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Under what conditions do firms benefit from the research efforts of other organizations?

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Abstract

Although R&D spillovers play a key role in the battle for technological leadership, it is unclear under what conditions firms build on and benefit from the discoveries of others. The study described here empirically examines this issue. The findings indicate that, depending on technological opportunities, firm size and competitive pressure, the net impact of R&D spillovers on productivity can be either positive or negative. Specifically, we find that although spillover effects are positively associated with the technological opportunities that a firm faces, this relationship is reversed when firm size is considered. Whilst external R&D affects large self-reliant firms negatively, its impact on the productivity of smaller firms (who usually introduce incremental innovations that are characterized by a strong reliance on external technologies) is positive, and even higher than that of their own R&D. We also demonstrate that the economic payoff for firms' own R&D is lower when they face intense competition. In cases of low-appropriability however, spillover effects are more positive, allowing firms to increase their performance using the inventions of others.

Keywords: R&D, Innovation, Spillovers, Productivity, Competition

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1 INTRODUCTION

It has been recognized that industrial Research and Development (R&D) may affect not only the productivity performance of the organization that undertakes such activities (Griliches, 1986; Hall and Mairesse, 1995), but also the performance of other firms. Empirical research confirms the existence of R&D spillovers, indicating that the productivity achieved by a firm depends on the pool of scientific knowledge accessible to it (Adams and Jaffe, 1996; Geroski, 1995; Griliches, 1992; Scherer, 1982). However, past empirical results are conflicting: even though many studies find the impact of R&D spillovers to be both positive and high (Bernstein, 1988; Branstetter, 1996; Raut, 1995), for reasons that are often unclear, other studies find that spillovers have negligible or even negative consequences for firm performance (Antonelli, 1994; Geroski, 1991; Wakelin, 2001). Although it is known that in order to unlock their economic potential, companies must actively search for and exploit external ideas and technologies (Chesbrough, 2003; 2007), there is a question that remains unanswered. When do firms utilize successfully external knowledge to create additional value, and when do they fail to do so?

This study extends previous research by addressing the above question and indicating that the reason for previously conflicting results may be an incomplete understanding of the factors influencing the spillovers-performance relationship. Put differently, drawing on theories of innovation and knowledge externalities, it examines the conditions under which a firm benefits from the technological achievements and research discoveries of other firms. Specifically, the study focuses on three factors that may influence the assets, resources and market positions of companies and in turn, the impact that spillovers have on their productivity performance. Initially, we analyze the role of technological opportunities and firm size. Although past studies have evaluated how these two factors impact on a firm's own innovation, there has been little research concerning their impact on the ability of organizations to benefit from external R&D. The third factor that the study investigates is that of competitive conditions. Theory suggests that higher competitive pressure is associated with imperfect appropriability and in turn, with stronger spillovers. We test this theoretical prediction and examine whether variations in the effects of R&D spillovers may be attributable to the level of competition. This is particularly important as existing research often ignores that the R&D undertaken by other firms increases not only the pool of scientific knowledge, but also the level of competitive pressure (Aghion et al., 2001).

In addition to the examination of the role of technological opportunities, firm size and competition, this paper differs from previous studies in a number of other ways. First, it distinguishes between the R&D undertaken by intra-industry competitors and that undertaken by external (inter-industry) innovators. Employing a variety of different weighting methods, it investigates whether firms successfully utilize knowledge gained from their rivals (whose products are often substitutes for their own products), or whether they gain more from firms in more distantly related industries (whose products either complement their own or are not directly related to them). Second, the study utilizes firm-level data (for the UK manufacturing sector). The use of micro-level data allows the separation of productivity advances that are result of a firm's specific capabilities, from those improvements that are general to the industry (Wakelin, 2001). Third, in contrast to studies that use the GDP price index to deflate R&D expenditures, this paper uses recently constructed R&D price indices, thereby capturing R&D-cost idiosyncrasies that vary across sectors. Indeed, the data indicate that R&D costs tend to rise more rapidly for low-tech sectors, implying that these firms have to pay more for industrial research.

The paper is organized as follows. The next two sections present the theoretical context of the study, and describe the methodology and the data. The fourth section presents the findings concerning intra- and inter-industry spillovers. We then explore the role of technological opportunities and firm size in the fifth section, while the sixth investigates the role of competition. Conclusions are drawn in the last section.

2 POSITIVE AND NEGATIVE R&D SPILLOVERS

The rationale behind R&D spillovers is that the technology and scientific knowledge developed by one firm is often useful to others as well (Griliches, 1992; Scherer, 1982). Hence, R&D may improve not only a firm's own productivity but also that of other firms of the same industry or even of other industries. R&D spillovers may occur through trade, i.e. when the new products that a firm develops are used as inputs by other firms (Mohnen, 1999). A good example is that of the IT industry, the products of which have advanced the productivity of many other sectors (Brynjolfsson and Hitt, 2003). R&D spillovers also occur when a firm exploits the knowledge and ideas that other firms have developed. As knowledge can be easily transferred through publications, reverse engineering, exchange of scientists and collaborations, firms can often build on external knowledge without having to pay for it (Geroski, 1995; Los and Verspagen, 2000).

What has not attracted much interest, however, is the negative effect of spillovers. Jaffe (1986) was one of the first to report that positive spillovers are confounded with negative effects such as lower profits and a higher depreciation rate of knowledge. In line with Jaffe (1986), a recent study of Bitzer and Geishecker (2006) finds that negative intra-industry spillovers often dominate their corresponding positive effects. Indeed, the R&D that a firm's rivals undertake, improves not only society's pool of knowledge but also their own products, processes and productivity. Although one might expect that the increased productivity levels of rivals would not negatively affect the productivity of a firm, frequently this appears to be the case.

Aitken and Harrison (1999) refer to a market-stealing effect that may force an organization to reduce output in response to competition from technologically superior rivals. In turn, this may shift its cost curve higher, resulting in lower productivity. De Bondt (1996) emphasizes that whilst R&D improves the competitiveness of one firm, it may reduce its rivals' profits. McGahan and Silverman (2006) argue that external innovations may negatively influence organizational performance either through direct market-stealing or indirect appropriation through licensing. Furthermore, as sales and productivity are correlated, what academic studies estimate is a comparative (or relative) measure of productivity.[1] When a firm loses market share because of the technological advances and the better competitive position of its rivals, a reduction in its measured 'comparative' productivity may be observed, despite the fact that its production capacity remains the same. Negative spillovers also imply some form of labour hoarding; otherwise, the drop in firms' output should be accompanied by a proportionate decrease in labour force.[2] Overall, these arguments suggest that R&D investments may impose negative externalities on rivals, even though positive knowledge transmission occurs (De Bondt, 1996).

Consider for example the computer processor industry, which is dominated by Intel and AMD. If Intel, by developing a new powerful processor, succeeds in significantly increasing its market share, the sales and consequently the measured productivity of AMD will be lower (even though Intel has created knowledge on which AMD can build). Thus, as Griliches (1979) emphasized, measured output goes up in terms of the revenues received, and productivity depends on the amount of returns that an innovator succeeds in appropriating for himself. However, the conditions for positive and negative spillovers vary between firms, and theory does not so far indicate which effect is likely to dominate. As noted earlier, this study analyzes three factors (technological opportunities, firm size and competition) that may influence the direction of the 'net' spillover effect, i.e. when the positive effect outweighs the negative (market-stealing) effect.

3 RESEARCH METHODS AND DATA OVERVIEW

3.1 Measuring Spillover Effects

[1] Sales and productivity are correlated simply because output, which is the numerator of any productivity measure, is usually defined as sales or value added (sales minus the materials that were used in production). Hence, both measures of output (and thus productivity) depend on sales.

[2] We would like to thank an anonymous referee for this comment.

Following past literature (Griliches, 1979; Scherer, 1982), our analysis is based on a production function. Besides the ordinary inputs of capital (K) and labour (L), it also includes the R&D capital (R) of a firm, as well as a measure of the aggregate R&D (S_{int}) undertaken by intra-industry competitors. This model however, becomes more complicated because '*we do not deal with a closed industry but with a whole array of firms and industries which borrow different amounts of knowledge from different sources according to their economic and technological distance from them*' (Griliches, 1992, p. 35). To represent the R&D undertaken by the firms in external industries (inter-industry spillovers), we have added one more variable (S_{ext}):

$$Q = f(K, L, R, S_{\text{int}}, S_{ext}) \tag{1}$$

This production function after accounting for time (t) and firm (i) differences and after transforming it into logarithmic form is:

$$q_{it} = \mathrm{a} + a k_{it} + \beta l_{it} + \gamma r_{it} + \delta s_{\text{int},it} + \zeta s_{ext,it} + \varepsilon_{it} \tag{2}$$

The lower case letters $(q, k, l, r, s_{\text{int}}, s_{ext})$ denote the logarithms of the variables whereas $\alpha, \beta, \gamma, \delta$ and ζ are the elasticities of capital, labour, R&D capital, intra- and inter-industry spillovers respectively. The term **a** is the residual of the production function and ε_{it} is the disturbance term. To serve the objectives of the study and examine the impact of R&D spillovers on firms' productivity performance, Equation 2 is re-written below in terms of labour productivity (output/labour):

$$(q_{it} - l_{it}) = \mathrm{a} + a(k_{it} - l_{it}) + \gamma(r_{it} - l_{it}) + (\mu - 1)l_{it} + \delta(s_{\text{int},it} - l_{it}) + \zeta(s_{ext,it} - l_{it}) + \varepsilon_{it} \tag{3}$$

We have not imposed the assumption of Constant Returns to Scale (CRS), when $\mu - 1 \neq 0$ the CRS assumption is rejected. To avoid biased estimates, the model also includes dummy variables to control for time and industry effects (not shown in Equation 3). The model will be estimated using the ordinary least squares (OLS) method.[3] The construction of the R&D and spillover variables is described below.

R&D Capital (R)

Following Griliches (1979), the R&D capital (or stock of scientific knowledge) is taken to be a measure of past and current R&D expenditures (RD):

$$R_{it} = RD_{it} + RD_{i(t-1)} + RD_{i(t-2)} + \dots \quad \textbf{(4)}$$

However, in order to innovate continuously, firms have to abandon past knowledge. Therefore, past research – as any other type of capital – depreciates and becomes less valuable over time. Additionally, part of a firm's research findings will be diffused, used and thus neutralized by other firms. In order to account for the declining usefulness of R&D, a depreciation factor (δ) is introduced to convert the gross research to net (the term k represents the lagged year):[4]

$$R_{it} = RD_{it} + \sum_{1}^{k} (1-\delta)^k RD_{i(t-k)} \quad \textbf{(5)}$$

R&D undertaken by intra-industry competitors (S_{int})

A measure of the aggregate R&D undertaken by intra-industry rivals was constructed in order to investigate whether their spillover effect has a positive or negative impact on productivity. In contrast to other studies that only take into account the R&D undertaken by the firms of their samples, following Harhoff (2000) this paper allows all private R&D in

[3] The model could also be estimated using the Generalized Method of Moment (GMM), random effects or by using other instrumental variable methods such as the Two Stage Least Square (2SLS) or the Indirect Least Squares (ILS) (also known as Reduced Form). As each method has its own advantages and faults, it is difficult to claim that one method is superior or that it yields less biased estimates. Many researchers have discussed the issue of the appropriate method. Griliches (1986) argues that such methods do not solve the important problem of simultaneity but merely shift it to the validity and exogeneity of external instruments. Gujarati (1995) points out that although some instrumental variable methods may decrease simultaneity, if there is no simultaneity then the estimates become less efficient, having larger variance. Taking into account the problems above, along with the fact that in practice, the findings of studies using methods such as the 2SLS and ILS (Cuneo and Mairesse, 1984; Griliches, 1980; Sassenou, 1988) are similar or only marginally better than those obtained from the ordinary least squares method (Mairesse and Sassenou, 1991), we prefer to use OLS that the majority of similar studies have employed.

[4] Based on the findings of Pakes and Schankerman (1984) and Goto and Suzuki (1989), Equation 5 is calculated using a depreciation rate of 20 percent. Additional measures of R&D capital are also calculated using rates of 15 and 25 percent. In line with the findings of other studies however (e.g. Harhoff, 1998), we found that the rate of depreciation did not have a significant impact on the findings.

the population of the UK R&D-performing firms to enter the spillover pool. Using Equation 5, we have constructed an intra-industry spillover capital for each firm separately.[5] This measure was also corrected for double counting.[6]

<u>Inter-industry Spillovers</u> (S_{inter})

To examine whether firms borrow knowledge from inventors of external industries, we have calculated an inter-industry spillover capital. Initially, we constructed a proximity matrix (W) that identified the technological distance between firms, i.e. the extent to which the technologies developed in different industries were useful for each firm of the sample. Earlier studies used either a patent-based or an input-output weighting. As patent data were not available in this study, we used input-output data on the use of intermediate goods to construct a technological-proximity matrix.[7] The data included a 122 x 122 dimensions table with information on the intermediate goods used to produce 122 different product categories. We grouped those products relevant to the study into 15 two- or three-digit industries. For example, products such as inorganic, organic and 'other' chemical goods were incorporated into the chemical industry. Hence, we constructed a table of 15 x 15 dimensions. Each firm's inter-industry spillover capital was thus the weighted sum of 14 different R&D capital stocks:

$$S_i = \sum_{j=1}^{14} w_{ij} R_j \qquad \textbf{(6)}$$

R_j represents the R&D capital of industry j, whilst w_{ij} is the weighting factor of the technological distance between firm i and industry j (taken from the input-output table).

3.2 Data Overview

To investigate the extent to which a firm (rather than an industry) benefits from external R&D, as well as to examine the differences across firms within an industry and to

[5] Following the work of Pakes and Schankerman (1984) and Goto and Suzuki (1989), the depreciation rate of this stock was set at 20 percent per year.
[6] Each firm's own R&D capital was deducted from the total intra-industry spillover capital.
[7] The input-output table was obtained from the UK Office for National Statistics.

avoid inferences biased by idiosyncrasies associated with a specific period, we collected firm-level panel data. Using Datastream, a wide range of data including firms' sales, capital, labour and R&D expenditure were collected for an 8-year period (1995-2002). The sample includes 138 UK manufacturing firms that reported their R&D expenditure. Data were also collected for the total R&D undertaken by each two- or three-digit UK industry.[8]

Although the UK accounting rules suggest that firms should report their R&D expenditure, there is no law to enforce this (Stoneman and Toivanen, 2001). As a result, 9 of the 138 firms reported zero R&D expenditure and thus were eliminated. Twelve more were eliminated either because of more than 3 missing R&D observations or because of their small size. The final balanced sample comprised 117 firms that accounted for approximately 80 percent of the total private R&D investment (thereby reducing the possibility of having a serious sample selectivity bias). Table 1 presents the sector analysis of the sample. To achieve the objectives of the paper, the model will be re-estimated for a number of sub-samples separately. For that reason, we divided the sample into smaller- and larger-firms sub-samples.[9] Additionally, following past studies (Griliches and Mairesse, 1984; Harhoff, 1998), we included industries such as metal manufacturing, minerals and mechanical machinery in the low-tech sample whereas industries such as pharmaceutical, electronics and aerospace were included in the high-tech sample.[10]

******************************** Table 1 ********************************

Using the raw data, several variables were constructed. As Jorgenson (1963) suggested, capital input should be a measure of the services flowing from it (rather than capital stock). Following Griliches (1980), the study approximated capital services using the depreciation of fixed capital stock (which is in fact the actual cost that a firm pays for

[8] These data were acquired from the UK Office for National Statistics.

[9] Following Griliches (1980), the large firm sub-sample comprises firms with over 1000 employees whereas the second sub-sample includes all firms which have fewer than 1000 employees. Smaller firms account for 46 percent of the whole sample; the remaining 54 percent are larger firms. Nevertheless, although firms which have less than 1000 employees are only a small fraction of other firms which may have a six digit number of employees, they still cannot be considered as small firms.

[10] The low-technology sample comprises 48 firms whereas the remaining 69 firms belong to high-technology industries.

using its capital assets). To minimize the danger of biased results, we also estimated the model using a measure of the net fixed capital stock. Labour input is defined as the number of employees. Both capital and labour input were corrected for double counting.[11] As a proxy for output, the sales of each firm were used. Although this is in line with the practice of many previous papers (Griliches and Mairesse, 1984; Goto and Suzuki, 1989; Hall, 1993; Harhoff, 2000; Wakelin, 2001), it may not be optimal. As Cuneo and Mairesse (1984) found, using sales instead of value-added may bias the elasticity of R&D downwards. Nevertheless, the results of Mairesse and Hall (1996) (who used both sales and value-added) showed that sales as dependent variable performs relative well.

Using the procedures described earlier, we constructed measures of R&D capital, intra-industry and inter-industry spillovers. Due to the lack of official R&D price indices, published studies usually utilize the GDP price index to convert R&D expenditures to constant prices. However, as the cost of R&D does not follow the path of prices within the economy as a whole (Mansfield, 1987), this approach does not measure accurately the level of R&D activity. In contrast to past research, the analysis undertaken in this study includes the fact that (depending on the industry involved) the cost of R&D may rise at different rates. To do so, it employs industry-specific R&D price indices (rather than the GDP index).[12]

Table 2 presents the descriptive statistics for the sample. Although the R&D-intensity (R&D/sales) of the high-tech and smaller firms is 6.9 and 6.7 percent respectively, it is much lower at 1.6 and 2.7 percent for the low-tech and larger firms. Interestingly, whilst the productivity for the technologically advanced, smaller and larger firms does not differ by much, the corresponding productivity for the low-tech firms is much lower. As was

[11] We deducted from ordinary fixed capital, plant and equipment devoted solely to the R&D department. Similarly, we deducted from ordinary employees, those who belong to R&D department.

[12] These price indices were constructed recently. For a full description of their construction process, see Kafouros (2008). The findings indicate that the difference between the GDP deflator and the industry-specific price indices is considerable in many sectors. The costs of R&D tend to rise more rapidly for low-tech firms, showing that they have to pay more for undertaking R&D.

expected, the average intra- and inter-industry spillover capital per employee is very high for both high-tech firms and for smaller firms, implying that their employees may draw knowledge from a large spillover pool.

******************************* Table 2 ******************************

4 MAIN FINDINGS: INTRA- AND INTER-INDUSTRY SPILLOVERS

It is frequently argued that corporate performance may be affected differently by the R&D undertaken by intra- or inter-industry firms. Mohnen (1996) explains that if the new product from outside R&D could replace the firm's own product, then R&D spillovers may decrease the price that a producer can charge for it. Similarly, McGahan and Silverman (2006) argue that the strength of such an effect depends on whether innovation has come from potential rivals or not. To examine the validity of these predictions, this section analyzes separately the impacts of the R&D undertaken by intra-industry competitors and that undertaken by external inventors.

4.1 The Impact of the R&D Undertaken by Intra-Industry Competitors

Table 3 presents the findings concerning intra-industry spillovers.[13] These are based on Equation 3.[14] The first model includes an unweighted spillover variable. The elasticity of R&D capital is high at 0.13, showing that a firm's own R&D investments increase significantly its productivity performance. To examine the impact of R&D price indices on the results, we re-estimated the model using the GDP deflator (rather than our R&D price indices). As a result of this, the elasticity of R&D decreased from 0.13 to 0.11. This suggests that as R&D-cost idiosyncrasies vary across industries, the lack of R&D price indices may bias the coefficient of R&D downwards, and underestimate the contribution of R&D.

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[13] Although the results are presented separately, both the intra- and inter-industry variables are included in the model (in order to avoid the bias due to inter-correlation of the two variables).

[14] These findings (as well as subsequent findings) are heteroscedasticity-robust. To investigate this problem, we initially conducted a 'white' heteroscedasticity test. This indicated that the null hypothesis of homoscedasticity cannot be rejected (at the 5 percent level). We also used the so-called Goldfeld-Quandt test to examine the null hypothesis that the variance of error terms is homoscedastic. The findings indicated that the null hypothesis cannot be rejected (at the 1 percent level), confirming that there is no evidence of heteroscedasticity.

The coefficient of intra-industry spillovers is zero and statistically insignificant, implying that intense R&D competition neutralizes positive spillovers.[15] This finding is consistent with Wakelin's (2001) work for the UK which found the effects of spillovers to be statistically insignificant between 1988 and 1992. However, it contradicts other studies that found positive spillover effects (Adams and Jaffe, 1996; Branstetter, 1996; Los and Verspagen, 2000). To incorporate in the analysis the possibility that the maximization of these effects may take some time, we employed one- and two-year lagged variables (not shown in Table 3). Despite the fact that the elasticity of R&D increased to 0.16, the effects of spillovers remained insignificant.[16]

****************************** Table 3 ******************************

Model 2 goes one step further. According to the absorptive-capacity hypothesis, the capability of capturing external know-how relates to a firm's prior R&D (Cohen and Levinthal, 1990). Levin et al. (1987) found that firms' own research was an effective way of investigating rival technologies. Similarly, studies of technological diffusion found that R&D-intensive companies adopted new technologies faster than less R&D-intensive firms (Baldwin and Scott, 1987). To test whether the data supported these arguments, we included an interaction variable (following the work of Harhoff, 2000). This variable is a measure of intra-industry spillovers weighted by each firm's own R&D (i.e. logS*logR). The coefficient of the new intra-industry spillover variable is slightly negative at -0.02 (but still not statistically significant). Additionally, because each firm's own R&D capital is

[15] When we re-estimated the model by using the unbalanced sample of 129 firms, we found similar results.

[16] The econometric framework described earlier assumes that the disturbance term ε_{it} is composed of two other types of disturbances: a permanent disturbance (υ_i) specific to the firm, and a transitory disturbance (w_{it}) (see Cuneo and Mairesse, 1984). The breakdown of the disturbance term leads to two types of estimates. The estimates of Table 3 have the advantage of being unaffected by biases coming from the correlation between explanatory variables and the disturbance w_{it}. These estimates, however, do not take into account the efficiency characteristics of the firm (e.g. managerial capability). To avoid this bias and ensure that the estimates are unaffected by υ_i disturbances, we re-estimated the model using differences (the equivalent of doing 'within firm' analysis; see Odagiri and Iwata, 1986). Other advantages of this method are that firstly it includes not only the characteristics of a specific industry but also the characteristics of each individual firm (Mairesse and Sassenou, 1991), and secondly, as Griliches (1986) suggested, it is a simple but effective way to remedy the problem of simultaneity that besets productivity studies. The new findings yielded by this method are consistent with the findings of Table 3, confirming that intra-industry spillovers are insignificant (the elasticity of R&D increased only slightly from 0.13 to 0.14).

incorporated in the new variable, multi-collinearity problems ensue, the effects of which are severe increasing the coefficient of R&D from 0.13 to 0.17. For that reason, we used a third approach.

The first two models include an unweighted measure of spillovers. As such, they implicitly assume that all rivals' R&D activities are relevant and useful to the firm. The usefulness of rivals' knowledge, however, may differ across industries. Calculations based on UK input-output data showed that approximately 40 percent of the inputs of firms such as electrical and electronics come from their own industry. By contrast, the corresponding figure for minerals and instruments manufacturers is less than 9 percent. For that reason, we weighted the spillover variable according to the extent to which a firm uses the technologies of its own industry. Model 3 presents the results. Once again the spillovers coefficient is zero, indicating that on average the spillover effects of intra-industry competitors are insignificant (rather than simply being an artifact of a particular variable construction process).

4.2 Inter-Industry Spillovers and the Role of Technological Distance

Table 4 presents the findings concerning the relationship between inter-industry spillovers and productivity performance. Model 1 indicates that this relationship is positive at 0.02, suggesting that the R&D undertaken by organizations in external industries has a positive – but relatively low – impact on productivity. To investigate whether the absorptive-capacity hypothesis is valid for inter-industry spillovers, Model 2 presents the results when the spillover variable is weighted by each firm's own R&D. The statistical significance of spillovers is now greater (at the 0.1 percent level) and the coefficient is slightly higher at 0.03. Although the findings favor the relevant hypothesis, the new coefficient is not significantly higher. The reason for this result may be the ease with which products may be imitated in a digital age without the need to possess basic scientific understanding (Liu and Buck, 2007).

****************************** Table 4 ******************************

Our previous models do not take into account the arguments of Griliches (1992) that the stock of knowledge available in an industry is not in itself indicative of how much of this knowledge spills over to other firms, nor who the potential recipients of the knowledge will be. Indeed, spillover effects may be weak when external technologies are so different from a firm's own know-how that they cannot be absorbed (De Bondt, 1996). Large and diversified firms may draw knowledge from a much wider knowledge pool than that constructed. Conversely, as smaller firms usually specialize in a specific niche (Griliches, 1992), they may draw knowledge from a much narrower product field. If this argument is valid, then our technological-proximity matrix may not represent accurately the real technological relationship between firms. As Cincera (1998, p. 178) argues '*it may be the case that firms characterized by an intermediary technological distance, i.e. Pij = .5, actually benefit much more or much less from R&D spillovers than firms at the extreme, i.e. firms very close or very distant from other firms*'.

To test the above arguments, we re-estimated the model using other definitions of technological proximity. Following Cincera (1998) and Harhoff (2000), we used weighting metrics that are nested within an exponential transformation. We transformed the weighting matrix w_{ij} as $w'_{ij} = w_{ij}^{a}$ (with $a > 0$). The rationale behind this transformation is that the distance between a firm's own R&D and external R&D might be a nonlinear function of the matrix w_{ij}. Hence, whilst the initial linearly-weighted spillover variable was based on $a = 1$, two new spillover variables were constructed for values of a equal to 0.33 and 2 (named SPILLS033 and SPILLS2 respectively). Figure 1 depicts the effects of these transformations. When a takes values smaller than 1, it allows distant R&D to be weighted more strongly in the constructed spillover variable. Conversely, when $a > 1$ then distant R&D is weighted less strongly (Harhoff, 2000).

****************************** Figure 1 ******************************

The last two models of Table 4 report the findings when the SPILLS033 or SPILLS2 variable took the place of the initial variable. The elasticity of SPILLS033 (giving emphasis to distant R&D) increased at 0.05, and became highly significant at the 0.1 percent level. In contrast, the coefficient of SPILLS2 (based on the notion that the R&D of neighbor firms is more important) slightly decreased at 0.015. These findings favor a broader definition of the spillover pool. It seems that when firms capture knowledge from firms outside their own industry, they draw knowledge successfully even from more technologically distant industries. This finding, however, contradicts Harhoff (2000) who found that the impacts of R&D spillovers for German firms remained relatively stable when alternative values of a were used. Another noteworthy observation not shown in Table 4, is that although the use of lagged variables did not change the intra-industry results presented in the previous section, they increased significantly the coefficient of inter-industry spillovers (from 0.02 to 0.05), implying that knowledge from outside industries takes some time to be absorbed.

5 TECHNOLOGICAL OPPORTUNITIES AND FIRM SIZE

The previous section assumed that R&D spillovers impact on the performance of heterogeneous firms in a similar way. This section examines two factors (technological opportunities and firm size) that may influence a firm’s ability to benefit from external R&D, and in turn the magnitude and direction of such externalities. A number of theoretical arguments guide the selection of these two factors. For instance, high-tech firms have a better infrastructure and understanding of technologies (Kafouros, 2006; Kessler, 2003). As such, they may be more capable not only of understanding external discoveries but also of integrating other firms’ research findings in their own products and processes.

Considerable evidence suggests that the innovative capacities, as well as the organizational and cultural foundations of technologically sophisticated firms differ from those of low-tech firms (Matheson and Matheson, 1998; Wang and Tsai, 2003). High-tech firms may also be more capable of benefiting from spillovers, simply because they participate in sectors where the understanding and the scientific knowledge in relation to innovation is rich and growing (Clark and Griliches, 1984). Furthermore, their employees use electronic resources more intensively, and are therefore better equipped to access the information transmitted from associate firms or competitors (Kafouros, 2005). Accordingly, spillover effects for high-tech firms may be more positive than for low-tech firms.

By contrast, the role of firm size is more ambiguous. On the one hand, theory suggests that larger firms are better equipped to benefit from knowledge externalities because they possess the technological expertise, know-how, and managerial qualities that could improve the understanding of inventions developed externally (Mansfield, 1968). They may also be able to use the research findings of other firms more efficiently as they can afford to have specialized scientists working on the systematic collection, analysis and circulation of information regarding newly-developed technologies and recently registered patents (Kafouros, 2008).

Nevertheless, there is also a case for suggesting the converse – that smaller firms are actually better able to profit from external technological information. First, it may prove more difficult for the R&D teams of larger firms to trace the relevant knowledge for their numerous products, processes and technologies. Tsai (2001) demonstrated that their limited degree of autonomy may hinder the monitoring of, and rapid response to the latest technological trends. Second, the net effect of spillovers depends on the extent to which external knowledge is crucial to a firm. The higher a firm's reliance on external technologies, the greater the likelihood that the positive spillover effects outweigh the negative effects (McGahan and Silverman, 2006). Similarly, Geroski (1995) argued that if technologies stand alone as isolated discoveries, R&D spillovers will substitute for a firm's own R&D. Conversely, in situations where external technologies are crucial and can be used as a base for future inventions, spillovers will be complementary to a firm's research. Previous research suggests that smaller firms develop incremental (rather than radical) innovations that are frequently characterized by a strong reliance on external technologies (Bound *et al*, 1984; Kleinknecht, 1989; Pavitt *et al*, 1987; Piergiovanni *et al,* 1997). As such, it is likely that the positive effect will dominate. As theory does not identify a clear relationship between firm size and spillovers, the following section examines this issue empirically.

5.1 Findings and Discussion

To examine the role of technological opportunities and firm size, after splitting the sample into different sub-samples, we re-estimated the model. Consistent with previous studies, the results of Table 5 show that whilst high-tech firms enjoy good returns to their own R&D, the corresponding payoff for low-tech firms is lower. Concerning the impact of the R&D undertaken by intra-industry rivals, the results for technologically-advanced companies show that the positive effect dominates. This confirms the theoretical predictions discussed earlier that high-tech firms achieve success utilizing the ideas and technologies of competitors. But these results could be interpreted differently by an R&D director who might simply see the research efforts of his own company improving the productivity of his rivals. The relationship is totally reversed in the case of low-tech firms. It appears that because of their limited ability to draw on external scientific knowledge, negative spillovers dominate, decreasing their performance.

****************************** Table 5 ********************************

The last two columns report the findings on firm size. The contribution of their own R&D to productivity is high for larger firms but much lower for smaller firms. In contrast, the opposite is true regarding the contribution of the information transmitted by intra-industry competitors. Its impact on smaller firms' productivity is not only positive, but also higher than that arising from their own R&D. Conversely, the R&D undertaken by intra-industry rivals has a strong negative impact on the productivity of larger firms, suggesting strongly that the negative effects of competition outweigh the positive ones.

Table 5 also presents the results for inter-industry spillovers. These spillovers are particularly important because as the data show, in industries such as motor vehicles, paper and printing, only 17 percent of intermediate inputs are taken from the other 14 industries of the sample. On the other hand, for industries such as metals this figure may be as high as 70 percent. The results indicate that inter-industry spillovers are positive for high-tech firms, showing that these companies profit from the R&D of firms in different external industries. Interestingly however, for firms in less technology-oriented sectors, spillovers are once again negative.

The findings of inter-industry spillovers for larger versus smaller firms are similar to those found for intra-industry spillovers. They suggest that firm size is negatively associated with the contribution of external R&D. These support the prediction that as smaller firms develop incremental technologies (Pavitt *et al*, 1987; Piergiovanni *et al*, 1997), there is a strong reliance on external knowledge, and therefore the positive effects outweigh the negative ones. Another explanation for this result relates to previous findings showing that small firms which are R&D-intensive have a better absorptive capacity (Cohen and Levinthal, 1990), and tend to adopt and respond to new technologies faster (Baldwin and Scott, 1987).[17]

Generally, the results show that when the positive spillover effect dominates, its magnitude is higher for the R&D undertaken by intra-industry rivals and lower for that undertaken by other inventors. This confirms the argument of Griliches (1992) that the usefulness of external R&D tends to be highest if it is undertaken by intra-industry firms. Indeed, firms in the same industry may benefit not only from the ideas of other companies, but also through the hiring of other firms' scientists and R&D engineers (Hall, 1996). Consistent with our results, Bernstein (1988) showed that intra-industry spillovers are more

[17] The descriptive statistics of Table 2 confirm this, showing that the R&D intensity of the smaller firms of the sample is very high at 6.7 percent.

significant than inter-industry spillovers. Similarly, Adams & Jaffe (1996) concluded that R&D outside the product field is less effective than R&D within the product field.

6 THE ROLE OF COMPETITION

Another factor that plays an important role in the appropriation (or not) of innovation is that of competition. Although the relationship between competition and innovation has been examined for more than six decades, it is still a subject for debate (Tang, 2006). Schumpeter (1942) suggested and many others argued similarly (e.g. Grossman and Helpman, 1991), that because oligopolistic and monopolistic environments provide profitable innovative opportunities, they are likely to promote R&D. In contrast, Arrow (1962) argued that markets with the characteristics of perfect competition provide more incentives to innovate. The rationale behind this claim is that intellectual-property law may allow an inventor to license his innovations to many firms, and thus maximize the returns to his research efforts.

It has also been recognized that R&D investments may allow a firm to gain a more advantageous competitive position in relation to its rivals (Aghion *et al*, 2001). Nevertheless, although firms innovate in order to escape competition, it may also be argued that when they invest in similar practices that involve new knowledge, many benefits are forwarded to other firms (Chen and Miller, 1994; Porter, 1980). In cases where a firm's R&D investments are neutralized by rivals' investments, R&D is no longer a decisive strategic weapon and there may even be an adverse effect on corporate performance. Indeed, a firm that participates in an R&D-intensive environment may capture the full value of its innovations only for a short period of time, as the inventions of rivals reduce the life cycle of technologies and lead to quick obsolescence of products.

Many studies have investigated the relationship between competition and a firm's own innovation. That objective however, differs from the aim of this section, which is to examine whether competition influences the impact of external R&D on corporate performance. Theory suggests that the appropriability of the benefits of R&D may vary depending on competitive conditions. McGahan and Silverman (2006) argue that even an important innovation may not have a significant effect if competition is high and does not allow a firm to capture its full value (which spills over to other firms). This implies that the presence of a high level of competition may lead to low returns to a firm's own R&D but may permit other firms to exploit successfully external R&D. In such cases of imperfect appropriability, we should expect the effects from R&D spillovers to be more positive. In contrast, lower competitive pressure may allow firms to better appropriate the full value of R&D, resulting in either less positive or negative spillovers.

Nevertheless, although one might expect that the magnitude and direction of spillovers may depend on the appropriability regime in an industry, this may not always be the case. The above arguments do not take into account the non-rival and non-excludable properties of knowledge: in contrast to a tangible good, knowledge can be used by many firms and it is difficult for the producer of knowledge to stop others from using it (Geroski, 1995). These suggest that it is possible for R&D to benefit simultaneously both the firm that undertakes such activities and other firms as well. Utilizing industry- and firm-level measures of competition, the following section tests these arguments and examines empirically the relationship between competition and spillovers.

6.1 Findings and Discussion

To examine the role of competition, we need to measure the competitive pressure that a firm faces, and generally the competitive conditions in each industry. To do so, previous research utilized a wide range of proxies such as profitability, barriers to entry, market concentration and market share (Greenhalgh and Rogers, 2006). One of the measures adopted here is that of concentration ratio. This industry-level proxy refers to the extent to which the largest firms contribute to the activity in an industry. It is defined as the 'sum of sales for the largest firms over total sales for an industry' and has been calculated for the top 15 firms of each industry of our sample.[18] This ratio varies widely between 10 and 80 percent, depending on the industry involved.[19]

After splitting the sample into lower- and higher-concentration subgroups, we re-estimated the model.[20] The first sub-sample contains industries that tend to have characteristics of perfect competition, whilst the second one includes industries that tend to have oligopolistic characteristics (i.e. a few firms dominate the market). Table 6 (Model 1) reports the results. These clearly support the Schumpeterian hypothesis and stand in direct contrast with the claims of Arrow (1962). They indicate that when a market tends to have perfect-competition conditions (first column), the returns to a firm's own R&D are significantly lower (at 0.09) than the corresponding returns (of 0.19) enjoyed by firms in oligopolistic markets.

The results confirm previous studies which showed that firms in oligopolistic or monopolistic environments face less market uncertainty, and can more easily appropriate the benefits of R&D (Kamien and Schwartz, 1982; Tang, 2006). In line with the previous theoretical discussion however, this relationship is reversed in the case of spillovers. We find that when the coefficient of R&D is low (i.e. when firms appropriate only a small portion of the fruits of their own innovation), the spillover effects are more positive, confirming that many of the relevant benefits are forwarded to other firms. This finding is consistent not only with theory but also with the fact that as less concentrated markets contain many firms, the likelihood that newly-developed knowledge will be exploited by external agents is higher. This result is also in line with the argument of McGahan and Silverman (2006) that in the presence of weak appropriabilty regime, a firm should benefit more readily from external innovations. In contrast, the results of the second column

[18] The data were collected from the database of the UK Office for National Statistics.
[19] In some industries the sales of the top 15 firms accounted for about 10 percent of the total industry sales. By contrast, in other industries (with high concentration) the corresponding figure was 80 percent. We should also note that the rank order remained similar when we used value added (rather than sales) and when we calculated the ratio for the top 5 (rather than top 15) firms of each industry.
[20] The sample was split by using the median of the concentration ratio, which was 50 percent.

indicate that in oligopolistic markets where the economic payoff for R&D is high (i.e. when firms capture the benefits of their own research efforts), the elasticity of intra-industry spillovers is negative.

****************************** Table 6 ********************************

Model 1 utilized an industry-level proxy of competition. As such, it is based on the assumption that all firms within an industry face similar competitive pressure. To confirm our previous findings and to investigate if there existed intra-industry differences under competitive conditions, we also employed a firm-level proxy of competition: the market share of each firm.[21] This approach has been used widely, and it has been theoretically accepted that the larger the market share a firm has, the lower is the competition that it faces. After splitting the sample into lower- and higher-market share subgroups, we re-estimated the model.[22] Model 2 of Table 6 reports the results (third and fourth column). These confirm the findings of Model 1. They indicate that market share has a positive association with the returns to innovation, i.e. the lower the competition that a firm faces, the better it can appropriate the benefits of its own R&D.

The results support Tang (2006) who argued that firms with significant market power can better finance their R&D activities because of the supranormal profits arising from such power. They are also in line with the results of Greenhalgh and Rogers (2006) who found that a higher market share increases the market valuation of patent activity. The findings concerning spillover effects are also consistent with both the theoretical predictions discussed earlier and our industry-level results. On average, they tend to be more positive when competition is intense, and less positive where there are lower levels of competition. The implication of this finding is important suggesting that even when firms do not capture the full value of their R&D, they may still increase their performance by exploiting successfully external discoveries.

[21] The market share of each firm is defined as the ratio of its sales over the total sales of the industry to which this firm belongs.
[22] To do so, we used the median of the market share, which was approximately 1 percent.

7 SUMMARY AND CONCLUSIONS

Although prior studies recognize the importance of monitoring external technological advances, they frequently (but incorrectly) assume that the impacts of R&D spillovers on productivity performance are similar across diverse firms. However, depending on their resources, assets, size and market positions, firms look at external inventions differently (Chesbrough, 2007). This study contributes to the innovation literature by examining under what conditions firms may benefit from the research efforts of other innovators. The analysis delivered a number of findings that may update the academic and managerial understanding of the spillovers-performance relationship. In order to survive the battle for technological leadership, firms must create additional value by exploiting external sources of innovation (Chesbrough, 2007), but our findings suggest that not all firms are able to do this. Rather, we found that depending on technological opportunities, firm size and competition, the net impact of R&D spillovers can be either positive or negative. An implication for theory is that future predictions about the net effect of spillovers should be linked to the above market- and firm-specific characteristics. Equally, in order to avoid inaccurate results, social scientists who empirically examine the mechanisms underlying R&D should incorporate these factors in their analyses.

The current study demonstrated that spillovers are positively associated with the technological opportunities that a firm faces. This finding is consistent with the behavior of high-tech firms to invest heavily in R&D, showing that they reap rewards not only from their own R&D but also from that undertaken by other companies. Conversely, negative market-stealing effects dominate in the case of low-tech firms, decreasing their productivity. As it is likely that a firm will experience more positive spillovers when its innovations place emphasis on technical information gathered from outside sources, it is advisable for low-tech firms to build more on external inventions. Improving the understanding of discoveries developed externally should be a central part of their strategy.

The analysis of the role of firm size demonstrated that it enhances a firm's capacity to improve performance through its own R&D. Contrary to theoretical expectations however, the impact of spillovers is negatively associated with firm size: external R&D has a strong but negative impact on the performance of larger firms. Because large firms have the financial resources to develop technologies internally, it seems that they are too self-reliant, ignoring the potential benefits of external R&D. However, the increasing complexity of products implies that firms – even the largest – can no longer rely only on their internal knowledge reservoir. To keep their innovation leadership, large corporations should refine their strategic plans in a way that effectively incorporates external inventions in their R&D processes (Chesbrough, 2007). Many innovation strategists have already started doing so by giving rewards and recognition to people who adopt ideas from elsewhere (De Bondt, 1996). Interestingly, the contribution of spillovers to smaller firms' productivity is higher than that of their own R&D. This finding reflects their strong reliance on external technologies and explains why despite the low returns to their R&D, smaller firms continue to be R&D-intensive. Even though their own research was not particularly important for performance, it may have enabled them to catch up with outside leading-edge technologies and increase productivity using the knowledge transmitted by other innovators.

The current research has also demonstrated that another key factor that explains variations across firms is that of competition. Irrespective of the data analyzed (industry- or firm-level), the results showed that the economic payoff for firms' own R&D was lower when they participated in environments of perfect-competition and generally when they face intense competition. In such cases however (where appropriability is low), spillover effects were more positive allowing firms to increase performance by using the discoveries of others. The implication of this finding is that innovation generates value regardless of the degree of competition: some firms gain more from their own research (but not from external R&D), whilst other organizations gain less from their own R&D but benefit significantly from R&D spillovers. The study also distinguished between the R&D undertaken by intra-industry competitors and that of other inventors. Although one might expect that firms would focus on the know-how of technologically-close firms, the findings indicate the opposite. They support the notion that firms utilize research results from apparently technologically-unrelated industries. This has implications for academic research, suggesting that our understanding of the concept of technological distance may be incomplete.

The analysis has a number of limitations that offer opportunities for future research. Firstly, the study has not identified the types of R&D that are spilled over more (or less) easily. More detailed data may allow us to shed light on the spillover mechanisms for basic, applied and outsourced R&D or for process and product R&D. Secondly, we used an imperfect measure of output (sales) that may bias the results. Another potential bias may come from the fact that our model does not incorporate the knowledge created by government laboratories, universities and international inventors outside the UK. Thirdly, proxies such as 'concentration ratio' and 'market share' do not measure accurately the level of competition, despite their wide use by prior studies. Future research should explore other factors that influence competitive conditions, such as the time needed by rivals to imitate a firm's products or to introduce a competing innovation (Levin *et al*, 1987). It is also interesting to note that although the existing empirical framework relies only on the level of firms' R&D, theoretically the effects of innovation and competition depend not only on how much R&D a firm undertakes, but also on how much is undertaken by its rivals. A better framework should allow for not only a firm's level of R&D, but also the difference of this level from the average level of competitors' R&D (Kafouros, 2008). Put simply, it should take into account that whilst R&D for some firms may work as a competitive weapon, in very competitive environments where firms are 'running to stand still', R&D may simply be a defense mechanism.

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Table 1
Sectoral analysis of the sample (117 UK firms, 1995-2002)

	SIC 80 Code	No of Firms
Low-Technology Industries		
Metal Products	22 & 31	3
Minerals	23 & 24	4
Machinery & Mechanical Engineering	32	28
Motor Vehicle Parts	35	6
Textiles	43	1
Paper & Printing	47	2
Rubber and Plastics	48	3
Other Manufacturing	49	1
	Total	**48**
High-Technology Industries		
Chemicals	25	15
Pharmaceuticals	257	6
Computing & Office Equipment	33	3
Electrical & Electronics	34	21
Telecommunication	344	10
Aerospace	364	6
Instrument Engineering	37	8
	Total	**69**

Table 2
Descriptive statistics (mean values) [a]

	Whole Sample	High-Tech Firms (69)	Low-Tech Firms (48)	Larger Firms (63)	Smaller Firms (54)
Sales / employee [b]	97	105	89	101	90
Capital / employee [b]	27	28	26	29	24
Number of employees	5,998	5,523	6,452	11,049	487
R&D capital / employee [b]	17	25	7	12	19
Intra-industry spillover capital [c]	2,851	3,166	2,609	2,772	2,881
Intra-industry spillover capital / employee [b]	6,593	9,228	2,550	783	13,807
Inter-industry spillover capital [c]	1,009	1,153	787	846	1,127
Inter-industry spillover capital / employee [b]	2,441	3,447	791	242	5,209
R&D intensity	4.30%	6.90%	1.60%	2.70%	6.70%

[a] The mean values have been estimated using 8 years of observation (1995-2002). Extreme values have been eliminated. The statistics for the spillover capitals indicate their approximate values as they may change depending on the weighting method utilized.
[b] These monetary values are in £1,000.
[c] These monetary values are in £1,000,000.

Table 3
Intra-industry spillovers [a]

	Model 1	Model 2	Model 3
Log (K/L)	0.18*** (0.02)	0.18*** (0.02)	0.18*** (0.02)
Log L	0.03^{ns} (0.02)	0.01^{ns} (0.01)	0.03** (0.01)
R&D Elasticity	0.13*** (0.01)	0.17*** (0.03)	0.13*** (0.01)
Intra-Industry Spillovers	0.00^{ns} (0.02)	-	-
Intra-Industry Spillovers (weighted by absorptive capacity)	-	-0.02 (0.009)	-
Intra-Industry Spillovers (weighted by I/O flows)	-	-	0.00^{ns} (0.01)
Control for Industry	yes	yes	yes
Control for Time	yes	yes	yes
R^2	0.32	0.33	0.35

[a] The dependent variable is labour productivity, ns = not significant, * 5% level of significance, ** 1% level of significance, *** 0.1% level of significance; the absence of a star indicates a level of significance of 10%.

Table 4
Inter-industry spillovers [a]

	Model 1	Model 2	Model 3	Model 4
Log (K/L)	0.17*** (0.02)	0.17*** (0.02)	0.17*** (0.02)	0.17*** (0.02)
Log L	0.04*** (0.01)	0.04*** (0.01)	0.06*** (0.01)	0.05*** (0.009)
R&D Elasticity	0.13*** (0.01)	0.07*** (0.02)	0.13*** (0.01)	0.13*** (0.01)
Inter-Industry Spillovers	0.02** (0.007)	-	-	-
Inter-Industry Spillovers (weighted by absorptive capacity)	-	0.03*** (0.005)	-	-
Inter-Industry Spillovers ^0.33	-	-	0.05*** (0.01)	-
Inter-Industry Spillovers ^2	-	-	-	0.015** (0.006)
Control for Industry	yes	yes	yes	yes
Control for Time	yes	yes	yes	yes
R^2	0.32	0.3	0.31	0.31

[a] The dependent variable is labour productivity, ns = not significant, * 5% level of significance, ** 1% level of significance, *** 0.1% level of significance; the absence of a star indicates a level of significance of 10%.

Table 5
The role of firm size and technological opportunities [a]

	Whole Sample (117 Firms)	High-Tech Firms (69 Firms)	Low-Tech Firms (48 Firms)	Larger Firms (63 Firms)	Smaller Firms (54 Firms)
Log (K/L)	0.18*** (0.02)	0.19*** (0.03)	0.16*** (0.02)	0.15*** (0.03)	0.13*** (0.04)
Log L	0.03[ns] (0.02)	0.10*** (0.03)	-0.02[ns] (0.03)	-0.10*** (0.03)	0.12*** (0.04)
R&D Elasticity	0.13*** (0.01)	0.18*** (0.02)	0.09*** (0.01)	0.18*** (0.02)	0.11*** (0.02)
Intra-Industry Spillovers	0.00[ns] (0.02)	0.07** (0.02)	-0.06* (0.02)	-0.11*** (0.03)	0.12*** (0.04)
Inter-Industry Spillovers	0.02** (0.007)	0.03** (0.009)	-0.10** (0.03)	-0.01ns (0.01)	0.05*** (0.01)
Control for Industry	yes	yes	yes	yes	yes
Control for Time	yes	yes	yes	yes	yes
R^2	0.32	0.33	0.34	0.51	0.2

[a] The dependent variable is labour productivity, ns = not significant, * 5% level of significance, ** 1% level of significance, *** 0.1% level of significance; the absence of a star indicates a level of significance of 10%.

Table 6
The role of competition [a]

	Model 1 (industry-level data)		Model 2 (firm-level data)	
	Competition	Oligopoly	High-Competition	Low-Competition
Log (K/L)	0.19*** (0.03)	0.11*** (0.03)	0.16*** (0.03)	0.24*** (0.03)
Log L	0.05* (0.03)	-0.05** (0.02)	0.28*** (0.05)	0.14*** (0.03)
R&D Elasticity	0.09*** (0.01)	0.19*** (0.02)	0.11*** (0.02)	0.16*** (0.02)
Intra-Industry Spillovers	0.02[ns] (0.02)	-0.05*** (0.02)	0.10*** (0.02)	0.09*** (0.03)
Inter-Industry Spillovers	0.06*** (0.01)	0.00[ns] (0.01)	0.19*** (0.06)	0.02* (0.01)
Control for Industry	yes	yes	yes	yes
Control for Time	yes	yes	yes	yes
R^2	0.26	0.50	0.40	0.45

[a] The dependent variable is labour productivity, ns = not significant, * 5% level of significance, ** 1% level of significance, *** 0.1% level of significance; the absence of a star indicates a level of significance of 10%.

Figure 1
Transformation of the weighting matrix