DOES TECHNOLOGICAL DIVERSIFICATION PROMOTE INNOVATION? AN EMPIRICAL ANALYSIS FOR EUROPEAN FIRMS.

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Abstract

This paper analyses the impact of technological diversity on innovative activity at the firm level. The empirical study on a panel of European R&D active companies shows that both R&D intensity and patents increase with the degree of technological diversification of the firm. Possible explanations are that, on the one hand, a firm that diversifies its technology can receive more spillovers from other (related) technological fields. On the other hand, diversification can reduce the risk from the technological investments and it creates incentives to spend more on R&D. The paper provides empirical evidence relevant to the diversity-specialization innovation debate.

JEL classification: D21, O31, O32

Keywords: technological diversification, innovation, R&D

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1. Introduction

A company in an imperfectly competitive market has incentives to constantly improve the quality of its products in order to avoid vulnerability to potential competitors. Such a quality improvement can require some diversification of its technological base, that is, firms need to "span their innovative activities over more than one technology" (Breschi et al., 2003). What are the consequences of a more diversified research portfolio for the firm's degree of innovation? As Breschi et al. (2003) point out, there are two possible hypotheses on the effects of technological diversification. Companies that focus their R&D in a small number of technological fields can profit from the specialization of their research activities. Specialization can enhance the economies of scale associated with the learning process, facilitate the transfer of knowledge between the core technologies of the firm, and benefit from the technological "comparative advantages" of the firm. Consequently, under these assumptions, it might be expected that more technologically specialized firms are more innovative than more diversified ones. However, although a certain degree of specialization is required in order to achieve the necessary expertise to improve the state-of-the-art of the complex techniques in the research process, firms that are more technologically diversified can have certain advantages in competitive markets. First of all, they can obtain a higher cross-fertilization between different, although related technologies (Granstrand, 1998, Suzuki and Kodama 2004), and also they can attain gains from unrelated technologies that take place in the firm. Nelson (1959) considered that firms that diversify their technological base are likely to benefit from new technological possibilities. Since many innovations are designed to solve unrelated problems, companies that are more diversified profit more from their own research activities, because they capture more of the social benefits of their innovations. Secondly, investments in R&D are used as competitive "weapons" (Baumol, 2002) and they entail some risks for the company. Scherer (1999) reports that on average, approximately only half of the technological projects that a firm undertakes are successful[1]. Additionally, the growing competition (especially in highly innovative markets), technological change, and the rate of imitation are sources of economic depreciation or obsolescence for the firm's technology ("creative destruction", Schumpeter, 1942). In this situation, technologically diversified firms may invest more in R&D, because the diversification in their research portfolio tends to reduce the risks inherent in the R&D projects. When a large company diversifies its areas of research, it can be reducing the variance associated with the returns these investments. Therefore risk averse managers can be more willing to invest a higher proportion of the firm's wealth in risky innovative research projects (Nelson, 1959, Tirole, 1988, Scherer, 1999). Thirdly, technological diversification can prevent a negative lock-in effect in one particular technology, and it can sustain the evolution and business renovation of the firm[2].

This article updates earlier work on the relationship between diversification and innovation (Scherer, 1984, Audretsch and Feldman 1999). Most of the empirical research that relates diversification and innovation at the firm level is based on product

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[1] These data come from a series of studies conducted by Mansfield et al. (1977).
[2] For further discussion and case studies see Suzuki and Kodama (2004).

diversification measures. These studies have shown some correlation between product diversification and different measures of innovation, such as R&D intensity (Grabowski, 1968, and Teece, 1980), number of technical workers (Gort, 1962), or number of patents (Scherer, 1984). Veugelers (1997) examines the impact of external sourcing strategies on own in-house R&D expenditures using the product diversification of the firm as one of the explanatory variables. However, product diversification is not necessarily a good measure of the firm's technological diversification, and thus it presents some problems[3]. Furthermore, firms' technological diversification is typically higher than their product diversification (Gambardella and Torrisi, 1998). As Heeley and Matusik (2004) argue technical and product market knowledge are very different since “they are originated in different stages of the value chain”, and there can be different motives behind these decisions. Product diversification can be determined by the optimal decision of the managers in the search to maximize the value of the firm. Decreasing returns to scale associated with production can create incentives to explore new productive opportunities and lead to an expansion into different and more attractive industries. If firms closer to decreasing returns to scale in production (therefore less productive, less profitable, and with less available cash flows to invest in R&D activities) are more likely to diversify its production, it might be expected a negative relation between product diversification and innovation (Gomes and Livdan, ?). However, this negative relationship can be reduced if the product diversification takes place among related business that share common assets,

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[3] Two products that are classified in a different industry category can share the same scientific or technological base. In this case, the positive relation between innovation and product diversification would indicate that there is a spillover effect among similar technological activities. Alternatively, two different products can be based on different scientific or technological bases. Using product diversification measures, it is not possible to distinguish between these two cases. Moreover, products that are included in the same industry category can have a different scientific or technology base.

since the fixed costs of entry are smaller, and firms can take advantages of synergies such that … Technological diversification can be motivated by the firm necessity to improve the quality of its products or reduce cost in one market, and it is also most likely that the firm can profit more from different research projects than from different products. The empirical research seems to support this hypothesis. The findings of Gambardella and Torrisi (1998) suggest that best performing companies are focused on their core business, but have a wide spectrum of technological capabilities, which possibly allows them to create more complex and developed products, and Granstrand et al. (1997) find that firms often acquire a wide variety of technologies to compete in a narrow range of products.

The empirical literature has recently paid more attention to the extent and persistence of firm technological diversification[4]. Pavitt et al. (1989) identify technological trajectories of innovating UK firms and report an increase of technological diversification in corporations. However, Cantwell and Vertova (2004) find the opposite tendency at the country level. These authors analyse whether the pattern of technological diversification of the countries has been stable over time, providing evidence that countries have tended to narrow the different fields of their research activities possibly for the location of multinationals that supports the concentration of the countries' technological processes. Most of the empirical literature indicates that the firms' diversification patterns have moved into related technological areas (Piscitello, 2000, and Breschi et al., 2003). Very few empirical studies have assessed the importance of the firm's technological diversity to promote innovation. Heeley and Matusik (2004) analyse

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[4] For discussion on the recent literature of technological diversification see Cantwell et al. (2004) and Fai (2003), and for a discussion of diversification dynamics and strategies in technology-base firms see Granstrand (1999).

whether firms with broad technological portfolio and narrow market diversification strategies are more innovative.

This paper contributes a microeconometric analysis of the effects of technological diversification on innovation. This is done by examining R&D, patents, and the technological position of a panel of EU firms from 1995 to 2000. The number of patents the firm applies for, and its R&D intensity are used to measure its innovation. For each firm a patent portfolio-based index (Jaffe, 1986) is calculated. Diversification is measured by one minus a Herfindahl index of concentration of this portfolio. After controlling for size, other characteristics of the firm, and the possible bias of the Herfindahl index (making different groups depending on the firm's number of patents, and using an adjusted Herfindahl index 9Hall, 2002a), the results suggest that technologically diversified firms invest a higher proportion of their sales in R&D, and that an increase in the diversification of the firm's technological portfolio affects positively the firm's number of patents. These results do not imply that larger firms are more technologically diversified and therefore more innovative (the empirical results of this article indicate indeed that small firms are more R&D intensive). Although it has not been assessed in the paper, possibly a certain minimum size threshold is necessary for a firm to be able to diversify its technological portfolio. It can be more likely that "small' firms are more likely to diversify than "large" firms. However, the results imply that the size effect does not account for all the effect of technological diversification on innovation.

The rest of the paper is organized as follows. Section 2 describes the data used. Section 3 details the hypothesis and econometric specification. Section 4 offers the main estimation results relating diversity, R&D, and innovation, and finally, Section 5 concludes this paper.

2. On data

This investigation uses data on 544 firms for 15 EU countries for the period from 1995 to 2000. For each firm are included yearly data on R&D expenditures, sales, liabilities, equity, and the main SIC industry classification for the whole period at the 4th digit level of disaggregation. All financial data are real annual figures deflated to the base year 1995 using country's GDP deflators. Financial data come from the Worldscope Global database, and GDP deflators from the OECD database.

The firm selection has been based on the availability of R&D expenditures for those firms in the database. Only EU firms that report R&D in at least three years have been included. Tables 1 to 3 report some summary statistics for the firms in the sample, broken down into 15 industry categories and into countries. The sample is biased towards large firms. Approximately half of the firms are British, followed by firms from Germany and France. The most representative sector in the sample is electronics, and the rest of the firms are fairly distributed across the other sectors. Figure 1 plots log R&D versus log Sales. This illustration summarizes the basic relationship between R&D and firm size in the data, showing that R&D and sales are highly correlated (in the sample, the correlation coefficient of sales and R&D is 0.80). There is a certain curvature in this relationship, some small firms contribute a large amount of R&D and some medium-sized firms do very little, indicating that, in this sample, small firms are more R&D intensive[5] than bigger ones.

Patent data are taken from the Depatis database[6]. All the EP patents of each firm have been selected[7]. Firms with less than two patents have been removed from the sample. The proportion of patents in size classes[8] is shown graphically in Figure 2. This graph shows that large firms tend to patent more although in a non-linear way. Each patent is classified following the IPC (International Patent Classification) system from WIPO (World Intellectual Property Organization). This system includes 627 patent classes at the three-digit level (in its 7th edition), though the classification system actually contains thousands of subclasses. The 627 patent classes have been grouped in 49 categories in the following way. The basic classes are taken from Hall et al. (2001). These authors grouped the 417 US patent classes into 36 technological categories. I matched the 627 IPC classes into the 417 US classes (the distribution of the US classes in IPC classes is available on the US Patent and Trademark webpage), initially getting 36

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[5] R&D intensity is measured by R&D over sales throughout the paper.

[6] This is the German Patent Information System on the Internet provided by the German Patent and Trade Mark Office.

[7] The decision to choose EP patents was based on the need for comparability. Some empirical works have taken US patents because the quality in terms of a genuine increase in the state-of-the-art that these patents represent, and also due to their advantage in terms of comparability. However, a small proportion of European firms patent in the U.S.: for 100 patents of German firms in Germany, there are 30 patents in the U.S., this relationship also holds for France. For 100 patents of British firms in U.K., there are only 20 patents in the U.S. (Eaton and Kortum, 1999). Besides, the same study has been done with WO (World Patents) and firm's national patents without significant changes.

[8] Sales are considered as a measure of the firm’s size.

classes. To make this grouping more accurate and better adjusted to the IPC classification, some groups have been changed until 49 categories[9] are finally obtained[10].

3. Econometric specification

In order to test the benefits of technological diversification on innovation at the firm level two alternative proxies of innovative activity have been considered in this paper, R&D intensity, and number of patents. Both variables are imperfect measures of innovativeness. R&D expenditure is a measure of innovative input that can be subject, in each firm, to different scale effects. Patents as indicators of innovation present some problems, on the one hand due to the difficulty of measuring the degree of technological advance that a patent represents, and on the other hand, because not all the innovations are patented (especially in basic science research). However, estimations using both measures can be regarded as a sensitivity analysis of the impact of technological diversification on innovation.

3.1. Technological diversification and R&D intensity

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[9] This seems to be a reasonable number of classes, also Jaffe (1986) constructed 49 categories, Branstetter and Sakakibara (1998) and Sakakibara (2001) constructed 50. The different technological fields are shown in the Table 1 in the Appendix.

[10] This last step was essentially ad hoc, based on the classes' names, and there can be a certain degree of arbitrarily in this process, although the grouping process is based on a technology and not in a product approach.

To evaluate the relationship between technological diversification and R&D intensity, equation (1) provides information about some of the determinants of the firm's R&D intensity.

$$\log (\mathrm{R\ \&\ D_{it}/sales_{it}}) = \alpha + \beta_1 \log \mathrm{sales_{it}} + \beta_2 \log (\mathrm{sales_{it}^2}) + \\ + \beta_3 \,\mathrm{financial\ constraints_{it}} + \beta_4 \,\mathrm{diversity_{it}} + \delta_{\mathrm{i}} + \varepsilon_{\mathrm{it}}. \qquad (1)$$

The variable $R\&D_{it}$ is firm i's R&D expenditures in year t, α is the constant term, $sales_{it}$ is firm i's sales in year t, $financial\ constraints_{it}$ is a measure of the external financial dependence of the firm, $diversity_{it}$ is the technological diversity of the firm, and δ_i are a set of industry and country dummies[11] used to correct for industry and country fixed effects. This inclusion of industry dummies allows taking into account whether the effect of the independent variables is high relative to the sector.

The variable $financial\ constraints_{it}$ tries to capture the influence of imperfections in capital markets to restrain R&D expenditures and growth (Rajan et al., 1998). Constraints in external financial funds can reduce the firms' investments. This factor can be especially important for R&D[12] investments for several reasons, for example high risks associated with R&D, lack of collateral, and problems for financial institutions to monitor R&D returns due to asymmetric information between investor and inventor.

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[11] This equation is not meant to be a realistic model of firm-level R&D spending. It does not mean that firms optimise R&D on the basis of their sales. Firm sales are included as a control for size. This is a standard specification in the R&D literature.

[12] For a discussion see Hall (1992, 2002b).

Several authors (Bond et al., 1999, Hall, 1992, Mulkay et al., 2001, …) have empirically studied the extent of financial constraints on R&D investments.

To measure financial constraints, three proxies have been used in this paper: total debt over total debt plus equity (denoted by *debt1*), total current liabilities over total current assets (denoted by *debt2*), and cash flows[13]. A positive coefficient of *debt1* implies that firms with less debt invest more in R&D activities. The variable *debt2* indicates the firm's capacity to pay its short-term debts (that is the inverse of the liquidity ratio). Consequently, a negative estimated coefficient reflects that firms with a higher proportion of current assets (with more capacity to pay their debts) invest more in R&D. Also the effect of the cash flow on R&D expenditures has been analysed. Leland and Pyle (1977), Bhattacharya and Ritter (1985) among others, suggest that R&D can be constrained by cash flow, due to a moral hazard problem in transferring information about risky projects from the firm to the investors. Hall (1992) and Mulkay et al. (2001) find a positive relationship between cash flow and R&D expenditures for a panel of firms. In order to control for this issue, two different measures of cash flow have been incorporated in the estimation: logarithm of cash flow (denoted by *cash1*), and logarithm of operating cash flow (denoted by *cash2*)

The key variable for this analysis is *diversity*. This variable tries to capture the degree of diversification in the distribution of the firm's technological portfolio. Technological diversification can affect firm innovativeness, on the one hand, due to a risk reduction in firm research activities. On the other hand, technologically diversified

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[13] Fazzari et al. (1988) pioneered this method.

firms can received more spillovers from other research activities that take place in the company. Some authors have empirically analysed the degree of technological diversification at the firm level. Fai (2003) considers the change in the degree of diversity in a firm's technological base. Nesta and Saviotti (2004) use a "survivor" measure of relatedness (Teece et al. 1994). Breschi et al. (2003) measure the distance between technological fields analysing the co-ocurrence of technological codes assigned to patents.

In this article the variable *diversity* has been constructed based on the Jaffe (1986) measure of technological proximity. For each firm its technological portfolio is calculated in the following way. With 49 technological fields indexed by j=1, …, 49, if the ith firm has N_i patents in the analysed period, each patent can be assigned to a technological field. N_{ij} represents the number of patents that the ith firm holds in category *j*, such that $\sum_{j=1}^{49} N_{ij} = N_i$. A Herfindahl index of concentration can be obtained for each firm and year. Subtracting this value from 1, the variable *diversity* is constructed as follows

$$\text{diversity} = 1 - \sum_{\text{j}=1}^{49} \left(\frac{N_{ij}}{N_i} \right)^2 .$$

A positive estimated coefficient of the diversity variable in equation (1) implies that more diversified firms invest a higher proportion of their sales in R&D, supporting Nelson's idea that technological diversity is more conductive to R&D activities, whereas a negative coefficient indicates that firms with a technological base concentrated in similar activities invest more in R&D, or in other words, that more technologically specialized firms are more R&D intensive.

3.2. Technological diversification and patents.

A possible proxy for innovation is the number of patents that the firm applies for. The basic specification to explain the relationship between technological diversity and innovation can be expressed through the following equation

$$\text{patents}_{\text{it}} = \alpha^{'} + \theta_1 \log(\text{R \& D}_{\text{it}}) + \theta_2 \log(\text{Sales}_{\text{it}}) + \theta_3 \text{K}_{\text{it}} + \theta_4 \text{diversity}_{\text{it}} + \delta_i + \varepsilon_{it}^{'} \;. \quad (2)$$

In (2), the variable $patents_{it}$ is the number of patents of the i$^{\text{th}}$ firm in period t. $R\&D_{it}$ is the R&D expenditure of the i$^{\text{th}}$ firm in period t, the variable Sales_{it} is controlling by the firm's size. Arguably, small firms can be less diversified than large firms. Consequently, technological diversification can be positively associated with size, and therefore the variable *diversity* can be capturing the influence of size on patent activity, instead of the effect of the distribution of the firm's technologies on innovation. Incorporating this variable in the regressions allows us to distinguish between the size effect, and the technological diversification effect on innovation. The term K_{it} represents the (external) spillover term (in logarithms) among the firms in the sample. It is constructed as in Jaffe (1989), including for each firm an available "pool" of outside R&D. This indicator measures the influence of external stock of R&D on the firm's incentive to innovate. This variable is defined as, $\text{K}_{\text{i}} = \sum_{l \neq i} P_{li} . R \& D_l$ The spillover (K_{it})

that the ith firm receives is the weighted average of all other firms' R&D spending ($R\&D_l$). The weights (P_{li}) are constructed using the proximity of the firms in their technology space

$$P_{li} = \frac{F_i . F_l^{'}}{\left(\left(F_i . F_i^{'}\right)\left(F_l . F_l^{'}\right)\right)^{1/2}} \quad ,$$

where $F_i = (N_{i1}, \ldots, N_{ij}, \ldots, N_{ik})$ is the technological space of a firm, and N_{ij} is the number of patents that the ith firm holds in the technological category j. This vector is constructed using the distribution of the firm's patents in the different technological areas (as in the previous sections, 49 areas have been considered).

In equation (2) $\alpha^{'}$ is the constant term, δ_i is a set of country and sector dummies, and $\varepsilon^{'}$ is the error term. The variable *diversity* is measured as in equation (1). A positive coefficient of the *diversity* variable indicates that the greater the degree of diversification is within the firm, the higher will be its patenting activity.

A problem with equation (2) that I want to point out is that, when the number of patents increases and its distribution does not change, the diversification index remains constant (in this case, the variable *diversity* would be independent of the *number of patents*). However, the diversity variable can be reflecting the fact that a firm has few patents, just because firms with less than 49 patents (the total number of groups) do not have the same chances to diversify (in the index) as firms with more than 49 patents (clearly a firm with one patent will have diversification zero, and for a firm with two patents, the highest value that the diversification index can take is 0.5). Therefore, the diversification index can be biased downwards for those firms with few patents. That poses a serious problem in the estimation of equation (2). To control for this fact, two different approaches have been taken:

First of all, equation (2) has been estimated separately for firms with different numbers of patents. Three different ways to group firms have been considered: firms with less than 10 patents and firms with more than 10 patents[14], firms with less than 20 patents and firms with more than 20 patents, and finally, firms with less than 10 patents, firms that have between 10 and 20 patents, and firms with more than 20 patents, are estimated separately. Taking firms that have the same possibilities to diversify, the dependence of the diversity variable on the number of patents is reduced. Additionally, the comparison of the results allows us to obtain some insight into the stability and robustness of the results.

Second, I use a non-biased diversity estimator. Hall (2002a) proposed the following variation of the Herfindahl index for citations based on patent counts,

$$\text{adjusted diversity} = \left(1 - \sum_{\mathrm{j=1}}^{49} \left(\frac{N_{ij}}{N_i} \right)^2 \right) \left(\frac{N_i}{N_i - 1} \right) .$$

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[14] Ten seems a reasonable number of patents because the most diversified firm appears in 10 different groups.

This estimator gives a higher value to the diversity index for those firms with fewer patents, and consequently, corrects the possible bias of the diversity index. However, in some cases the diversification index can be reflecting the real technological diversification of a firm with few patents. In this case, the results obtained with the adjusted diversification index will be biased downwards. Hence, the adjusted diversity index can be considered as a lower bound of the effect of the degree of diversification on innovation.

4. The results.

4.1 Technological diversification and R&D intensity

Table (5) shows the estimations of the relationship between technological diversification and R&D intensity as expressed in equation (1). The numbers in italics are the t-statistics and all regressions include country and industry dummies. Columns (i) to (viii) show the effect of technological diversity on R&D intensity when different measures of financial constraints are used. In column (i), the variable *total current liabilities/total current assets* is the considered measure of financial constraints. This variable affects negatively the R&D intensity, as expected. Column (ii) includes the variable $sales^2$ to account for possible non-linearities between size and R&D intensity. In columns (iii) and (iv), the effect of *total liabilities/(total liabilities+equity)* is estimated. The estimated coefficient is significant and positive when $sales^2$ is included in the regression (column (iv)). As an alternative specification, the next columns, (v) to (viii), show the positive effect of cash flow on R&D intensity. The results are supportive of the hypothesis that there can exist financial constraints that affect negatively the degree of R&D intensity in the firm. In all the cases (in columns (i) to (viii)), an increase of the firm's technological diversity leads to an increase in the firm's R&D intensity. Columns (ix) to (xiv) report the impact of technological diversity when the variable *adjusted diversity* is used as an explanatory variable, in order to control for a possible bias in the variable diversity. The results are again consistent with previous estimations, and indicate a lower bound of the effects of technological diversification on R&D.

An econometric issue such as endogeneity can arise; technological diversity can be an endogenous variable since it can depend on the amount of R&D invested. To control for this possible problem, Table 6 explores the use of instrumental variables in the regression. I use instrumental variables instead of panel data techniques because of the short time frame. The variable *diversity* is lagged one period, and also the variable *diversityc* is used. This new measure of diversification (*diversityc)* assigns a unique value of diversity for each firm using all the patents of the firm, or in other words, it is the average technological diversification for each firm in the period 1995-2000. The estimated value for the technological diversity is slightly higher than in Table 5, and in all cases positive and significant. These results support the idea that technologically diversified firms are more innovative in terms of its R&D intensity.

4.2. Technological diversification and patents

Table 7 reports the results of the estimation of equation (2) by a Binomial Negative model[15]. The variable spillover (*K*) measures the fact that firms with a larger available external R&D pool can have more incentives to innovate, because their research costs can be lower. A positive value of the estimated coefficient of the spillover variable (*K*) means that firms benefit from the research activities taken by other firms with a similar scientific base. An important difference between the spillover variable and the technological diversification variable is that the spillover is external to the firm, while the diversification degree is a decision variable for the firm, meaning that the firm can choose how wide or narrow is its research program.

To remove the possible bias from the unobserved heterogeneity in the estimation, a proxy of the past values of the dependent variable (previous to the estimation sample) is added to the estimation. The variable *pat* is a dummy variable that takes the value 1 if the firm has at least one patent between 1985 and 1990, and 0 otherwise.

The results suggest that a higher technological diversity leads to more innovation. This is shown in column (i). The spillover variable is also significantly different from zero and positive, sustaining the hypothesis that firms benefit from the available pool of knowledge from other firms with a common scientific base. The variable *pat* is also significant. If firms have patented in the past, there is a positive effect on present patenting activity. This result illustrates the importance of the persistence in the

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[15] The Binomial Negative specification has been chosen because the dependent variable counts the number of patents a firm applies for, that is a count variable. In addition to that, there can be some overdispersion in the data. That is, that the variance of the variable can be larger than the mean, because some firms can have zero patents in a year and several patents in other years. For this reason a Poisson specification can be misspecified.

patenting activity of the firms. Columns (ii) to (vi) of Table 7 show the same estimation specification when the sample is split into different groups. For firms with more than twenty patents, the diversification effect is considerably smaller, although it increases for firms with less than twenty patents. Finally, for firms that have between ten and twenty patents, the diversity impact is negligible. This result is probably caused by the small sample size of this estimation (only 103 observations).

In order to control for the possible bias of the diversity variable, the same estimations have been calculated using a variation of the Herfindahl index as proposed by Hall (2002a). The *adjusted diversity* variable has a significant, although smaller effect on innovation than in the previous estimations (columns (vii) to (xii) in Table 7). This is due to the fact that this index gives more weight to the firms with fewer patents (those more likely to be more technologically concentrated). These results can be regarded as a lower bound of the technological diversity effect on innovation and show the positive relationship between technological diversity and number of patents.

The spillover effect (*K*) is more important for firms with a large number of patents. For firms with more than twenty patents, columns (iv) and (x), an increase in the available external knowledge pool by 10 percent enhance their patent activity by at least 4 percent. Firms benefit from the knowledge generated in other companies with a similar research menu, and at the same time, they are more innovative the wider their technological portfolio is.

If firms wrongly report their R&D expenditures, the regressor would be subject to measurement error. In addition to that, as it has been shown in the previous estimations, technological diversity affects the number of patents indirectly through R&D. For these reasons, equation (2) is estimated using the variables sales and debt instead of R&D as explanatory variables. The main results are shown in columns (i) and (ii) of Table 8. The estimated coefficient of the *diversity* variable is very similar to the one obtained in previous estimations. Finally, columns (iii) and (iv) in Table 8 present the estimations incorporating the variable *sales* as a control for firm's size. (although this relationship has been indirectly controlled by the variable *R&D*). As expected, there is a reduction of the estimated coefficients associated with the variables *sales* and *R&D* due to the correlation between these variables. The influence of both *diversity* and *adjusted diversity* on innovation decreases slightly with respect to previous estimations, although it remains significant, corroborating the direct relationship between patents and technological diversification. The reported findings in Table 8 remain very similar in terms of size and statistical significance to the previous ones.

5. Conclusions

More competition, more openness, and other factors that lead to an increase in the range of the firm's technological areas can reduce the variance of the firm's research portfolio. An increase in the firm's technological diversification can promote the cross-fertilization between different technological areas, and reduce the lock-in low profitable technologies. These are possible different channels through which the firm's technological diversification can create incentives to enhance innovation, and to raise the firm's investments in R&D.

This investigation examines empirically the effects of the technological diversity of firms on R&D intensity and number of patents. An econometric analysis based on panel data of 544 European firms from 1995 to 2000 indicates a positive relationship between technological diversity and innovation at the firm level. Although the results are based on a small sample of European firms, they support the hypothesis that technological diversification promotes innovation. The findings also show that small firms are more R&D intensive, although in a non-linear way, and illustrate the importance of the persistence the patent activity to promote innovation. Additionally, this article has tested the hypothesis that financial constraints are important for R&D investments. All the results are consistent with previous studies in the literature that assert the fact that firms prefer to use their internal funds to finance R&D investments, possibly due to asymmetric information, and moral hazard problems between financial institutions and inventors. Concerning the effect of external spillovers, the results suggest that firms with a larger available R&D pool have more patents, and that a certain absorptive capacity is necessary to benefit from the research activities of other firms.

The empirical analysis of this article has certain limitations. Patents and R&D expenditures are both imperfect measures of innovativeness at the firm level. Therefore the results and implications have to be taken cautiously. Moreover, it has left aside one important aspect of the characteristics of the technological diversification. The technology diversification measure that has been used throughout this paper does not distinguish between diversification in knowledge-related areas (Breschi et al., 2003) or unrelated areas, and consequently, it is not able to differentiate between these two cases.

More work is needed to empirically identify the links between diversification and innovation. One possible channel that can have influence on innovation is risk-sharing. Risk-adverse managers can be willing to assume more risks[16] when the returns of the technological projects are uncorrelated. Possibly, different risk attitudes caused by diverse economic environments (such that differences in risky borrowing regulations, bankruptcy exemptions across countries or regions) have important implications for the conduct of R&D investments. Additionally, managers of large and established companies can have different degrees of risk aversion than entrepreneurs of small or start-up firms.

One conclusion of this article involves with the proposition that big companies can damage the public interest, however they can be better qualified to innovate[17]. This study has emphasised the importance of technological diversification to promote innovation, rather than the importance of the size of the firm. Although there seems to be a minimum threshold for firms to diversify their research menu, there is no evidence for a linear relationship between size and technological diversification. More research, both empirical and theoretical, is necessary to examine the different determinants of

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[16] Therefore they may be also more willing to invest more resources in high-innovative R&D.

[17] Baumol (2002) among others.

technological diversification in static and dynamic frameworks, and its precise relationship with firm size and other firm characteristics, as well as its impact on firm performance in the marketplace.

ACKNOWLEDGEMENTS

I thank William Baumol, Jose A. Herce, Helena Huergo, participants in the VIII Jornadas de Economia Internacional (Castilla La Mancha University), 5th ZEW Summer Workshop (Mannheim), and seminars at University Carlos III (Madrid) and University Complutense (Madrid) for helpful discussions and comments on an earlier draft. I want to thank Jordi Casals for the use of the database at the IESE, and constructive comments of three anonymous referees. All errors are mine.

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TABLES AND FIGURES

Table 1

Comparison of average R&D spending and sales by industry (period 1995-200).
In millions of U.S. Dollars.

Industry	No. of firms in the sample		Average				
	all firms	% over total	Sales	max sales	R&D	max R&D	R&D/Sales
1 Chemicals and oil, gas, coal, and related services	63	12%	14866	751445	993	107953	7%
2 Electronics	104	19%	2354	73894	188	5445	8%
3 Drugs, cosmetics and health care	43	8%	2051	17690	223	2753	11%
4 Construction	31	6%	1443	15517	24	560	2%
5 Recreation	13	2%	1785	8657	29	299	2%
6 Metal product manufacturers and metal producers	32	6%	2474	15989	27	207	1%
7 Machinery and equipment	62	11%	1267	10245	59	1412	5%
8 Food, beverages and tabacco	36	7%	5598	57404	76	1119	1%
9 Automotive	22	4%	21345	154429	913	5973	4%
10 Utilities	28	5%	8036	46024	116	1037	1%
11 Electrical	20	4%	2447	17312	65	894	3%
12 Textiles	10	2%	595	4204	4	17	1%
13 Transportation, aerospace	10	2%	3969	14855	178	1473	4%
14 Others: paper, printing and publishing	59	11%	2803	27154	32	482	1%
15 Professional and scientific instruments	11	2%	393	3566	23	235	6%
Total	544						

Table 2

Comparison of average R&D spending and sales by country.

	No. of firms	Sales	R&D	R&D/Sales
France	56	11840	1108	5%
Germany	70	10653	504	6%
Greece	13	167	2	2%
Italy	23	8133	175	4%
Spain	2	206	8	4%
Sweden	27	3966	214	7%
UK	253	2400	48	4%
Lux	1	943	0	0%
Netherlands	23	10814	257	7%
Finland	39	2008	57	3%
Austria	10	1551	21	2%
Belgium	6	3267	133	3%
Denmark	10	870	62	7%
Ireland	11	1261	18	3%
Average		4148	186	

Table 3

Comparison of average R&D spending and sales by industry, for firms that patent (period 1995-2000).
In millions of U.S. Dollars.

	Industry	No. of firms	Sales	R&D	R&D/Sales
1	Chemicals and oil, gas, coal, and related services	47	17170	1307	8%
2	Electronics	65	1984	174	9%
3	Drugs, cosmetics and health care	35	2508	273	11%
4	Construction	22	1617	31	2%
5	Recreation	7	1753	40	2%
6	Metal product manufacturers, and metal producers	19	3102	37	1%
7	Machinery and equipment	51	1260	69	6%
8	Food, beverages and tabacco	21	8318	126	2%
9	Automotive	19	23722	1012	4%
10	Utilities	16	11152	167	2%
11	Electrical	17	2764	75	3%
12	Textiles	5	724	4	1%
13	Transportation, aerospace	7	4903	242	5%
14	Others: paper, printing, and publishing	42	3284	41	1%
15	Professional and scientific instruments	8	419	23	6%
	Total	381			

Table 4

Size distribution

size class (averaged sales)	No. of firms	No. of firms/total	EP patents no. of firms that patent	EP patents % firms that patent	% of total sales	% of total R&D
Less than 1 million	0	0	0	0%	0%	0%
1 to 10 million	10	0.02	8	2%	0.0%	0.1%
10 million to 100 million	108	0.20	34	10%	0.2%	0.3%
100 million to 1 billion	207	0.38	126	39%	3.0%	2.2%
1 to 10 billion	163	0.30	112	34%	22.2%	13.7%
Over 10 billion	56	0.10	47	14%	74.5%	83.7%
Total	544		327			

OLS estimation of the R&D intensity determinants

t-statistics in italics
All regressions include country and industry dummies
Dependent variable: R&D/sales

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)
log sales	-0.12	-1.79	-0.15	-1.96	-0.09	-0.20	-0.17	-1.62	-0.09	-0.12	-0.07	-0.18	-0.16	-1.61
	-5.56	*-11.95*	*-6.74*	*-12.24*	*-1.90*	*-5.37*	*-4.74*	*-9.52*	*-4.48*	*-5.74*	*-1.46*	*-4.88*	*-4.27*	*-9.43*
log sales^2		0.14		0.15				0.12						0.12
		11.27		*11.41*				*8.68*						*8.70*
debt1	-0.32	-0.26					-0.31	-0.27	-0.33				-0.32	-0.28
	-7.00	*-6.02*					*-6.73*	*-6.10*	*-7.14*				*-6.80*	*-6.15*
debt2			0.01	0.21						-0.01				
			0.10	*2.47*						*-0.07*				
cash1/sales					0.04						0.05			
					1.00						*1.07*			
cash2/sales						0.09	0.10	0.08				0.09	0.11	0.08
						2.63	*3.19*	*2.56*				*2.71*	*3.27*	*2.63*
diversity	0.24	0.22	0.25	0.24	0.25	0.23	0.21	0.20						
	4.72	*4.56*	*4.68*	*4.89*	*4.78*	*4.19*	*3.99*	*3.99*						
adjusted									0.11	0.12	0.13	0.12	0.11	0.11
diversity									*2.71*	*2.71*	*3.01*	*2.65*	*2.50*	*2.56*
constant	-0.82	4.19	-0.80	4.66	-1.10	-0.79	-0.89	3.55	-0.98	-0.95	-1.24	-0.91	-1.01	3.47
R-squared	0.51	0.57	0.48	0.54	0.48	0.5	0.53	0.57	0.5	0.47	0.48	0.49	0.52	0.56
adjusted R-sq	0.49	0.55	0.46	0.53	0.47	0.48	0.51	0.55	0.49	0.45	0.46	0.47	0.5	0.55
sample	965	965	950	950	811	810	810	810	965	950	811	810	810	810

debt1=total current liabilities/total current assets
debt2=total liabilities/(total liabilities+equity)
diversity is a year-variable for any firm
cash1 is log of operating cash flow
cash2 is log of total cash flow

Table 5

Table 6

OLS estimation of the R&D intensity determinants

t-statistics in italics
All regressions include country and industry dummies
R&D/sales

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
log sales	-0.14	-0.18	-0.15	-0.22	-0.16	-0.19	-0.13	-0.30	-0.27
	-6.02	*-7.84*	*-3.13*	*-5.23*	*-10.05*	*-11.54*	*-3.47*	*-10.82*	*-9.81*
debt1	-0.28				-0.30				-0.30
	-6.03				*-8.23*				*-8.44*
debt2		0.18				-0.03			0.16
		2.02				*-0.42*			*6.60*
cash1/sales			0.07				0.05		
			1.58				*1.56*		
cash2/sales				0.09				0.15	
				2.35				*6.04*	
diversity_{-1}	0.27	0.30	0.30	0.28					
	4.80	*5.42*	*5.43*	*4.73*					
diversityc					0.27	0.27	0.21	0.23	0.22
					5.62	*5.65*	*4.46*	*4.69*	*4.60*
constant	-0.67	-0.60	-0.82	-0.65	-1.04	-1.00	-1.43	-0.94	-1.03
R-squared	0.52	0.50	0.52	0.50	0.53	0.50	0.49	0.52	0.55
adjusted R-sq	0.50	0.48	0.50	0.48	0.52	0.49	0.48	0.51	0.54
sample	790	783	681	670	1637	1603	1359	1372	1372

debt1=total current liabilities/total current assets
debt2=total liabilities/(total liabilities+equity)
diversity_{-1} is a year-variable for any firm, values are lagged one year.
diversityc is the average firm diversification of each firm (different among firms).
cash1 is log of operating cash flow
cash2 is log of total cash flow

Table 7

Binomial negative estimation of the number of patents.

z-statistics in italics
All regressions include country and industry dummies
Dependent variable: number of patents

		np1	np2	npa1	npa2	npa3		np1	np2	npa1	npa2	npa3
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(xix)	(x)	(xi)	(xii)
log R&D	0.90	0.78	0.05	0.62	0.19	0.01	1.05	0.81	0.10	0.64	0.27	0.01
	19.78	*13.13*	*1.19*	*8.59*	*4.54*	*0.20*	*23.38*	*13.73*	*2.45*	*8.85*	*6.14*	*0.24*
K	0.32	0.61	0.04	0.46	0.06	0.00	0.55	0.66	0.06	0.50	0.10	0.00
	3.01	*3.60*	*0.52*	*2.22*	*0.78*	*0.04*	*4.68*	*3.86*	*0.82*	*2.40*	*1.22*	*0.03*
diversity	1.69	0.75	0.87	0.86	1.09	-0.02						
	12.01	*2.92*	*9.09*	*2.48*	*11.39*	*-0.14*						
adjusted diversity							0.69	0.37	0.28	0.57	0.40	-0.01
							5.27	*1.46*	*4.34*	*1.62*	*4.93*	*-0.09*
pat	0.60	1.22	0.17	1.18	0.32	0.06	0.72	1.20	0.22	1.17	0.40	0.05
	5.53	*7.10*	*2.44*	*6.30*	*4.28*	*0.48*	*6.39*	*6.96*	*3.29*	*6.24*	*5.14*	*0.38*
constant	-5.06	-6.80	0.91	-5.12	0.22	2.53	-7.66	-6.89	0.54	-5.20	-0.27	2.56
Log likelihood	-3514	-2191	-897	-1704	-1418	-250	-3561	-2194	-930	-1706	-1467	-251
Sample	890	435	455	314	576	103	890	435	455	314	576	103

Column (i) and (vii) all firms
np1: firms with more than 10 patents
np2: firms with less or 10 patents
npa1: firms with more than 20 patents
npa2: firms between one to 20 patents
npa3: firms between 10 to 20 patents
pat: dummy variable. one if firm has patented in the past. zero otherwise

Table 8

Binomial negative estimation

z-statistics in italics
All regressions include country and industry dummies
Dependent variable: no. of patents

	(i)	(ii)	(iii)	(iv)
log R&D			0.25	0.29
			7.97	*9.14*
log sales	0.43	0.51	0.19	0.23
	18.82	*22.30*	*5.59*	*6.48*
debt1	-0.37	-0.41		
	-3.87	*-4.27*		
K	0.49	0.59	0.43	0.52
	4.22	*4.91*	*3.85*	*4.49*
diversity	1.77		1.59	
	12.28		*11.15*	
adjusted diversity		0.72		0.59
		5.36		*4.58*
pat	0.47	0.60	0.52	0.64
	4.29	*5.29*	*4.75*	*5.74*
constant	-8.06	-9.62	-7.20	-8.51
Log likelihood	-3505	-3559	-3496	-3543
Sample	888	888	890	890

debt1=total current liabilities/total current assets
pat: dummy variable. one if firm has patented in the past, zero otherwise

Figure 1. Relationship between size and R&D expenditures.

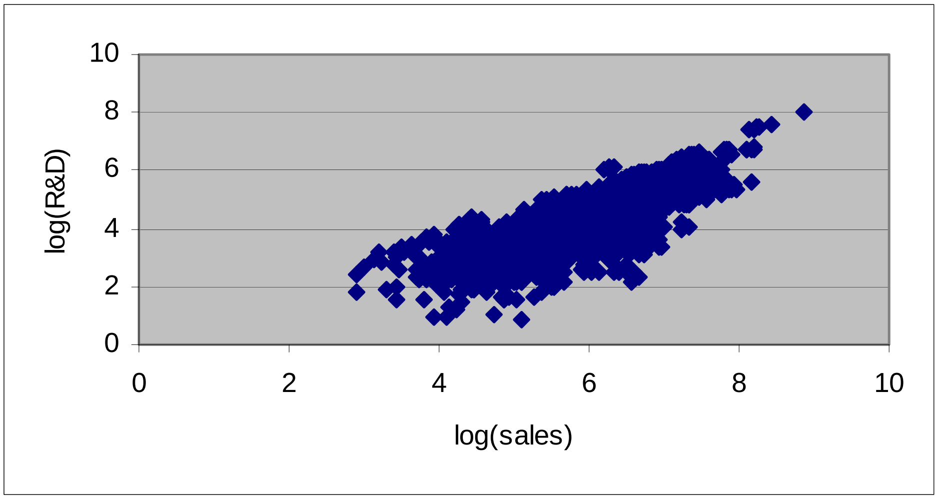
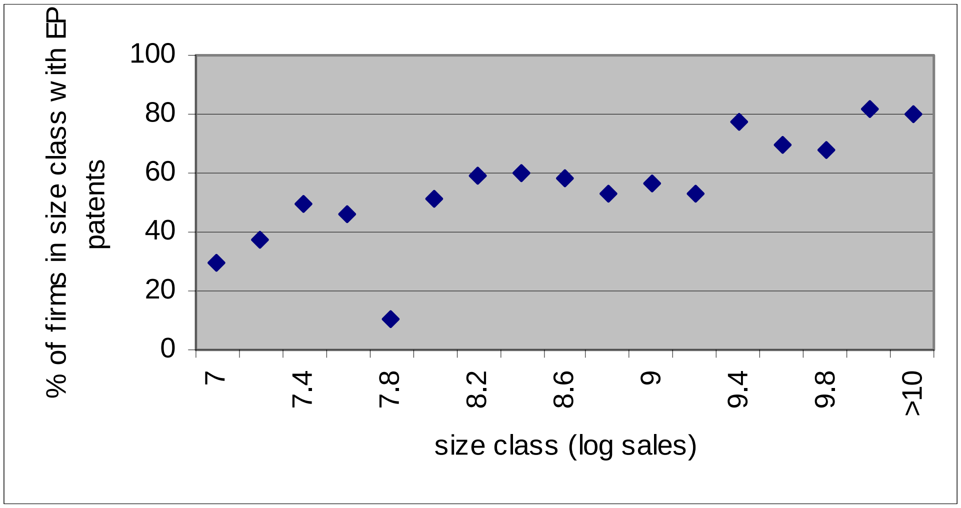


Figure 2: Relationship between size and patent activity.



APPENDIX

Table A.1.

Technological fields			
1	Coating (chemicals)	26	Motors, Engines and Parts
2	Gas	27	Optics
3	Organic compounds	28	Transportation
4	Resins	29	Cycles
5	Explosives and matches	30	Working plastic and non-metalic articles
6	Glass, mineral or slag wool	31	Weapons (mechanical)
7	General chemical	32	Checking-devices
8	Agriculture (chemicals)	33	Husbandry Agriculture
9	Food (chemicals)	34	Food
10	Metallurgy	35	Amusement Devices
11	Communications	36	Textile Appareil
12	Computer Hardware and Software	37	Earth Working and Wells
13	Drugs and Perfumes	38	Furniture, House Fixtures
14	Surgery and Medical Instruments	39	Heating, ventilation and refrigeration
15	Biotechnology	40	Constructions of roads railways and bridges
16	Electrical devices	41	Receptacles Luggages
17	Electrical Lighting	42	Printing and books decoratives arts
18	Measuring and Testing	43	Saddlery upholstery
19	Nuclear and X-Rays	44	Measuring and testing
20	Power Systems	45	Music
21	Semi conductor Devices	46	Treatement of water and solid waste
23	Materials Processing and Handling	47	Cleaning
24	Abrading	48	Performing operations
25	Metal Working	49	Others