Ln Isg	16.99	0.60	15.52	19.45

Notes: 8080 observations (10 years x 808 firms).

Appendix 3. Representativeness of data: firms' R&D in % of domestic R&D expenditures

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Country										
Europe ^a	37.0	42.8	43.6	44.6	44.8	45.5	45.9	46.4	46.8	47.3
Japan	30.0	33.0	33.9	36.7	39.4	40.0	40.4	41.2	42.0	42.5
Usa	42.9	43.7	44.2	45.3	45.5	46.7	47.3	47.8	48.2	48.7

Sources: Worldscope database and OECD.

Notes: a) Europe is represented by the following countries: UK, Germany, France, Finland, Italy, Switzerland, Sweden, Norway, Nederland, Belgium and Denmark.

Appendix 4. Number of firms and means by sector and economic area

ISIC		# of firms	Labour x1000	# of patents x1000	in %	R&D Intens.	Ln TS	Ln TSg
10x-14x	Mining	9	42.3	5.8	0.01	1.97	18.82	18.95
15x-17x	Construction	19	9.3	11.6	0.02	0.99	18.41	19.09
20x-21x	Food & tobacco	22	39.5	17.4	0.03	1.23	17.72	19.04
22x-23x	Textile & apparel	10	3.0	5.8	0.01	1.72	18.01	19.05
24x-25x	Wood & furniture	7	12.3	5.8	0.01	0.77	18.60	19.01
26x-27x	Paper & printing	18	12.0	11.6	0.02	1.48	18.51	19.10
28x exc.283	Chemicals	100	15.0	69.6	0.12	3.33	18.91	19.07
283	Pharmaceuticals	54	11.4	40.6	0.07	8.96	18.31	19.05
291	Petroleum	8	33.5	6.0	0.01	1.40	18.48	18.95
30x	Rubber & plastics	19	10.9	11.6	0.02	2.10	18.89	19.08
32x	Stone & glass	14	15.4	12.0	0.02	1.83	18.73	19.06
33x	Primary metal	29	12.9	23.2	0.04	1.70	18.94	19.08
34x	Fabricated metal products	31	9.0	23.2	0.04	1.61	18.68	19.09
35x exc. 357-	Machinery & equipment	91	12.4	63.8	0.11	3.00	18.73	19.03
357x	Computers	44	37.6	29.0	0.05	7.84	18.99	19.01
36x exc. 365-367	Electrical equipment	29	19.9	23.2	0.04	3.26	18.78	19.10
365-367	Electronics	102	13.4	75.4	0.13	7.30	18.79	19.03
37x	Transportation equipments	54	64.6	40.6	0.07	3.19	18.84	19.03
38x	Instruments	90	6.5	63.8	0.11	6.95	18.64	19.02
39-48	Other	11	48.4	5.8	0.01	2.51	18.42	19.03
50x	Wholesale	10	12.7	5.8	0.01	3.43	18.70	19.04
73x-87x	Services	37	4.1	29.0	0.05	9.16	18.76	18.99
	EU	116	46.5	77.2	0.13	4.70	18.65	18.95
	JP	227	9.5	156.1	0.27	3.18	18.76	19.12
	USA	465	15.7	346.7	0.60	5.36	18.68	19.03
	TOTAL	808	18.4	580065	1	4.65	18.70	19.04

Appendix 5. Correlation matrix

	Ln S	Ln L	Ln C	Ln K	Ln Ts	Ln Tsg
Ln S	1					
Ln L	0.92*	1				
Ln C	0.96*	0.88*	1			
Ln K	0.85*	0.83*	0.83*	1		
Ln Ts	0.21*	0.19*	0.21*	0.28*	1	
Ln Tsg	0.09*	0.02**	0.08*	0.05*	0.12*	1

Notes:

**=statistically significant at the 5 (10)% level.

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