The Impact of Internal and External Basic Research on the Technological Performance of Pharmaceutical Firms

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Abstract

This paper evaluates the impact of basic research on the technological performance of firms. We improve on existing research by distinguishing between, and jointly analyzing, self-performed basic research (internal basic research) and the exploitation of external basic research findings (external basic research) in firms' technology activities. We hypothesize that firms that engage in internal basic research increase their technological performance, in particular when these activities are undertaken in collaboration with universities. In addition, a positive impact of the exploitation of external basic research findings is expected. Finally, we argue that internal basic research and the usage of external basic research are complementary activities in the sense that internal basic research provides firms with the skills and methods to exploit external basic research more effectively in their technology activities. Using improved measures for internal and external basic research, we find empirical support for all these hypotheses in a fixed-effect panel data (1995-2002) analysis of the patent and publication activities of 33 of the largest R&D spending American, European and Japanese pharmaceutical firms in the world.

Keywords: Basic Research, Industrial Innovation, Pharmaceutical Industry

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1. Introduction

There is abundant evidence of the important role of basic research in driving innovation, economic growth and welfare (Mansfield, 1980; Jaffe, 1989; Griliches, 1986; Adams, 1990)[1]. Basic research can be defined as activities that are directed towards the general advancement of men's knowledge about the physical world, having no specific commercial objectives (Nelson, 1959). These activities expand the knowledge base available for firms (external basic research) to use in their technological activities (Klevorick et al, 1995).[2] To what extent it is rational for firms to be involved themselves in basic research has been subject to a long debate among economists. Nelson (1959) argues that firms are reluctant to invest in basic research due to high degrees of uncertainty, long time frames to fruition, and appropriability problems. Appropriability problems result from the fact that the outcome of basic research, i.e. knowledge, is (at least partly) believed to be a public good and therefore freely available to other firms, (Arrow, 1962). Rosenberg (1990), on the other hand, argues that, despite these difficulties, there are rational reasons for profit-seeking private firms to conduct internal basic research activities. Firms that perform basic research may benefit from first-mover advantages, and improve the efficiency of their technology activities by developing a deeper understanding of the phenomena under study. In addition, internal basic research capabilities help firms to monitor, interpret and appraise findings from basic research activities that are conducted outside the focal firm.

A small number of empirical studies have examined the impact of basic research on the technological performance of firms, providing mixed results. These studies focused either on internal basic research or on the usage of external basic research findings. A first group of studies studied the effect of internal basic research on the technological performance of firms. Gambardella (1992) found that US pharmaceutical firms with stronger in-house basic research skills produced a greater number of inventions. Cockburn and Henderson (1998) did find, for a sample of pharmaceutical firms, positive effects of internal basic research only when it was

[1] An elaborate overview of the empirical literature that studied the economic benefits from basic research can be found in the overview article of Salter and Martin (2001).

[2] Numerous important technical inventions were the direct result of advances in scientific knowledge resulting from basic research. A famous example is the development of the transistor at the Bell Telephone Laboratories in 1948 as a result of basic research activities of company scientists on the workings of semiconductors (Nelson, 1962).

undertaken in collaboration with university scientists. Lim (2004) found no effect of internal basic research on the technological performance of pharmaceutical firms, while a negative effect was found for semiconductor firms. Using a sample of pharmaceutical and biotechnology firms, Fabrizio (2009) found that firms which do more basic research produce higher value inventions. A second set of studies examined the effect of the exploitation of external basic research findings (measured by citations to scientific literature in firm patents) on the value of firm inventions. Cassiman et al (2008) reported an insignificant relationship between the presence of scientific references on firm patents and their technological value, measured by forward patent citations. Fleming and Sorenson (2004) did find a positive relationship, but only for patents in complex technologies, suggesting that benefits of using external basic research differ across technologies.

This paper extends prior empirical work on firms' basic research activities by jointly examining the impact of self-performed basic research (internal basic research) and the usage of external basic research findings in firms' technology activities (external basic research) on the technological performance of firms. Hereby we explicitly test the complementary character of both types of basic research activities. In other words, we examine whether firms with stronger internal basic research capabilities are better positioned to benefit from the usage of external basic research findings in their own technology activities. To investigate firms' basic research activities, we have collected panel data (1995-2002) on the patent and publication activities of 33 of the largest R&D spending pharmaceutical firms in the world. Our study uses more accurate indicators for basic research than prior empirical work. Prior studies have used the number of corporate scientific articles as proxy for internal basic research activities[3], or, alternatively, references to scientific articles in firm patents as proxy for the exploitation of external basic research findings in firms' technology activities. However, scientific articles are an imperfect measure of basic research because a large share of these articles report on applied research activities (Hicks, 1994).[4] Using information on the journals in which firms' articles are published and the CHI classification scheme for basic versus applied research (Hamilton, 2003), we

[3] The study of Lim (2004) is the only exception. Firms' internal basic research activities are measured in this study via firm publications in basic research journals (similar approach as the one taken in this paper).
[4] Applied research in the pharmaceutical industry refers to clinical research, i.e. the hands-on analysis of the effects of drugs on patients. A large share of articles of pharmaceutical firms reports on clinical trials (Hicks, 1994).

constructed more accurate indicators of internal and external basic research by relying on the subset of corporate scientific articles in ‘basic research’ journals.[5]

Controlling for firm fixed effects, our analyses reveal that firms that engage in internal basic research increase their technological performance, in particular when these activities are undertaken in collaboration with universities. In addition, we find that firms can improve their technological performance by more frequently exploiting external basic research findings in their technology activities. The impact of the exploitation of external basic research findings on firms’ technological performance is positively moderated by the internal basic research capabilities of firms. Hence, internal basic research and the exploitation of external basic research findings act as complementary activities for firms.

The remainder of the paper is organized as follows. The next section provides a brief overview of the existing literature on the relationship between basic research and innovation. The hypotheses are described in section three, followed by a description of the data and empirical methods in section four. The empirical results are discussed in section five. In the final section, we summarize the main findings of the paper, conclude and suggest avenues for further research.

2. Literature Background

Basic research has received many definitions (Rosenberg, 1990). We adopted the definition of the National Science Foundation (NSF) where basic research is defined as the systematic study directed towards greater knowledge or understanding of the fundamental aspects of phenomena and observable facts without specific immediate commercial applications in mind, although research may be in fields of present or potential commercial interest of those performing the research activities (NSF, 2009). Applied to the pharmaceutical industry basic research includes attempts to reveal the mechanisms and processes of diseases, and does not include applied research activities such as compound screening, clinical trials and dosage testing (Lim, 2004).

[5] In section four, we report in detail on the distribution of the publication output of pharmaceutical firms over different types of journals, ranging from (very) applied to (very) basic. Only publications in basic research journals are used to construct our measures of internal basic research and the exploitation of external basic research findings.

Basic research activities conducted by firms are concentrated in two different respects. First, the majority of basic research is conducted in a small number of industries such as pharmaceuticals, chemicals, electrical machinery and aerospace (Mansfield, 1980; Rosenberg, 1990). These sectors are called ‘science-based industries’ in Pavitt’s (1984) sector taxonomy. Second, within these sectors a handful of firms perform most of the basic research activities. These firms are typically large firms with diverse product and technology portfolios who are confident that they will be able to put both anticipated and unexpected findings from basic research into commercial use (Nelson, 1959). A noticeable exception is the pharmaceutical industry, in which both large pharmaceutical firms and small biotechnology firms perform basic research (Rosenberg, 1990).

Basic research is a process of learning of the physical world that generates knowledge which is available for firms to draw upon in their applied technology activities (Klevorick et al, 1995). Mansfield (1995 & 1998) examined the importance of basic research for firms’ technology activities by surveying samples of US firms across different industries. He found that, during the period 1975-1985, 11% of firms’ new products and 9% of new processes could not have been developed (or with substantial delay) in the absence of basic research conducted by universities. These numbers are higher for the period 1986-1994 (respectively 15% and 11%), suggesting that basic research findings have become increasingly important for industrial technology activities. Another indication of the growing reliance of industrial technology activities on (basic) scientific knowledge can be found in the analysis of citations to scientific literature in patent documents. For instance, Narin et al (1997) reported a threefold increase in the number of citations to scientific literature in industrial patents in the United States during the early and mid 1990s.

Basic research is an important source of knowledge for industrial innovation in many industries, but particularly in the pharmaceutical industry (McMillan et al, 2000). Patents in drugs and medicine classes cite significantly more scientific articles than patents in other classes (Narin et al, 1997) and cite more heavily basic scientific research (Narin and Olivastro, 1992). The strong reliance of pharmaceutical firms on basic research becomes also apparent from the case histories of the discovery of 21 important drugs described by Cockburn and Henderson (1998). Fundamental insights in basic science played a role in the discovery of sixteen of these drugs. The link between basic research and drug discovery has increased over time (Lim, 2004).

Pharmaceutical firms have moved away from randomly screening a large number of potentially useful compounds against a certain disease, towards a more systematic approach called rational drug design. This approach involves exploiting knowledge about the biochemical mechanisms causing a disease to identify and develop compounds that inhibit the mechanisms (Pisano, 1997).

Basic research has become part of the drug discovery processes in most pharmaceutical firms. Based on case studies of US pharmaceutical firms, Gambardella (1992) has however shown that pharmaceutical firms pursue different strategies with respect to the importance given to internal basic research and the exploitation of external basic research findings in their technology activities. For example, Merck invested strongly in internal basic research and used this knowledge to exploit and further build on externally generated basic research findings; Bristol-Myers on the other hand has had only modest internal basic research skills (Gambardella, 1992). Besides investigating the overall complementarity of internal and external basic research, the purpose of this study is to examine whether differences in internal and external basic research strategies of pharmaceutical firms translate in differences in technological performance.

3. Hypotheses

Company researchers often consult scientific literature to solve technical difficulties in their technology activities (Allen, 1977; Gibbons and Johnston, 1974). Organizations that frequently consult and exploit external basic research findings in their technology activities are expected to develop a deeper understanding of the fundamental principles of the phenomena under study (Rosenberg, 1990). Basic scientific knowledge allows firms to anticipate the results of research experiments without performing them, what helps firms to prioritize research avenues and to avoid costly and time consuming research trials that lead to low-value outcomes (Fabrizio, 2009). In other words, basic scientific knowledge informs firms on the success probabilities of different directions to conduct applied research (Fleming and Sorenson, 2004). Basic scientific knowledge also helps firms to evaluate the outcomes of applied research and to perceive its implications (Rosenberg, 1990). A firm that exploits more external basic research findings in its technology activities is therefore expected to increase its technological performance.

Hypothesis 1: The exploitation of external basic research findings in firms' technology activities has a positive impact on firms' technological performance.

Firms that conduct internal basic research benefit from the scientific knowledge that is generated by these research activities in a similar way as firms that exploit external basic research findings. Basic scientific knowledge serves as a map of the technological landscape which firms search for inventions, guiding them towards the most promising directions (Fleming and Sorenson, 2004). Performing in-house basic research has however additional advantages for firms' technological performance. First, internal basic research capabilities may act as an admission ticket to R&D partnering with universities and PROs (Liebeskind et al, 1996; Cockburn and Henderson, 1998). Internally performed basic research activities demonstrate the scientific competence firms need to enter into relationships of information exchange with public sector scientists (Hicks, 1994). Second, internal basic research may act as a powerful recruiting tool, since the highest quality researchers ('stars')[6] are reluctant to work for firms in which they are not allowed to do basic research and publish scientific findings (Henderson and Cockburn, 1994; Hicks, 1999). Publishing is one of the most important means for scientists to establish their reputations (Stephan, 1996) and corporate scientists are found to be willing to accept lower wages in exchange for the permission to conduct and publish scientific research (Stern, 2004). Employing star scientists has a large positive impact on the research performance of firms (Zucker et al, 2002; Furukawa and Goto, 2006). Taken together, these arguments suggest that firms can increase their technological performance by conducting internal basic research activities.

Hypothesis 2: Internal basic research has a positive impact on firms' technological performance.

There are reasons to believe that the benefits of internal basic research are larger when research activities are conducted in collaboration with university scientists. Collaboration with university scientists often leads to extensive debate, exchange of ideas and discussions. This provides firms with access to tacit knowledge of university scientists, which is not provided in journal articles (Cockburn and Henderson, 1998). Furthermore, these collaborations may help firms to get access to relevant codified scientific research of university scientists that is not yet published, allowing

[6] In R&D, a few people are very productive ('stars') and many others are much less so (Narin & Breitzman, 1995).

firms to build faster on recent research findings in their own research activities (Fabrizio, 2009). Controlling for the amount of internal basic research done by the firm, firms that do more of this research in collaboration with university scientists are expected to increase their technological performance.

Hypothesis 3: Internal basic research has a larger positive impact on firms' technological performance when it is done in collaboration with universities.

External basic research findings are not a completely free input to firms' own research activities. As Cohen and Levinthal (1990) have noted, learning is a cumulative, incremental process which is influenced by capabilities that are already present at the individual and organizational level. Individuals learn through a process whereby new events are stored in their memories by establishing linkages with pre-established concepts and ideas. Therefore, the ability of organizations[7] to learn from external research findings depends on the commonality between the organizations' internal knowledge base and the external research findings (Teece et al, 1997). Hence, firms that want to take advantage of research conducted outside their organizations need to invest in an 'absorptive capacity' in the sense of accumulating knowledge and skills to understand and utilize externally generated knowledge. The creation of an 'absorptive' capacity for external basic research findings, involves the employment of a cadre of scientists and granting them the freedom to perform basic research activities (Rosenberg, 1990; Pavitt, 1991). Based on the absorptive capacity argument, firms with stronger in-house competences in basic research are expected to be better equipped to benefit from the exploitation of external basic research findings in their own R&D activities. This leads to the following hypothesis.

Hypothesis 4: The impact of the exploitation of external basic research findings on firms' technological performance is augmented when firms conduct more internal basic research.

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[7] An organization's ability to learn depends, at least in part, on the ability of its individual members to learn as organizational learning involves the joint contribution of individual members to solve problems (Helfat, 1994).

4. Data and Methods

4.1. Sample

To examine the effects of internal basic research and the exploitation of external basic research findings on the technological performance of firms, we have constructed a panel dataset on the patent and publication activities of 33 large R&D spending firms in the pharmaceutical industry. The sample firms are selected as top R&D spenders in the pharmaceutical industry from the '2004 EU Industrial R&D Investment Scoreboard'. This scoreboard lists the top 500 corporate investors in R&D whose parent is located in the EU, and the top 500 companies whose parent is located outside the EU (mainly US and Japan), based on corporate R&D expenditures in 2003. The sample firms have headquarters in the United States, Europe and Japan and are observed over a period of eight years (1995-2002). The sample consists of 30 pharmaceutical firms and 3 large biotech firms (Chiron, Amgen and Genzyme)[8]. The R&D investments of the firms totaled 40.2 billion US dollars in 2002. The smallest company R&D budget in our sample amounts to 175 million (Sepracor) and the largest R&D budget reaches almost 6 billion US dollars (Pfizer).

4.2. Dependent Variable

Technological activity of firms is measured by means of patent data. There are numerous advantages to the use of patent indicators (Pavitt, 1985; Basberg, 1987; Griliches, 1990; Hall et al, 2005): patents contain highly detailed information on the technological content, owners and prior art of patented inventions; patent data is objective in the sense that it has been processed and validated by patent examiners; and patent data is easily available from patent offices and covers long time series. Like any indicator, patent indicators are also subject to a number of drawbacks: not all inventions are patented and those that are patented vary in their technical and economical value (Griliches, 1990; Trajtenberg, 1990; Gambardella, 2008). The first problem

[8] Arora et al (2009) showed that old biotech firms display strategic behavior and innovation performances similar to pharmaceutical firms. Removing the biotech firms from the sample does however not change the empirical results.

can be addressed by limiting patent analyses to industries with high patent propensities[9] and studying firm-level patent time series[10]. The 'value' problem can be taken care of by weighting patent counts by the number of forward patent citations received by these patents (Trajtenberg, 1990; Harhoff et al, 1999; Hall et al, 2005). Both approaches are followed in this paper.

Because company names in patent databases are not unified and patents may be applied for under names of subsidiaries or divisions of a parent firm, we collected patent data at the consolidated parent firm level. Therefore, we searched, for each parent firm, for patents under the name of the parent firm as well as all their majority-owned subsidiaries. For this purpose, yearly lists of companies' subsidiaries included in corporate annual reports, yearly 10-K reports filed with the SEC in the US, and, for Japanese firms, information on foreign subsidiaries published by Toyo Keizai in the yearly 'Directories of Japanese Overseas Investments', were used. The consolidation was conducted on a yearly basis to take into account changes in the group structure of sample firms due to acquisitions, mergers, green-field investments and spin-offs. Acquisitions are considered part of a parent firm from the year the acquisition transaction has been completed.

In this study we have chosen to work with patent data from the European Patent Office (EPO). The technological performance of the sample firms (dependent variable) is measured as the number of EPO patent applications of a parent firm in a year, weighted by the number of forward patent citations received by those patents over a fixed window of 4 years. The number of forward patent citations is calculated on a fixed time window because the number of forward citations to any patent depends on the length of the citation window (Hall et al, 2005; Trajtenberg, 1990). Forward patent citations are calculated on the EPO patent citation database of Webb et al (2005) and are calculated for all citing EPO patents and national patents with EPO patent equivalents.

The dependent variable is a count variable with only non-negative integer values. In this case, nonlinear count data models are preferred to standard linear regression models as the former

[9] The majority of inventions in the pharmaceutical industry are patented (Arundel and Kabla, 1998; Campbell, 2005).

[10] Individual companies only seldom change their patenting policy, making firm-level patent time series more meaningful to study than between-company differences in patenting.

explicitly take into account the non-negativity and discreteness of the dependent variable (Cameron and Trivedi, 1998). We have used Negative Binomial count data models which control for overdispersion in the dependent variable. To control for the presence of unobserved firm-specific effect (which may correlate with, and bias the effect of explanatory variables in the models, if not controlled for) fixed effects panel data estimators are used in all regression models.

4.3. Internal Basic Research

We used information on scientific publications authored by the sample firms and published in peer reviewed international journals to assess the internal basic research activities of firms. Publication data are extracted from yearly updates of the Science Citation Index database of ISI/Thomson Scientific; documents of the type article, letter, note and review have been selected. Publication data is collected at the consolidated parent firm level, following a similar approach as the one followed for the collection of patent data. This approach consists of identifying all publications on which the parent firms, or their subsidiaries, are listed as publishing institutes. In line with studies of Hicks et al (1994) and Cockburn and Henderson (1998) we find that pharmaceutical firms publish extensively; sample firms published on average 263 publications per year in the SCI database over the period 1995-2002. We collected bibliographic information (journal name, volume, pages etc.) for all the publications belonging to the 33 sample firms.

A method was needed to determine which firm publications report on basic research activities. We classified a publication as ‘basic research’ based on the journal in which it is published and the CHI journal classification scheme which classifies each of the SCI journals in one of four research levels, in a spectrum ranging from very applied, targeted research to basic research. For biomedical journals the four different research levels are called clinical observation (level 1), clinical mix (level 2), clinical investigation (level 3) and basic biomedical research (level 4)[11]. Journals that are classified in level 4 are considered as reporting mainly basic research findings. About 36% of the SCI publications of the sample firms are published in basic research journals.

[11] An example of a journal that is classified in level 1 is the *Journal of the American Medical Association*. The *Journal of Biological Chemistry* is an example of a journal that is classified in level 4 (Hamilton, 2003).

The remaining 64% of SCI publications report on applied research activities of the sample firms (clinical trials) and are not used in the construction of the internal basic research variables.
The internal basic research variable is constructed on the basis of a 4-year moving time window. The internal basic research expertise of a firm in year t is measured as the sum of firm publications that are published in basic research journals in the past 4 years (t-4 to t-1) by firm subsidiaries that were part of the parent firm in year t. The variable is divided by the size of the firm's R&D expenditures in year t-1 to make it independent of the scale of the firm's R&D activities, as it was done in the studies of Cockburn and Henderson (1998) and Fabrizio (2009).

Following prior work by Cockburn and Henderson (1998) and Fabrizio (2009), the intensity of collaboration between the firm and university scientists in basic research is measured as the share of firm publications in basic research journals that are co-authored with universities. To identify firm publications that are jointly written with university scientists we checked for the presence of the words *university*, *college* or *regents* in the publishing institutes names of firms' publications.

4.4. Exploitation of External Basic Research Findings

Our measure of the exploitation of external basic research findings in firms' technology activities is based on references in the prior art of firms' patents to publications in basic research journals (not published by the firm itself). The prior art section of a patent contains references to prior patents and non-patent literature, including scientific articles. The legal purpose of the references is to indicate which parts of the knowledge described can be claimed by the patent and which parts have been claimed by other patents and non-patents. Patent references restrict the scope of patent claims to novelty and represent a link to the pre-existing knowledge base upon which patents have been built (Criscuolo and Verspagen, 2008; Jaffe et al, 2004). This fact has been used by prior studies (Narin et al, 1997; Fleming and Sorenson, 2004) to justify the use of patent references as information source on the knowledge base of patent applicants.

One critique to this particular use of patent references is that the prior art section of patents includes references provided by patent applicants while filing their patents as well as references added later on by patent examiners during their search for relevant prior art (Alcacer and

Gittelman, 2006). The problem is that patent applicants may not know part of the references cited in the prior art of their patents, especially references made by patent examiners (Brusoni et al, 2005). However, surveys of USPTO patent inventors (Jaffe et al, 2004; Fleming and Sorenson, 2004; Tijssen et al, 2000) have shown that inventors are aware of a significant part of the patents and scientific articles that are cited in the prior art of their patents, including some of the references made by patent examiners[12]. Using data on EPO patents and responses to the Community Innovation Survey (CIS) for a sample of French firms, Duguet and MacGarvie (2005) find a positive correlation between the number of references in firms' patents and the intensity to which firms have sourced external knowledge. Altogether, this evidence justifies the use of patent references in USPTO and EPO patents of firms as indicator of the knowledge base that firms have used, or at least had a minimal awareness of, in their technology activities.

Non-patent references are extracted for all EPO patents of the sample firms, using information from the patents' search reports. Patents cite a variety of non-patent references, such as scientific articles, books, newspapers, company reports and industry related documents, which do not all refer to basic research findings (Harhoff et al, 2003; Callaert et al, 2006). We have used non-patent references to scientific articles in basic research journals in the calculation of our firm-level indicator of the usage of external basic research. These references are identified via a text-matching algorithm and the CHI list of all research journals (applied/basic) in the SCI database.[13] Patents of our sample firms cited on average 1,62 non-patent references in their prior art section. About 70% of these non-patent references referred to publications in scientific journals (SCI database)[14]; 40% of these NPRs referred to publications in basic research scientific journals. Because we want to measure the exploitation of *external* basic research findings in firms' R&D activities, references to own firm publications are removed from our indicator. On average, 7%

[12] In their survey of USPTO patent inventors, Jaffe et al (2004) find that patent inventors have a moderate to high familiarity with more than 50% of the cited patent references. Given that, on average, 63% of patent references in USPTO patents are provided by patent examiners (Alcacer and Gittelman, 2006), this shows that patent applicants are also aware of part of the patent references that are added by patent examiners. Compared to references to patent prior art, references to scientific articles more frequently come from patent applicants themselves (Narin and Noma, 1985), what explains the high degree of familiarity of patent inventors with scientific articles cited in the prior art of their patents; Fleming and Sorenson (2004) and Tijssen et al (2000) report that patent inventors in their surveys are, in respective order, aware of 62% and 84% of the cited articles in their patents.

[13] More specifically, non-patent references (NPRs) to scientific articles in the SCI database are identified by checking for the presence of SCI journal names (6,400 journals) in the text strings of NPRs in sample firms' patents.

[14] These numbers are comparable with numbers found in prior studies. Analyzing NPRs in German or EPO patents, Harhoff et al (2003) and Callaert et al (2006) respectively found that 60% and 64% of NPRs are scientific articles.

of the cited publications in basic research journals referred to publications of the citing firm. The identification of NPRs to own firm publications was done by collecting (for all scientific NPRs) information on the *volume*, *year* and *starting page* of the publication to which the NPR refers.[15] An NPR was considered to refer to an own firm publication when the journal name, volume, year and starting page in the NPR text were identical to the same information of one firm publication.

In parallel with the internal basic research variable, our measure of the exploitation of external basic research findings in firms' technology activities is computed on a 4 year moving window. More specifically, the external basic research variable is calculated as the average number of citations to publications in basic research journals (not belonging to the firm itself) in patents that are applied for by the firm (subsidiaries of the firm in year t) in the past 4 years (t-4 to t-1). The variable is expressed as an *intensity* to make it independent of the scale of firms' R&D activities.

4.5. Control Variables

Our empirical models control for other (time varying) firm-level factors that are likely to impact on firms' technological performance. First, we control for differences in firms' R&D expenditures, opting for a one-year time lag between R&D expenditures and firm patents. The data on firms' R&D expenditures are collected from corporate annual financial reports (source: Worldscope & Compustat databases) and are measured in millions of US dollars.[16] Second, we control for differences in the patent intensity of firms, measured as the one-year lagged ratio of the number of firm patents and R&D expenditures. Third, we include an indicator for the level of technology diversification in a firm's patent portfolio. Technology diversification is measured as the 'spread' of patents in a firm's 4-year patent portfolio over technology classes. Technology class information on patents is derived from the IPC classes assigned to patents. We distinguished between 120 different 3-digit IPC classes to construct the diversification measure. The technology diversification variable is the inverse of the so-called Herfindahl index: it takes higher values when the level of technology diversification increases. Both linear and quadratic

[15] Using a list of keywords we were able to retrieve this information for 83% of the NPRs to scientific articles.
[16] Remark that R&D expenditures of pharmaceutical firms encompass both expenditures on *drug discovery* and *clinical trials*. We prefer to use data on drug discovery expenditures as measure of the size of firms' research inputs. However, this information is not publicly available, forcing us to use total R&D expenditures as control variable.

terms of technology diversification are included in the regression model to test for the existence of an inverted U-shape relationship between technology diversification and firm performance.[17] Finally, the empirical models include time dummies (1995 as base category) to account for time-specific factors affecting the technological performance (weighted patent numbers) of firms.

Summary statistics of the dependent and explanatory variables can be found in Table 1. There is substantial variation between the sample firms in the internal and external basic research variable, with maximum values being several times larger than minimum and mean values. The sample firms do actively collaborate with universities in internal basic research activities; the percentage of internal basic research publications that are co-authored with universities is on average 46%, while it ranges from 11% to 78%.

Insert Table 1 about here

Table 2 reports the coefficients of correlation between the variables of interest. As to be expected, the correlation between technology diversification and its squared term is considerable; none of the other reported correlations is excessively high. There is a positive correlation between internal and external basic research. This suggests that firms which conduct more internal basic research do more actively exploit external basic research findings in their technology activities, providing first evidence of the complementary character of both types of basic research activities.

Insert Table 2 about here

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[17] Prior studies (Henderson and Cockburn, 1996; Nesta and Saviotti, 2005; Leten et al, 2007) found an inverted U-shape relationship between technology diversification and the technological performance of pharmaceutical firms.

Figure 1 shows the internal and external basic research activities for the firms in our sample[18]. While the positive correlation between the two types of basic research is apparent, the figure also illustrates that the firms are heterogeneous in their focus on internal versus external basic research. For example, whilst both companies on average make a comparable number of citations to external basic research in their patents (about 130), the basic research strategy of Novartis places relatively more emphasis on internally performed research than Bristol-Myers Squibb in terms of its publications in basic research journals (630 versus 340).

Insert Figure 1 about here

Finally, Figure 2 shows the evolution in internal and external basic research activities over the sample period. The average basic research publication activity across firms has remained roughly constant. In comparison, Gambardella (1992) reported figures on the whole of basic and applied publications by a small number of US pharmaceutical firms in the period 1973-1986. He observed a significant upward trend for some firms (e.g. Merck), but not for all (e.g. Eli Lilly). Turning to the citations of (non-firm) basic research publications on patents, there is a clear increasing trend, in line with the findings of Narin et al (1997).

Insert Figure 2 about here

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5. Empirical Results

The empirical results of the fixed effects Negative Binomial regression models on the relationship between internal basic research, the exploitation of external basic research findings in technology activities and the technological performance of firms are reported in Table 3.

[18] Internal and external basic science are measured as the firm's average number of publications per year and the firm's average number of NPRs per year, respectively. Only a subset of firms has been labeled in the graph for expositional reasons.

Model 1 includes only the control variables and acts as point of comparison for the other models. The R&D expenditures and patent intensity variables have the expected positive signs and are both statistically significant. Technology diversification has a positive linear term, and a negative quadratic term. The linear term is significant in all models; the quadratic term is only significant in the most complete model 5. These results confirm the existence of an inverted U-shape relationship between technology diversification and firms' technological performance. The peak of the inverted U-shaped curve occurs at a value of 4,78 (calculation done for model 5), with 19% of the sample firms having larger values for the technology diversification variable.

Insert Table 3 about here

In model 2, the external basic research variable is added to the set of controls. This variable is positive and significant, confirming hypothesis 1: Firms can increase their technological performance by exploiting more external basic research findings in their technology activities. The internal basic research variable is added to the list of regressors in model 3. The coefficient of this variable is positive and significant, while coefficients of the other variables do not change. This supports hypothesis 2: Internal basic research has a positive impact on firms' technological performance.[19] In model 4, the variable 'collaboration with universities in internal basic research' is added. The collaboration variable has a positive and significant coefficient, confirming hypothesis 3: Internal basis research has a larger positive impact on firms' technological performance when basic research is conducted in collaboration with universities.

In model 5, the interaction effect between internal basic research and the exploitation of external basic research is added to the analysis. The interaction effect is created as the product of the demeaned values of *internal basic research* and the *exploitation of external basic research*. This approach allows evaluating the main effects of both basic research variables at 'meaningful' values (mean value of the other basic research variable) rather than at the out-of-sample value 0.

[19] The 'size' of the impact of basic research on firms' technological performance can be derived directly from the estimated coefficients of both basic research variables, which can be interpreted as semi-elasticities. Both variables have the same semi-elasticity: a one-unit change in one basic research variable increases firm performance by 33%.

The coefficient of the interaction variable is positive and significant, while the coefficients of the both main effects also remain positive and significant. Unlike in OLS, in non-linear regression models such as the Negative Binomial model, the sign and significance of the interaction variable is no definitive indication of the sign and significance of the interaction effect (Hoetker, 2007). The interaction effect, in which we are interested, is captured by the partial cross-derivative of the conditional mean function of the fixed effect Negative Binomial model with respect to both interacted variables (internal basic research and usage of external basic research). The magnitude, and even the sign, of such a derivative can differ across observations. Therefore, we have calculated the value of the cross-derivative function for all sample observations. The average coefficient for the cross-derivate is our sample is 89.22, and it takes positive values for all 245 sample observations (significant at 10% level for 244 of the 245 observations). This supports hypothesis 4: The impact of the exploitation of external basic research findings on firms' technological performance is augmented when firms conduct more internal basic research.

Figure 3 illustrates the interplay between internal and external basic research. More specifically, it shows the predicted citation-weighted patents (on the vertical axis) for different combinations of internal and external basic research[20] (on the horizontal axes) with the other regressors evaluated at their respective sample means. The surface plot confirms the main effect of internal and external basic research, and more importantly, illustrates the magnitude of the interaction effect of both variables. While both internally performed basic research and externally sourced basic research have a positive impact on firms' patent output, it is the mutually reinforcing combination of both activities that leads to a sizeable increase of innovative performance.

Insert Figure 3 about here

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[20] Internal and external basic research are expressed as intensities, as explained in sections 4.3 and 4.4, respectively. For both internal and external basic research, we consider values within one standard deviations from the mean.

6. Conclusion and Discussion

In this paper we have examined the impact of basic research on the technological performance of firms. We extended prior empirical work by jointly examining the impact of self-performed basic research (internal basic research) and the usage of external basic research findings in firms' R&D activities (exploitation of external basic research) on firms' technological performance. Hereby we explicitly tested for the complementary character of both types of basic research activities. We investigated firms' basic research strategies using a panel dataset (1995-2002) on the patent and publication activities of 33 of the largest R&D spending pharmaceutical firms in the world. Internal basic research activities are measured by firm publications in basic research journals. Our measure of the exploitation of external basic research findings in firms' technology activities is based on references in the prior art of firms' patents to publications in basic research journals.

Based on fixed-effects panel data analyses, we find that firms that engage in internal basic research increase their technological performance, in particular when these research activities are undertaken in close collaboration with university scientists. This finding confirms the 'connectedness' idea put forward by Cockburn and Henderson (1998), which states that collaboration with academics in basic research offers opportunities for debate, discussion, and exchange of valuable tacit knowledge which improves the quality of the performed research.

Further, we find that firms can increase their technological performance by exploiting more frequently external basic research findings in their technology activities. The impact of the exploitation of external basic research findings in technology activities on firms' performance is higher when firms conduct more internal basic research. Hence, internal basic research and the exploitation of external basic research findings act as complementary activities for firms. Our findings demonstrate that basic scientific knowledge is not a public good, and that firms need to invest in a sufficient 'absorptive capacity' to fully benefit from external basic research findings. Building up this absorptive capacity is however not inexpensive; it involves hiring (top)scientists and granting them the freedom to use scarce corporate resources to conduct basic research.

We hesitate to generalize our findings on the pharmaceutical industry to firms in other sectors, particularly since the pharmaceutical industry is exceptional in the relevance of basic research findings for technology activities (McMillan et al, 2000). However, we suspect that our results have relevance to firms in other industries in which basic scientific research and invention activities are closely interlinked. The investigation of the relationship between basic research and firm performance in other industries is considered as an interesting direction for further research.

There are several other fruitful avenues for future research. For example, one could investigate under which conditions internally conducted basic research is most effective to firms. According to Rosenberg (1990) corporate basic research is probably sterile and unproductive when it is conducted isolated from the rest of the firm's activities; and it is likely most effective when it is highly interactive with the work, or the concerns, of applied scientists and engineers. Some first evidence of the complementary nature of basic and applied research activities of firms is provided in the study of Henard and McFadyen (2005). Using data on 14 US manufacturing firms, they found that the impact of basic research on firms' financial performance depends on the amount of applied research that has been conducted by firms. However, future research could investigate the assertions of Rosenberg (1990) more directly by analyzing collaboration and citation patterns between corporate scientists doing applied and basic research; information which can be constructed from publicly available patent and publication data on a set of firms.

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Tables

Table 1: Descriptive Statistics

N=245	*Mean*	*St. Dev.*	*Min*	*Max*
Citation Weighted Patent Count	136.85	154.67	1	651
R&D Expenses (million $)	791.51	856.90	21.70	4847
Patent Intensity (patents per million $ R&D)	0.16	0.17	0.02	1.04
Technology Diversification	3.36	0.94	1.70	5.69
External Basic Research (NPRs per patent)	0.75	0.45	0.08	2.33
Internal Basic Research (publications per million $ R&D)	0.60	0.60	0.04	4.27
Fraction Internal Basic Research with Universities	0.46	0.12	0.11	0.78

Table 2: Correlation Coefficients

N=245	1	2	3	4	5	6	7	8	9
1 Citation Weighted Patent Count	1								
2 log (R&D Expenses)	0.63	1							
3 Patent Intensity	0.12	-0.45	1						
4 Technology Diversification	0.10	-0.07	0.47	1					
5 Technology Diversification^2	0.08	-0.10	0.48	0.99	1				
6 External Basic Research	-0.25	-0.21	-0.06	0.23	0.17	1			
7 Internal Basic Research	0.26	-0.17	0.56	0.25	0.22	0.10	1		
8 Share Internal BS with Universities	-0.24	-0.17	0.08	0.18	0.17	0.25	-0.24	1	
9 Internal BS * External BS	-0.06	-0.06	-0.12	-0.10	-0.07	-0.17	-0.36	-0.01	1

Table 3: Joint Effect Internal and External Basic Research on Technological Performance

	Model 1	Model 2	Model 3	Model 4	Model 5
Log (R&D Expenses)	0.23**	0.24**	0.29***	0.32***	0.38***
	(0.11)	(0.11)	(0.10)	(0.10)	(0.10)
Patent Intensity	0.96**	1.05***	0.79**	0.69*	0.70*
	(0.38)	(0.39)	(0.40)	(0.40)	(0.40)
Technology Diversification	0.62*	0.61*	0.63*	0.62*	0.67**
	(0.33)	(0.34)	(0.34)	(0.34)	(0.34)
Technology Diversification^2	-0.06	-0.06	-0.06	-0.06	-0.07*
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
External Basic Research		0.33**	0.33**	0.35***	0.36***
		(0.13)	(0.13)	(0.13)	(0.13)
Internal Basic Research			0.33***	0.36***	0.44***
			(0.08)	(0.08)	(0.09)
Fraction Internal BS with Universities				0.97*	1.02**
				(0.52)	(0.51)
Internal BR * External BR					0.48**
					(0.21)
Time Dummies	YES	YES	YES	YES	YES
Intercept	-2.42	-2.74*	-3.62**	-4.40***	-4.80***
	(1.58)	(1.56)	(1.55)	(1.54)	(1.57)
Number of Observations	245	245	245	245	245
Number of Firms	33	33	33	33	33
Wald Chi2	95.53***	103.27***	125.36***	131.26***	140.20***
Log Likelihood	-972.83	-969.94	-964.14	-962.42	-959.90

Notes: Significance of coefficients is indicated by *(0.1), **(0.05) and ***(0.01). Standard errors are reported between parentheses. All models include firm-level fixed effects.

Figure 1: Internal versus External Basic Research

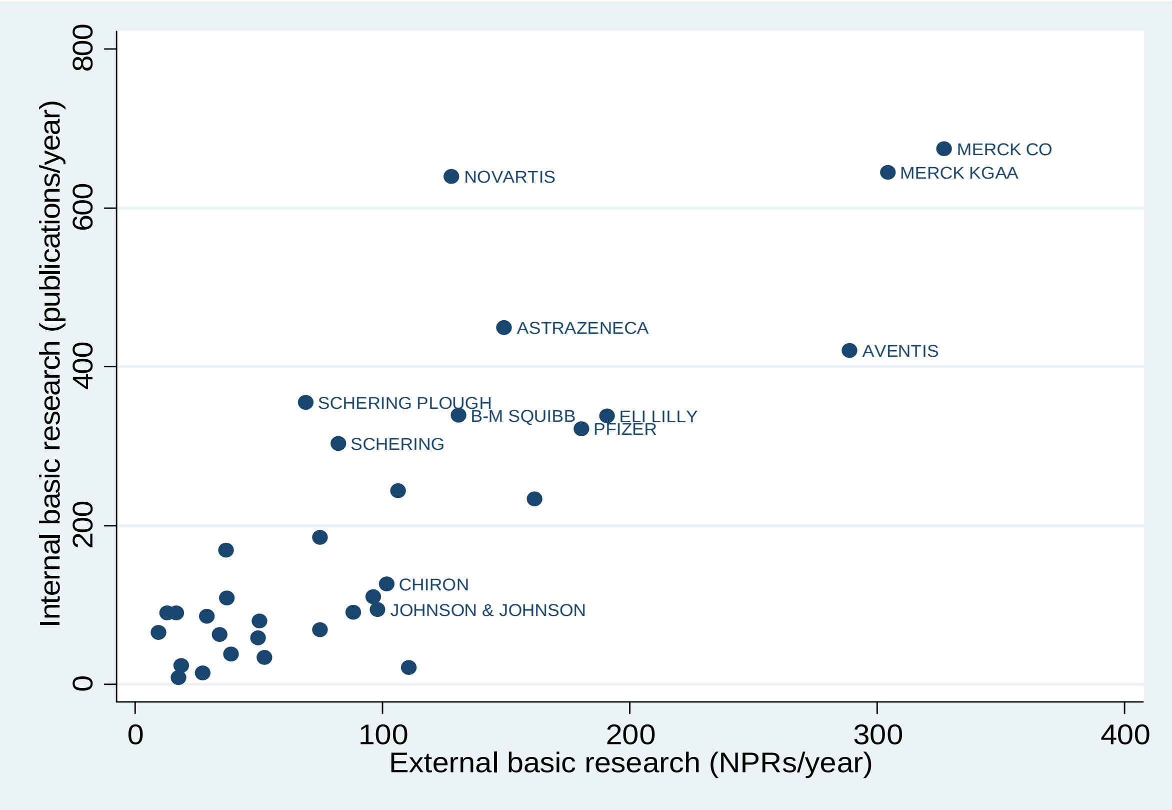

Figure 2: Evolution Internal and External Basic Research (averages across firms)

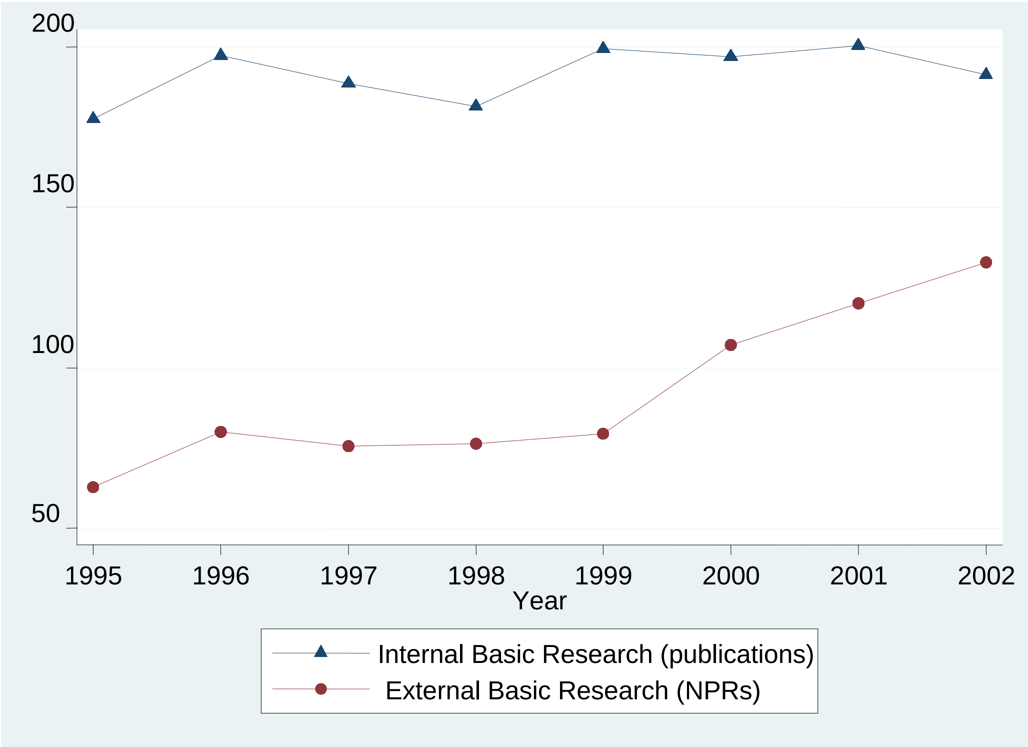

Figure 3: Predictions at the Means of the Explanatory Variables