Els Opuscles del CREI

num. 23

September 2009

Complementarities in Innovation Strategy and the Link to Science

Bruno Cassiman

CREi

Centre de Recerca en Economia Internacional

The Centre de Recerca en Economia Internacional (CREI) is a research centre sponsored by the Universitat Pompeu Fabra (UPF) and the Generalitat de Catalunya. It is located at the campus of the UPF in Barcelona.

CREI's objective is to promote research in international economics and macroeconomics subject to the highest standards of academic scholarship.

Els *Opuscles del CREI* are the instruments for the diffusion of CREI's research beyond the academic world. Each *Opuscle*, aimed at a general public, gathers together conclusions and observations of specialized papers published, or about to be published, in professional journals. The opinions stated in *Els Opuscles del CREI* are the sole responsibility of the authors.

Published by: CREI
Universitat Pompeu Fabra.
Ramon Trias Fargas, 25-27 08005 Barcelona
Tel. 93 542 13 88

Design: Fons Gràfic
Printed by: Masanas Gràfiques

ISSN: 1137 - 7828
Legal register: B-35.826-2009

"Complementarities in Innovation Strategy and the Link to Science"

Bruno Cassiman (*)

1. Introduction

A recent widely publicized study by Booz Allen Hamilton — a well known consulting firm — on the 1000 publicly held companies from around the world that spend the most on research and development (Global Innovation 1000) claimed that there is no obvious relationship between R&D spending and the primary measures of economic or corporate success, such as growth, enterprise profitability, and shareholder return (Jaruzelski, Dehoff and Bordia, 2005). These results might seem rather shocking in the light of the abundant economic evidence relating R&D expenditures with economic growth.

In this *opuscle* we will attempt to reconcile the macroeconomic evidence that (basic) R&D improves economic performance with these micro-level findings. The mechanism connecting R&D and economic growth proposed in the macro literature is (partially) based on the effect of spillovers — knowledge flows between economic actors for which the receiver does not compensate the sender — fueling endogenous growth models. We argue that in order for R&D to turn into growth firms need to engage in other — complementary — activities to effectively access and capture these spillovers at the individual firm level. For example, in addition to own R&D expenditures firms will cooperate with customers to understand better their clients needs; collaborate with suppliers to improve inputs; complement their own knowledge through outsourcing some R&D to more specialized organizations; or license technology to cover some of their technology gaps. Successful innovators are active along all these dimensions. Procter & Gamble, for instance, has engaged in all these activities after launching their Connect & Develop program. Their objective is to generate 50% of new product ideas from outside the company through these initiatives. Hence, rather than tracking a narrow measure of R&D, the combination of innovation activities of a company should be considered to evaluate the innovation process at the firm level and relate it to innovation success.

Firms slowly are realizing that successful innovation — implementation and commercialization of new ideas — and R&D are not equivalent. Pouring more money into R&D does not seem to generate the expected returns due to decreasing marginal returns to R&D as additional investments in R&D will access less profitable or more risky projects. Possibly reducing R&D spending and increasing effort in alternative innovation activities might dramatically improve innovation results. In effect, Procter & Gamble claims to have reduced its R&D intensity (R&D as percentage of sales) while increasing innovation output through its Connect & Develop program. But, is there any evidence beyond this casual evidence that such a re-allocation of R&D expenditures across various innovation activities might improve innovation outcomes? What are the relevant alternative innovation activities to consider? And, most importantly, why is it that these alternative innovation activities affect innovation performance? While many of these questions are still heavily debated, in this *opuscle* we will discuss our recent findings on the relation between innovation activities and innovation performance at the firm level and delve deeper into the key drivers of this relationship. As we will show, different innovation activities are indeed complementary, reinforcing one another within the innovation process. This implies that different innovation activities need to be combined and need to move in lock-step with each other for innovation performance to be affected. Furthermore, we argue that basic R&D and active links to science actually enhance the firm's ability to exploit these complementary effects between innovation activities.

In the following sections we will gradually build up our arguments starting with the relation between innovation and growth at the macroeconomic level. Next, we discuss the recent literature on innovation and firm performance before finally delving into a deeper understanding of the drivers of innovation at the firm level. We end with some policy conclusions derived from this firm-level analysis related to innovation policy.

2. Innovation and growth: The big picture

The economics literature now widely recognizes that R&D and innovation are a major driver of economic growth and welfare. An economy's ability to exploit novel technologies and to adapt to a rapidly changing technological environment is seen as essential to its prospects for improving standards of living and prosperity. The endogenous growth literature (Romer, 1990) identifies commercially oriented innovation efforts as a major engine of this technological progress and productivity growth.

Following the pioneering work of Zvi Griliches a large number of empirical studies at the firm, sectoral and aggregate level have confirmed a positive impact of R&D activity on value added and productivity growth (Griliches, 1998). In some countries, the average rate of return on R&D investment is more than twice the rate of return on investment in capital equipment. But the social rates of return are even higher, as knowledge spillovers between different actors in the economy can double the rate of social return. Although such knowledge spillovers are a major driver of economic growth, the economics literature has also pointed out that their public good character has complex implications for firms' R&D investment and innovative activities. As firms are unable to appropriate the returns to these knowledge spillovers generated by their own R&D investments, they tend to underinvest in R&D from a social welfare perspective. Innovation policy attempts to correct for such underinvestment by creating opportunities to appropriate higher returns to own R&D under the form of monopoly rents in the patent system, or subsidizing R&D through tax benefits, grants and direct public funding of research. Nevertheless, the performance of an economy in terms of innovation and productivity is not only the direct consequence of public and private investments in tangibles and intangibles by individual elements in the system. The innovative performance of an economy is strongly influenced by the character and intensity of the interactions between the elements of the system, as strongly advocated in the literature on "National Innovation Systems" (Nelson 1993). In this view, innovation and technological development depend increasingly on the ability to utilize new knowledge produced elsewhere and to combine this with knowledge already available in the economy. The capacity to absorb new knowledge, to transfer and diffuse knowledge, and the ability to learn by interaction are crucial success factors in innovation at the aggregate level. These interactions instigate the process through which knowledge spillovers will influence economic growth, as detailed in the endogenous growth theory literature and documented in the empirical evidence. Building on the "National Innovation Systems" view, the work on the "Triple Helix" model, which rose to prominence in the technology management literature in the second half of the 1990s (Etzkowitz and Leydesdorff, 2000) draws our attention to the interaction between industry, academia, and government, and its role in the generation, transfer and use of knowledge in a national or global innovation system. One of the key explanations for the EU lagging the USA in innovative performance is precisely the lack of these connections between academia and industry in the European innovation system.

Hence, as formulated by the theoretical endogenous growth models and suggested by the innovation systems view, individual firms will only thrive in innovation if they are able to tap into these spillovers and knowledge flows within the economy, linking individual performance to aggregate performance of the economy. Therefore, empirically, R&D is likely to correlate well at the aggregate level with innovation performance of the economy as a whole as R&D and links in the innovation system are complementary. However, at the individual firm level, the question remains as to how well R&D expenditures correlate with these other activities of tapping into the existing knowledge flow. If different innovation activities are indeed complementary, firms with own R&D expenditures that are not tied into their national innovation system, will not benefit from these external knowledge flows in the economy and are, therefore, unlikely to be very successful in their innovation process. Empirical research is, hence, bound to find more variation in results of innovation performance at the firm level than at the aggregate economy-wide level.

3. Firms' innovation strategy and innovation activities

We need a better understanding of the innovation process at the micro level in order to foster innovation at the firm level and develop the correct policy measures at a more aggregate level. What do we know about the relation between the organization of the innovation process and innovation outcomes? In what follows, we start by describing the innovation strategy of innovation-active companies and will hypothesize about why we believe some types of innovation strategy are more successful than others.

Today even the largest and most technologically self-sufficient organizations require knowledge from beyond their boundaries. In order to access alternative knowledge sources, the *innovation strategy* of the firm will combine different *innovation activities*. In addition to doing own research and development, firms typically are engaged in the acquisition and sale of knowledge on the technology market and cooperate actively in R&D with suppliers, customers, competitors and research organizations. However, external knowledge sources and spillovers do not automatically find their way into the firm's innovation process. An important task in innovation management, therefore, is to optimally integrate external knowledge into the firm's innovation process. Unfortunately, many firms attempting to innovate fail and many policy measures do not generate the desired effect due to a lack of understanding the firms' innovation strategy at the micro level.

While there is ample theoretical and empirical research on firm and industry determinants of (internal) R&D, the literature deals less with the choice between, and the combination of, different *innovation activities* that together form the *innovation strategy* of the firm. For a sample of innovation-active firms from the Community Innovation Survey in Belgium,[1] Table 1 indicates that firms tend to use different innovation activities. Not surprisingly, most innovation-active firms have own R&D activities (79%). More interestingly, many of these innovation-active firms (76%) are engaged in some form of external knowledge acquisition activity. External activities can range from buying a license (28%), to contracting out R&D (36%), acquiring (part of) a company (16%) or hiring outside people with the required knowledge (53%).

4. Combining innovation activities

While most innovation-active firms should be engaged in some of these innovation activities, it is less clear whether firms *combine* or *should combine* different innovation activities. Much of the literature that exists on the choice of innovation activities by individual firms focuses on the choice between external knowledge sourcing versus internal development as substitute innovation activities, i.e. the classical "make" or "buy" decision applied to innovation. This literature stresses the existing trade-off between these choices. On the one hand, external knowledge sourcing has the advantage of tapping existing and often more specialized knowledge if available. This leads to time gains and lower innovation costs to the extent that economies of scale in R&D exist and can be more efficiently exploited by the R&D supplier. On the other hand, technology outsourcing may generate considerable transaction costs: *ex ante* in terms of search and negotiation costs to locate, describe and contract on the external knowledge; and *ex post* to execute and enforce the contract. The typical uncertain and complex nature of R&D projects considerably exacerbates these problems. Due to these trade-offs external knowledge sourc-

Table 1
Innovation activities of Belgian manufacturing firms

	Variable description	Number of Firms without missing values N = 522
MAKE	Innovative firms that have own R&D activities and have a positive R&D budget.	**413 (79%)**
BUY	Innovative firms acquiring technology through at least one of the following external technology acquisition modes: licensing and/or R&D contracting/R&D advice and/or take-over and/or hire-away.	**396 (76%)**
Buy License	Innovative firms acquiring technology through licensing.	145 (28%)
R&D Contracting	Innovative firms acquiring technology through R&D contracting.	190 (36%)
Take-over	Innovative firms acquiring technology through take-over.	83 (16%)
Hire-away	Innovative firms acquiring technology through hiring-away personnel.	277 (53%)

A total of 1669 firms responded to Belgian Community Innovation Survey 2004, 793 firms actively engaged in innovation in the full sample, 522 firms without missing values.
Source: based on Cassiman and Veugelers (2006), with data from CIS4.

ing is more likely to occur for generic, non-firm specific R&D that allows for specialization advantages and scale, such as routine research tasks like materials testing. In addition, external technology sourcing is more likely when knowledge is easily protected through patents or other legal instruments, as is the case in the pharmaceutical and chemical industry where it can more easily be traded when protected.

Instead of discussing make or buy or cooperate as substitute choices of knowledge acquisition, there is the potential for combining internal and external knowledge sourcing modes as complementary innovation activities. Although one activity may substitute for the other, as discussed before, combining internal and external knowledge sourcing creates extensive scope for complementarities. External knowledge sourcing activities serve as enabling tentacles for the firm to access and capture external knowledge, ideas and spillovers. At the same time in-house R&D — in addition to being an alternative for developing new knowledge internally — is required to integrate these external knowledge sources into the innovation process. Cohen and Levinthal (1989) defined this additional function of own R&D as the “Absorptive Capacity” of the firms, enhancing the return to the external knowledge acquisition modes. Case studies in the pharmaceutical industry, for example, show that in-house scientific research actually raises the ability of firms to take advantage of “public” science.

While the “open innovation” movement (Chesbrough, 2003) has recently advocated the need for firms to leverage external sources of knowledge in their innovation process, this phenomenon is not recent. Already in the seventies the Sappho study identified the more efficient use of external know-how in the innovation process as a distinct feature of successful innovative firms (Rothwell *et al.* 1974). While examining the critical success factors of 40 innovations, the authors found external sources of technical expertise combined with in-house basic research that facilitate these external linkages to be crucial in explaining success of the innovation. Consistent with these findings UK firms performing in-house research during the early 20th century were the ones drawing most heavily upon the cooperative research associations set up after World War I in the UK. These research associations were intended to assist firms in technical matters. Policy makers expected that firms without any internal research facilities would draw most heavily upon these research associations as a way of substituting for these activities through external means. However, the research associations actually served as an important complementary source of scientific and technical information for firms performing own in-house R&D. Additional evidence of this seemingly complementary relation between internal and external knowledge sourcing comes from examining the payment streams for technology licenses. If internal and external knowledge acquisition activities were substitute activities, one would expect payments to flow from firms that lack any in-house R&D capabilities to firms that have strong in-house R&D programs. In reality the payment flows are primarily between firms that have important in-house R&D activities. Together, this more qualitative evidence seems to indicate the existence of a strong complementary relation between in-house knowledge development and external knowledge acquisition.

The paper by Cassiman and Veugelers (2006) is the first to carefully examine the complementarity between the different innovation activities in the firm's innovation strategy. While Table 1 indicated that firms tend to use a variety of innovation activities, the first column of Table 2 goes one step further by showing that most innovation-active firms (63% of our sample) actually combine internal and external knowledge acquisition strategies. Next, we consider the effect of different combinations of innovation activities on innovation performance — the percentage of sales coming from new or substantially improved products that have been introduced in the past two years. Using data from the Community Innovation Survey on Belgian manufacturing firms, we show in the second column of Table 2 that firms that engage simultaneously in own R&D and external knowledge acquisition activities (Make&Buy) clearly outperform other firms, with 11.9% of sales coming from new or substantially improved products introduced in the past two years. This compares favourably to the benchmark case where firms do not engage in own R&D nor in external knowledge acquisition activities (NoMake&NoBuy), but are able to generate 2.1% of sales from new or substantially improved products. These firms typically invest in new equipment with embedded technological improvements which allow them to generate new or substantially improved products. Interestingly, firms only active in internal R&D (MakeOnly) do not perform very differently, with 6.5% of sales from new products. Finally, firms only acquiring knowledge externally (BuyOnly) seem to be slightly worse off in terms

Table 2

Frequency of innovation strategies and innovation performance by innovation strategy

	Frequency innovation strategy	***% Sales from new products***
NoMake&NoBuy	39 (7%)	2.1%
MakeOnly	87 (17%)	6.5%
BuyOnly	70 (13%)	5.0%
Make&Buy	**326 (63%)**	**11.9%**
TOTAL	**522 (100%)**	**9.4%**

Categories are exclusive. This sample (*N*=522) only includes firms that reported non-missing observations on all variables used in the analysis. Source: based on Cassiman and Veugelers (2006), data from CIS4.

of generating sales from new products, with 5.0% of sales from new products.

Complementarity between innovation activities, however, is a statement about the incremental effect of different activities on innovation performance. The incremental improvement in innovation performance for firms engaging in internal R&D activities only, i.e. without sourcing knowledge externally (going from 2.1% to 6.5%, a difference that is not statistically significant), is lower than the incremental performance for a firm already engaged in external knowledge sourcing to engage in both activities (going from 5.0% to 11.9%). This result is strongly consistent with complementarity between own R&D and external knowledge sourcing activities, implying that a firm engaged in external knowledge acquisition activities would have a very strong incentive to engage in own R&D activities in order to improve the output from its innovation process. In a careful econometric analysis — controlling for many other industry and firm-level effects — Cassiman and Veugelers (2006) confirm these results.[2]

Why would innovation activities be complementary in the innovation strategy of the firm? First, as argued by Arora and Gambardella (1994), performing internal R&D allows the firm to scan the environment and screen the different technological options better because of an improved understanding of the basic technology and knowledge. This in turn improves the innovation performance of firms combining both innovation activities as better knowledge is accessed and developed. Second, as mentioned earlier, external technology is more easily integrated into the innovation process given the absorptive capacity that internal R&D activities provide (Cohen and Levinthal, 1989). Many firms engage in this kind of "research tourism," but the ones with own R&D operations are better capable of capitalizing on the available external knowledge and spillovers. Finally, external technology increases the efficiency of the internal R&D activities because the complementary knowledge outside the boundaries of the firm already exists and transferring this knowledge is less costly than developing it from scratch. For example, several companies such as Eli Lilly, Boeing, Dupont or Procter & Gamble post technology queries on Innocentive, a web-based site with access to more than 75 000 scientists world wide. These external scientists can propose solutions to these specific queries and win an award. However, without internal R&D capabilities it would be hard for these companies to post, evaluate and screen proposed solutions, and then integrate them into their own innovation process to effectively leverage this external knowledge source.

5. Understanding sources of complementarity

Our empirical investigation in the previous section seems to confirm that different innovation activities are indeed complementary. Nevertheless, the complementarity in the innovation production function might depend on particular strategic decisions of the firms or on specific industry characteristics of the industry within which the firm operates. In a next step we attempt to identify the firm and industry characteristics that are most conducive to choosing innovation activities jointly in order to shed some light on the drivers of complementarities between different innovation activities. We will focus on two particularly relevant issues: the R&D orientation of the firm and the appropriation regime prevalent in the industry. The former refers to the strategic decision of the firm to be involved in more or less fundamental type of research. As we will argue in the next section, such a decision will directly affect the organization of the innovation process and its likely output. The appropriation regime of the industry relates to the way that firms appropriate returns to their innovations. In some industries such as chemicals or pharmaceuticals, patents might be more effective. However, in most industries the more effective mechanisms to capture the returns to innovations are keeping knowledge secret, generating lead-time over competitors, creating more complex innovations, or continuous innovation. These mechanisms typically make imitation or reverse engineering harder while patents are less effective and divulge valuable information.

A first key finding is that firms with a more basic R&D profile are more likely to take advantage of the complementarities between internal and external knowledge acquisition activities as indicated by the higher chosen frequencies for the Make&Buy innovation strategy and the innovation performance of these choices in Table 3.[3] The incremental improvement in innovation performance of adding own R&D when already acquiring knowledge externally goes from 4.2% to 10.4% for firms with low basic R&D relatedness compared to going from 5.6% to 15.7% for firms with high basic R&D relatedness. Firms with a more basic R&D profile, therefore, seem to find that these different innovation activities are more complementary and they are more likely to capitalize on this complementarity between these different innovation activities. In the next section we will delve deeper into this finding as we believe it is an important micro result hinting at the mechanism through which successful innovators access and capture external knowledge and spillovers and as a result are more successful in their innovation process.

A second key finding is that legal and strategic measures to protect and appropriate returns from innovation, i.e. intellectual property protection, are important drivers for the different innovation strategies. Legal protection covers patent and copyright protection. Strategic protection refers to protec-

Table 3:
Frequency of innovation strategies and innovation performance by innovation strategy for low and high basic R&D relatedness of firms

	Low basicness		***High basicness***	
	Frequency	% Sales from new products	Frequency	% Sales from new products
NoMake&NoBuy	7 (4%)	0.6%	5 (4%)	2.0%
MakeOnly	32 (18%)	5.1%	10 (8%)	4.7%
BuyOnly	18 (10%)	4.2%	9 (7%)	5.6%
Make&Buy	**124 (68%)**	**10.4%**	**106 (81%)**	**15.7%**
TOTAL	181 (100%)		130 (100%)	

Categories are exclusive. This sample (*N*=311) only includes firms that reported non-missing observations on all variables used in the analysis.
Source: own elaboration based on Cassiman and Veugelers (2006), with data from CIS4

tion of knowledge through secrecy, complexity of the innovation, continuous innovation and/or lead time, i.e. being a first (fast) mover. Table 4 shows by industry the percentage of firms that consider legal and/or strategic protection very effective for appropriating the returns to their innovation strategy.

Table 4:
Capturing returns to innovation

	% firm that consider protection mechanism very effective	
	Legal protection	Strategic protection
Chemicals	23%	62%
Mechanical engineering & machinery	23%	67%
Textile & clothing	21%	49%
Food & beverages	18%	38%
Wood & paper	13%	51%
Transport equipment	8%	56%
Metal products	8%	47%
Furniture	6%	47%
Research services	58%	74%
Wholesale	22%	40%
Computer services & software	16%	58%
Business services	10%	46%
Retail	9%	19%
Transport services	3%	16%
Financial services & insurance	0%	18%
Total	**16%**	**48%**

Legal protection (patents, copyrights and trade marks), Strategic protection (secrecy, complexity, lead time, continuous innovation, and/or shorter cycle time)
Source: based on Veugelers and Cassiman (1998), with data from CIS4

Table 5:
Innovation strategy and appropriation

	% firm that consider protection mechanism very effective	
	Legal protection	Strategic protection
NoMake&NoBuy	3%	36%
MakeOnly	7%	41%
BuyOnly	15%	38%
Make&Buy	**26%**	**68%**

Source: own elaboration based on Veugelers and Cassiman (1998), with data from CIS4

In general, it is interesting to note that in spite of being the most discussed measure for capturing returns to innovation, legal protection is systematically rated less effective than strategic protection in capturing returns to innovation. As expected, however, legal protection is relatively more effective in the chemical sector and, in particular, for firms making contract research their business (research services). More interestingly, in Table 5 we compare the different combinations of innovation activities (Make, Buy) and the effectiveness of legal and strategic protection. Clearly, when both types of protection are higher firms are more likely engaged in both types of innovation activities. Hence, the appropriation regime is positively related to the observed complementarity between these innovation activities (Cassiman and Veugelers, 1999 and 2006). The correlation with strategic protection, however, seems more pronounced, an issue we also return to later. When secrecy is effective in protecting innovations, internal R&D activities are encouraged as outsiders have a harder time figuring out what is happening inside the company. Nevertheless, combining internal and external knowledge increases the complexity of the innovation allowing for better protection through strategic means when complexity is important for the protection of innovations. In addition, acquiring external knowledge allows firms to gain lead time by moving faster. But without an own internal R&D capability to integrate the external knowledge a firm is unlikely to build a sustainable competitive advantage solely based on externally acquired knowledge as other firms can easily follow the external knowledge acquisitions of the firm. Hence, industries where appropriation of returns of innovation relies mainly on strategic protection measures, i.e. most industries, will benefit from combining internal and external knowledge acquisition as it generates more complex and harder to imitate innovations and results in important lead time advantages.[4]

6. Building complementarity through links with science

In the previous section we have identified the R&D orientation of the firm and the prevailing appropriation regimes as being key drivers of the complementarity between internal and external knowledge acquisition. An interesting question then becomes how firms can build up this complementarity in order to improve the returns to their innovation process. While firms operate in a particular industry where the appropriation regime is rather constant over time, links with science can be built and exploited by firms in order to improve their innovation performance. In this final section we examine this important route to innovation success more closely. We start by linking science and growth at the aggregate level. Next we show that these links can materialize through various channels. At the micro level the effects of the link of firms with science has been a black box. We next discuss the performance effects of these links at the firm level and eventually attempt to locate these effects of science within the organization.

6.1 Links with science and growth

A multitude of economic studies have shown the importance of *basic research* for technology, innovation and economic growth (Griliches, 1998). However, a coherent body of theory and insight into the multifaceted nature of the links between science and markets is still lacking (Stephan, 1996). There are some industries where the link between science and innovation is explicit and direct. Industries such as biotechnology, pharmaceuticals, organic and food chemistry are "science-based" in the classic sense and rely heavily on advances in basic research to feed directly into their innovations (Levin *et al.* 1987). In non-science based industries much innovation also derives from other-than-basic-research related activities. Nevertheless, even here innovation is facilitated by better use of basic research resources, such as the training of skilled researchers which helps to increase the absorptive capacity of industry.

An important and recurrent concern in economics has been to understand to what extent science explains technological progress. The answer to this question has profound implications for public policy, notably for the decision to fund basic research conducted by private and public organizations. The works by Jaffe (1989) and Adams (1990) have shown the importance of basic science (inputs, e.g. public research expenditures or outputs, e.g. publications) for economic growth. At the same time research by Acs, Audretsch and Feldman (1992) and others, has revealed the significant externalities (spillovers) stemming from local academic research on private R&D and patenting. The importance of science for economic growth together with the fact that spillovers are generated for the private sector has led to several forms of government policy intervention for funding science directly through funding of university research and research centres or by providing grants to firms and other organizations participating in science.

Recent studies suggest that the links to basic research by private firms have actually been increasing in the last decades and they manifest themselves today in multiple ways: such as university-industry collaboration (e.g. joint research, sharing of equipment and research tools) and contracting, industry financing university research, university spin-offs and licensing, mobility of university researchers, citations to university patents, and so forth. One of the most visible indications of growing science linkages by industry is found in the citations to science in patent documents.[5] Narin, Hamilton and Olivastro (1997) reported a threefold increase in the number of citations to academic literature in industrial patents in the USA through the mid 1990s. Accordingly, 73 percent of the papers cited by industry patents were authored at academic, governmental, and other public institutions and had a strong national component in citation linkage, with inventors preferentially citing locally authored papers. Branstetter (2004) found that such dramatic rising was closely linked to the new technological opportunities generated by academic research in the cross-field of biosciences and biotech-based technologies. Nevertheless, he also shows an important shift in the methods of invention, with an increased emphasis on the use of the knowledge generated by university-based scientists in later years to generate new inventions by firms.

The discussed patterns evidence the increasing role played by links to science in the search for competitive advantage through innovation by private firms. Corporations appear to look more extensively towards public science as one of the external sources allowing rapid and privileged access to new knowledge, especially in the life sciences. Fuelled by the notion that strong (local) interactions between science and industry become more important for the success of innovation activities and ultimately economic growth, the economics and technology management literature have started only very recently, independently of each other, to investigate in more detail how the fruits of academic research can be exploited in a market environment. In order to understand the functioning of these links to science it is necessary to investigate at the micro level the factors which motivate or hamper connections between scientific research institutions and firms, requiring integrating research insights obtained from economics and management. We turn to these issues next.

6.2 Channels to link with science

Industry-science links refer to the various types of interactions between the industry and the science sector. These include formal relationships, such as collaborative agreements between science and industry, R&D contracting, own licensing policies and intellectual property management, and, spin-off activities of science institutions. But behind this multitude of formal relationships lies a myriad of informal contacts, gatekeeping processes, personnel mobility and industry-science networks based on personal or organizational relations. These informal contacts and human capital flows are ways of exchanging knowledge between enterprises and public research and creating spillovers. These flows are more difficult to quantify, but nevertheless extremely important and often a catalyst for instigating further formal contacts. All these channels for linking with science, while clearly important, cannot be analyzed independently from the organization of the firm's innovation process. As argued before, different innovation activities have been shown complementary to each other. Furthermore, a more basic research orientation seemed to reinforce this complementarity.

Empirical studies have attempted to quantify knowledge transfers from academic research through various proxies. Most of the empirical firm-level studies have focused attention on research partnerships as a mechanism for firms to link with science. Key findings of these studies are that critical firm size and own R&D spending affect a firm's likelihood to engage in R&D cooperation with public research institutions. However, as firms attempt to access and capture spillovers through these agreements, Cassiman and Veugelers (2002) found that there is a significant correlation between external information flows and the decision to cooperate in R&D. Consistent with the drivers of complementarity highlighted above, firms that rate generally available (public) external information sources (so called *incoming spillovers*) as more important inputs to their innovation process are more likely to be actively engaged in cooperative R&D agreements. At the same time, firms that are more effective in appropriating the results from their innovation process (i.e., controlling *outgoing spillovers*) are also more likely to cooperate in R&D. Differentiating between incoming spillovers and appropriation proves particularly important when examining their effect on different types of cooperative agreements such as agreements with suppliers and customers, or agreements with research institutions. Research institutions are the preferred partner when incoming spillovers are important. This finding seems to suggest that these collaborations in more fundamental research are aiding the firm in capturing external knowledge from a broad range of sources, not only scientific or university based.

As discussed above, cooperative agreements with universities are typically not the sole component in a firm's overall innovation strategy. More importantly, we show that a more basic R&D orientation of the firm — presumably incorporating some cooperative agreements with the university — seemed to enhance complementarity between the activities of the innovation process. Consistent with these findings on complementarity between innovation activities, results from Veugelers and Cassiman (2005) suggested the existence of complementarity between R&D cooperation with universities and other innovation activities of the firms, such as sourcing freely available public information and cooperative agreements with suppliers and customers. These findings on collaboration with universities as a channel to science, therefore, indicate that in order to really capitalize on these more "basic knowledge" spillovers and the incoming spillovers from a broad range of sources, successful firms in innovation simultaneously need to engage in complementary, more applied innovation activities such as own R&D and collaboration with suppliers and customers.

6.3 Firm level performance effects of links with science

The studies on the channels linking to science discussed before typically do not relate this behaviour to innovation performance of the firms directly. Surveys have provided some estimates of the importance of basic research for industrial innovation and economic performance. For instance, relying on a survey of 76 US firms in seven industries, Mansfield (1991) found that 11% of new product innovations and 9% of process innovations would not have been developed (without substantial delay) in the absence of recent academic research. In addition, firms declared that 8% of their products were developed with substantial input from recent academic research (6% of process innovations). Both the 1983 Yale Survey and the 1994 Carnegie Mellon Survey (CMS) of R&D have shown the relevance of university research for innovation as conceived by managers. According to the CMS, American firms consider publishing by universities and patenting amongst the most important sources of knowledge to innovate (Cohen, Nelson and Walsh, 2002). A different perception is found in Europe.

The evidence from the Community Innovation Survey shows that only a small fraction of innovative enterprises consider scientific information, i.e. information from universities and public research labs, as an important information source in their innovation process. In the Eurostat-Community Innovation Survey CIS-III (1999-2000), of all reporting innovative EU firms (excluding UK) 4.5% rated universities as important sources of information, while 68% indicated universities as not important at all. The CIS results also show the importance of science as information source to be highly firm size and technology specific. Could this contrast in perceived relevance of science for the innovation process between the USA and Europe explain (part of) the difference in the productivity in their respective innovation processes? We believe it very well might and, as Belderbos, Carree and Lokshin (2004) show with European data, cooperating with universities does lead to higher growth in sales of 'new to the market' products.

Why would science be useful at the individual firm level? Several strategic advantages have been identified to explain the firm's choice on whether to adopt or link to science. These include an increase in the productivity of applied research effort and substantial gains in overall R&D productivity, the development of absorptive capacity, and, labour cost reductions, amongst others. Science through advancing a "theory" about why some technology works, serves as a map for technological landscapes guiding private research in the direction of most promising technological venues, avoiding thereby wasteful experimentation. As scientists report successes and failures from basic research, science, in addition, increases the efficiency of private research as firms avoid unfruitful research avenues. The dissemination of scientific advances publicly through freely accessible scientific publications reduces the degree of redundant effort, providing useful information about technological opportunities, new industrial applications or re-combination of existing knowledge pieces. Furthermore, the adoption of pro-publication incentives by firms helps these firms to attract high quality academic researchers whose economic value might often be higher than their actual remuneration. Stern (2004) has shown that researchers looking for academic reputation, may want to pursue research projects leading to publications and, as a consequence, are happy to accept lower salaries in exchange of permission to engage in scientific research. These researchers are twofold valued, they do not only imply important labour costs reductions for the firm, but also they constitute a bridge with the scientific or academic world, providing access to important external knowledge sources. In spite of such paybacks, the adoption of science remains limited to a restricted set of firms, as empirical evidence shows. The adoption of science is not costless: it is highly conditional on human capital and adoption of new, complementary organizational practices in the innovation process, as we discussed earlier.

Mostly focused at the firm level of analysis, the empirical literature has taken a stab at assessing the role of connections with science for innovation performance. While they provide little explanation about the process through which science actually affects private innovation, the studies examining the patents generated by the firms have found that science involvement and ties with academic star scientists, can lead to more and higher quality patents. Moreover, the work by Cockburn and Henderson (1998) has shown that not only absorption capacity in basic research matters but also direct and active involvement with science is needed in order to benefit from these links. Using data on co-authorship of scientific papers for a sample of pharmaceutical firms, they showed that firms connected to science have a higher performance in drug discovery and that this connectedness is closely related to the number of star scientists employed by the firm. Similarly it has been found that location of top star scientists predicts firm entry into biotechnology (by new and existing firms) both in the USA and Japan, or that firms enter nanotechnology where and when scientists are publishing breakthrough academic articles. A vigorous local academic environment is, therefore, an important ingredient for an active innovation environment. Collaborations between university star scientists and firms have a large positive impact on firm research productivity, increasing the average firm's biotech patents by 34%, products in development by 27%, and products on the market by 8% (Darby and Zucker, 2001). These studies underscore that accessing and capturing spillovers requires active, local links between science and industry and a conscious innovation investment strategy by the firms to combine these different complementary innovation activities.

Little research exists on the evaluation of the (performance) effect of scientific links at the level of *inventions or patents*. In a sample of 83 pharmaceutical and biotechnology firms, Markiewicz (2004) shows that absorption capacity (R&D intensity and own firm publications) and co-publishing with universities alter the innovation process: these firms are more likely to exploit published scientific research by developing patented technologies based on previous scientific research. Moreover, these firms display shorter time lags between the development of new knowledge and its incorporation in new firm inventions. The advantages of these alterations of the firm's innovation process due to links with science directly reflect in the complexity of their innovations and the lead-time over competitors through these innovations. Both these advantages — complexity and lead-time — constitute important appropriation mechanisms for innovation as discussed earlier.

The contribution of science-links to patent quality is less conclusive. One would expect that patents relying on more fundamental knowledge would be more original and more likely to influence different technologies. This argument has found some support in previous studies on university patents. University patents consistently receive more citations than non-university patents; which confirms the higher quality and reach of academic inventions. Nevertheless, the research that has evaluated the determinants of the value of patents owned by private firms provides more mixed results. Harhoff, Scherer and Vopel (2003) found that patent citations to the scientific literature are informative about the technological and economic value of pharmaceutical and chemical patents, but not in other technical fields. In a study of US patents, Fleming and Sorenson (2004) show that having a reference to scientific literature matters for the technological impact of patents but that the benefits of using science really depend upon the complexity of the inventive problem being addressed: science only appears beneficial when researchers work with highly interdependent knowledge pieces, which makes the probability of discovery more uncertain. But the upside is that conditional on discovery, the invention is more complex, which again allows the firm to appropriate the returns more effectively.

6.4 Digging deeper: Locating the spillovers from science within the firm

Linking up with science, therefore, does seem to improve innovation performance of firms through the creation of more complex and harder to imitate technologies. But we still know little about the effect of these science links within the firm. In this final section we dig a little deeper into the internal organizational effects of the link to science. We argue that there are at least two interesting dimensions to consider: space and time. On the one hand the effects of science manifest themselves in space across different research teams where the link with science enhances the firms applied technologies. On the other hand, the effects of the link with science manifest themselves over time as new and better ideas are encountered and exploited. Both of these effects are very subtle and explain why it is hard to encounter strong direct effects of links with science in the data.

6.4.1 Spillovers across teams

In spite of these growing connections to science our understanding of how these knowledge transmissions take place and how they modify the innovation process by private firms still remains unclear. Using patent data combined with firm-level data, Cassiman, Veugelers and Zuniga (2008) evaluate the contribution of science linkages to the innovation performance of a firm at the patent level. They examine the effect on the quality of patents of *i*) firm level linkages to science (publications by the firm) and *ii*) invention-specific linkages to science (citation in patents to scientific publications). Earlier research evidences the highly skewed distribution of patent quality and economic value across patents, namely only a fraction of the patents accounts for most of the value. However, researchers have often ignored the characteristics of the firms — firm level linkages to science in this case — as determinants of the quality of patents. But Cassiman *et al.* (2008) claim that part of this skewed distribution of value of patents can be explained by the heterogeneity across the patent owners, in particular by the scientific capabilities of firms. These capabilities allow them to decode advances in fundamental knowledge, and transfer basic research into a sequence of technology applications. The distribution of these scientific capabilities of firms has been found to be equally skewed across firms, and is therefore an interesting candidate for being matched with the skewedness in patent quality. Contrary to earlier findings, the analysis suggests that patent citations to scientific publications are less relevant in explaining patent quality once controlling for the scientific capability of the firm. But scientific references do influence the scope of citations received by these patents in terms of generality. These patents do receive citations from a broader range of future technologies, indicating that these technologies have been important for later technology developments. This finding can be explained by the fact that patents citing science may contain more complex and fundamental knowledge. Any potential application of this knowledge, while indeed pioneering, is still far from the market and therefore not easily diffused. What is more, a firm's overall proximity to science as measured by their scientific publication record matters for patent quality: in particular, patents protecting applied technologies are more frequently, more broadly in geographical terms, and more quickly cited when these patents belong to firms with firm-level scientific linkages — scientific publications in this case. These findings suggest the existence of internal spillovers within scientific-oriented firms (knowledge transfer across inventors). On the one hand, these firms are more likely to develop technologies with a close link to science. Nevertheless, these technologies are still far from actually commercializable technological innovations. But, on the other hand, these firms are more effective at distilling applied technologies from these technologies, allowing them to write more valuable applied patents. This evidences a process of innovation which consists in achieving high impact inventions building on more fundamental innovations, and transferring knowledge across inventions to more applied technologies. We, therefore, claim to have found a trail of the spillovers of science within successful firms across space, and between more basic and more applied research teams.

6.4.2 Spillovers across time

Firms that tend to establish regular links with universities do not involve them in all of their activities. Yet the focus at the firm level, which characterizes much of the prior research, cannot really shed light on the factors that make the university the preferred partner in specific R&D activities and not in others. Cassiman, Di Guardo and Valentini (2007), therefore, adopted the R&D project as their unit of analysis, and examined the role played by the specific attributes of the R&D activities in the project organization decision and evaluated the performance of these projects with a university partner relative to other R&D projects.

Their results highlight that the attributes of the knowledge involved in a R&D project significantly affect its organization. Cooperation with universities is common practice for developing new knowledge as opposed to applying existing knowledge to a new problem. But when this new knowledge directly enhances the competitiveness of the firm making the firm more reluctant to partner, contracting for innovation with universities is more likely. This happens for experimental projects, in which original and strategically relevant knowledge is developed. Often these contracts cover the early project stages.

More interestingly, Cassiman *et al.* (2007) explored the performance consequences of such agreements with the university, again at the project level. In this way, they were able to contrast the process they presumed underlies project organization (why links are established) to the actual performance results obtained. They find that project managers appreciate two distinct dimensions of project performance — efficiency and learning, with mixed effects of university presence on these performance dimensions. In particular, the presence of a university seems to negatively affect the efficiency of the project, often leading to delays and budget overruns. But, on the contrary, the presence of a university positively impacts learning *across* projects *over time*. Unexpected results and ideas tend to surface during these projects which can then be successfully applied to future projects. Cassiman and Valentini (2009) speculate that project managers (i.e., those who take the decentralized decisions on project organizations) do not have sufficient incentives to invest in this type of learning as learning effects materialize as positive externalities on future projects, which are captured at the *firm* level rather than at the project level. Again, we trace out spillovers due to collaboration with universities. These spillovers materialize over time and within the firm, and, thus, enhance innovation performance at the firm level.

Both types of within-firm spillover from links with science — across teams or over time — are hard to capture. We argue that exactly this fact, i.e. the fact that benefits from science are so hard to trace and quantify, makes firms reluctant to actually make linking with science a strategic imperative for enhancing their innovation performance.

7. Conclusion

In this *opuscle* we argued the existence of complementarity between different innovation activities as well as identified the sources of complementarity between different innovation activities. Both issues are important for managing a firm's innovation strategy. When innovation activities are found to be complementary, it is less efficient to concentrate on one single innovation activity, i.e. internal R&D *or* acquiring knowledge externally. In addition, it makes copying the innovation strategy of a successful player more difficult because of its increased complexity as one needs to engage in several innovation activities simultaneously to be successful. Therefore, the innovation process, i.e. managing the complementarity between the different innovation activities, can be an important source of sustainable competitive advantage for individual firms. Moreover, understanding these complementarities and their likely sources is crucial to develop policy measures to stimulate innovation. Stimulating for example own R&D will not necessarily result in successful innovation when external knowledge acquisition activities cannot easily adjust simultaneously. Furthermore, as strategic protection seems more effective to capture the returns to innovation, probably less effort should be spent on strengthening formal (legal) protection measures such as the patent system and more on policy measures stimulating the different innovation activities directly. Not surprisingly, many firms attempting to innovate fail and many policy measures do not generate the desired effect due to a lack of understanding of the elements affecting a firm's innovation strategy. At the same time it is not surprising that a rather simplistic study as done by Booz Allen Hamilton hardly finds any relation between R&D expenditures and performance.[6] While at an aggregate level R&D expenditures correlate well with all other innovation activities performed in the industry of an economy, at the firm level the effect of omitting these activities is more substantial. Actually, in a follow-up study Booz Allen Hamilton point out, although not in these exact words, that successful innovators — smart spenders — in the Global Innovation 1000 sample are exactly those companies that are able to manage the different complementary activities in the innovation value chain (Jaruzelski, Dehoff and Bordia, 2006).

One key element the *opuscle* highlighted is the importance of science, not as a direct generator of private returns to firms, but rather as an indirect mechanism through which the external knowledge acquisition activities increase in value. While we do not advocate a science-based strategy for all firms in every industry, we strongly believe that based on the evidence presented "links to science" at the micro level constitute part of the mechanism through which firms access and capture spillovers produced through research in the overall economy. Firms with active links to science develop better and more complex innovations with sufficient lead-time to actually appropriate returns from these innovations. But to reach this stage these firms need to adapt their internal innovation process in order to generate long lasting connections across teams doing basic research and applied research as well as over time transmitting and spreading ideas and knowledge generated from these active links to science across projects.

At the policy level these findings resonate well with the findings when comparing the USA with the EU. The European weakness in industrial innovation has precisely been linked to the absence of tight links of European industry to science. Compared to the USA, the EU has fewer firms active in science. While the "European Paradox" — the fact that Europe does well in science but not in connecting industry to science — has been recently dispelled showing that Europe does lag the USA in terms of research quality and output (Dosi, Llerena and Sylos Labini, 2006), it remains true that European firms seem to benefit less from the high quality scientific research produced in Europe. From the findings in the *opuscle* we offer two related explanations. First, Europe might encounter itself in a catch-22 situation. External knowledge acquisition opportunities in Europe might be more limited as firms in general devote more limited resources to R&D and innovation. Given the complementarity between internal and external innovation activities in the innovation process, as discussed, internal R&D adjusts to the activity in limited supply. Europe, therefore, resides in a bad outcome from which it is hard to escape without a coordinated effort. As we saw, local opportunities to link to science could be a lever to overcome this outcome, but these opportunities are at the moment rather limited. Second, even when these external knowledge acquisition opportunities would be present in the economy, individual firms need to adapt their individual innovation process to actually capture the benefits of these external knowledge sources. Hence, we believe that an important explanation for this fact also lies within the European firms themselves in the organization of their innovation process, rather than at the policy level. While the former problem needs coordinated effort from the different actors in the economy, the latter requires a more careful understanding of the innovation process and management principles. We hope to have provided a first step in this better understanding through the analysis in this *opuscle* where we have focused more on the demand side of the problem. At the same time, however, Europe needs sustained policy measures to spur the science supply side to ensure a sufficient flow of relevant output for industry to actually connect to.

Notes

(*) I am grateful to Doh-Shin Jeon, Giovanni Valentini and an anonymous reviewer for their careful remarks and suggestions on an earlier version. Furthermore, I am indebted to Reinhilde Veugelers for the many hours of discussions on these and related issues and for having been a great research partner in many of the investigations mentioned in this opuscle.

(1) The Community Innovation Survey (CIS) has been organized by Eurostat and the European Commission in each of the member countries since 1993. The data presented in this opuscle *is from the fourth CIS held in 2005 referring to innovation activities of Belgian companies between 2002 and 2004. This is the latest data available to date. All tables replicate our earlier work using the first CIS from the early 90s.*

(2) The results in Cassiman and Veugelers (2006) confirm the following: suppose there are two firms, from the same industry, of the same size and spending the same total *amount on innovation activities. If one firm only invests in own R&D while the other firm invests in both own R&D and external knowledge acquisition, the latter firm will outperform the former in its innovation process.*

(3) The relatedness of the firm to basic R&D measures the importance for the innovation process of the firm of information from research institutes and universities relative to the importance of suppliers and customers as an information source — see Cassiman and Veugelers (2002, 2006).

(4) See Boldrin and Levine (2006) for a more provocative argument that small lead-time advantages should provide sufficient appropriation opportunities for innovators making patent protection and related monopoly rights excessive and unneeded.

(5) In order for patents to be valid they need to claim novelty of the invention. This requires the inventor to refer to "prior art" by citing existing technologies, which are typically protected through patents and in some case by referring to the scientific basis of the invention by citing the relevant scientific literature. By citations to science we mean the latter type of citation included in the official patent document.

(6) See Foray, Hall and Mairesse (2007) for a just and more technical critique of the Booz Allen Hamilton findings.

References

Acs, Z. J., D.B. Audretsch, and M.P. Feldman (1992), "Real Effects of Academic Research". *The American Economic Review*, 82, 363-367.

Adams, J. (1990), "Fundamental Stocks of Knowledge and Productivity Growth". *Journal of Political Economy* 98, 673-702.

Arora, A. and A. Gambardella (1994), "Evaluating Technological Information and Utilizing It: Scientific Knowledge, Technological Capability, and External Linkages in Biotechnology". *Journal of Economic Behavior & Organization*, 24(1), 91-114.

Belderbos, R., M. Carree, and B. Lokshin (2004), "Cooperative R&D and Firm Performance". *Research Policy*, 33(10), 1477-1492.

Branstetter, L. (2004), "Exploring the Link between Academic Science and Industrial Innovation". Unpublished working paper.

Boldrin, M. and D. Levine (2006), "Against Intellectual Monopoly". Manuscript (www.micheleboldrin.com).

Cassiman, B. and R. Veugelers (2002), "R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium". *The American Economic Review*, 92(4), 1169-1184.

Cassiman, B., R. Veugelers, and P. Zuniga (2008), "In Search of Performance Effects of (in)Direct Industry Science Links". *Industrial and Corporate Change*, 17(4), 611-646.

Cassiman, B. and R. Veugelers (2006), "In Search of Complementarity in Innovation Strategy: Internal R&D, Cooperation in R&D and External Technology Acquisition". *Management Science*, 52(1), 68-82.

Cassiman, B., C. Di Guardo and G. Valentini (2007), "Organizing Links with Science: Cooperate or Contract? A Project Level Approach". IESE working paper, mimeo.

Cassiman, B. and G. Valentini (2009), "Strategic Organization of R&D: Basicness and Openness". *Strategic Organization*, 7(1), 43-73.

Chesbrough, H. (2003), *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business School Press.

Cockburn, I. and R. Henderson (1998), "Absorptive Capacity, Coauthoring Behavior, and the Organization of Research in Drug Discovery". *Journal of Industrial Economics*, 46(2), 157-182 .

Cohen, W. and D. Levinthal (1989), "Innovation and Learning: the Two Faces of R&D". *The Economic Journal*, 99, 569-596.

Cohen, W., R. Nelson and J. Walsh (2002), "Links and Impacts: The Influence of Public Research on Industrial R&D". *Management Science*, 48(1), 1-23.

Darby, M. and L.G. Zucker (2001), "Capturing Technological Opportunity Via Japan's Star Scientists: Evidence from Japanese Firms' Biotech Patents and Products". *Journal of Technology Transfer*, 26(1/2), 37-58.

Dosi, G., P. Llerena, and M. Sylos Labini (2006), "The Relationships between Science, Technologies and their Industrial Exploitation: An Illustration through the Myths and Realities of the so-called 'European Paradox'". *Research Policy*, 35, 1450-1464.

Etzkowitz H. and L. Leydesdorff (2000), "The Dynamics of Innovation: From National Systems and 'Mode 2' to a Triple Helix of University-Industry-Government Relations". *Research Policy*, 29, 109-123

Fleming, L., and O. Sorenson (2004), "Science as a Map in Technological Search". *Strategic Management Journal*, 25, 909-928.

Foray, D., B. Hall and J. Mairesse (2007), "Pitfalls in Estimating the Returns to Corporate R&D using Accounting Data". CEMI working paper. Mimeo.

Griliches, Z. (1998), *R&D and Productivity*. Chicago University Press.

Harhoff, D., F.M. Scherer, and K. Vopel (2003), "Citations, Family Size, Opposition and the Value of Patent Rights", *Research Policy*, 32(8), 1343-1363.

Jaffe, A. (1989), "The Real Effects of Academic Research". *The American Economic Review*, 79, 957-970.

Jaruzelski, B., K. Dehoff, and R. Bordia (2005), "Money isn't Everything". Strategy+Business magazine, Booze Allen Hamilton.

Jaruzelski, B., K. Dehoff, and R. Bordia (2006), "Smart Spenders: The Global Innovation 1000". Strategy+Business magazine, Booze Allen Hamilton.

Levin, R, A. Klevorich, R. Nelson, and S. Winter (1989), "Appropriating Returns from Industrial Research and Development". *Brookings Papers on Economic Activity*, 3, 783-820.

Mansfield, E. (1991), "Academic Research and Industrial Innovations". *Research Policy,* 26, 773-776.

Markiewicz, K. (2004), "Absorptive Capacity and Innovation: Evidence from Pharmaceutical and Biotechnology Firms". Working paper, UC-Berkeley.

Narin, F., K. Hamilton, and D. Olivastro (1997), "The Increasing Linkage between US Technology and Public Science". *Research Policy*, 197, 101-121

Nelson, R.R. (Ed.) (1993), *National Systems of Innovation: A Comparative Study*. Oxford: Oxford University Press.

Pisano, G. (1990), "The R&D Boundaries of the Firm: An Empirical Analysis". *Administrative Science Quarterly*, 35, 153-176.

Romer, P. (1990), "Endogeneous Technological Change". *Journal of Political Economy*, 98, 71-102.

Rosenberg, N. (1990), "Why do Firms do Basic Research (with their Own Money)?". *Research Policy,* 19, 165-174.

Rothwell, R., C. Freeman, A. Horlsey, V. T. P. Jervis, A. B. Robertson and J. Townsend (1974), "SAPPHO updated - project SAPPHO phase II". *Research Policy*, 3(3), 258-291.

Stephan, P. (1996), "The Economics of Science". *Journal of Economic Literature*, 34, 1199-1235.

Stern, S. (2004), "Do Scientists Pay to Be Scientists?" *Management Science*, 50(6), 835-853.

Teece, D. (1986), "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy". *Research Policy*, 15, 285-305.

Veugelers R. and B. Cassiman (1998), "Innovatiestrategieën van Vlaamse Industriële Ondernemingen". Conference Volume of *Vlaams Wetenschappelijk Economisch Congres*.

Veugelers, R. and B. Cassiman (1999), "Make and Buy in Innovation Strategies: Evidence from Belgian Manufacturing Firms". *Research Policy*, 28, 63-80.

Veugelers, R. and B. Cassiman (2005), "R&D Cooperation between Firms and Universities: Some Empirical Evidence from Belgian Manufacturing". *International Journal of Industrial Organization*, 23(5-6), 355-379.

Opuscles already published

1. **Reconsidering Spanish Unemployment**
   Ramon Marimon (June 97)
2. **Reducing Unemployment. At Any Cost?**
   Fabrizio Zilibotti (December 97)
3. **Capital and Labor Taxes, Macroeconomic Activity, and Redistribution**
   Albert Marcet (November 98)
4. **The Lender of Last Resort in Today's Financial Environment**
   Xavier Freixas (November 99)
5. **Why does the Public Sector Grow? The Role of Economic Development, Trade and Democracy**
   Carles Boix (November 99)
6. **Gerontocracy and Social Security**
   Xavier Sala-i-Martin (July 2000)
7. **The Political Viability of Labour Market Reform**
   Gilles Saint-Paul (December 2000)
8. **Are EU Policies Fostering Growth and Reducing Regional Inequalities?**
   Fabio Canova (May 2001)
9. **Agglomeration Effects in Europe and the USA**
   Antonio Ciccone (September 2001)
10. **Economic Polarization in the Mediterranean Basin**
    Joan Esteban (May 2002)
11. **How do Households Invest their Wealth?**
    Miquel Faig (October 2002)
12. **Macroeconomic and Distributional Effects of Social Security**
    Luisa Fuster (April 2003)
13. **Educating Intuition: A Challenge for the 21st Century**
    Robin M. Hogarth (September 2003)
14. **Capital Controls in Post-War Europe**
    Hans-Joachim Voth (April 2004)
15. **Taxation of Financial Intermediaries**
    Ramon Caminal (September 2004)
16. **Ready to Take Risks? Experimental Evidence on Risk Aversion and Attraction**
    Antoni Bosch-Domènech / Joaquim Silvestre i Benach (November 2005)

17. **Social Networks and Labour Market Outcomes**
Antoni Calvó-Armengol (January 2006)

18. **The Effects of Employment Protection in Europe and the USA**
Adriana D. Kugler (February 2007)

19. **Urban Sprawl: Causes and Consequences**
Diego Puga (January 2008)

20. **Western European Long Term Growth, 1830-2000: Facts and Issues**
Albert Carreras and Xavier Tafunell (June 2008)

21. **Overcoming Coordination Failure in Firms and Organizations: Experimental Evidence**
Jordi Brandts (March 2009)

22. **The Misallocation of Talent**
José V. Rodríguez Mora (May 2009)

23. **Complementarities in Innovation Strategy and the Link to Science**
Bruno Cassiman (September 2009)

Bruno Cassiman

Bruno Cassiman is professor of Strategy at the Strategic Management Department of IESE Business School in Barcelona and at the Department of Managerial Economics, Strategy and Innovation at the University of Leuven (KULeuven). He is a fellow of Centre for Economic Policy Research (CEPR) and the SPSP Research Center at IESE Business School. He earned his PhD in Managerial Economics and Decision Sciences from the Kellogg School of Management of Northwestern University in 1996 and a degree in Engineering and Management from the KULeuven, Belgium in 1990. His research interests have centered on the relation between strategy and innovation with a particular focus on the connections between science and industry in the innovation process. His work has been published in several of the top Economics and Business journals including *The American Economic Review, Management Science, European Economic Review, International Journal of Industrial Organization, Industrial and Corporate Change* and, *Research Policy*. Furthermore, he is the department editor of business strategy at *Management Science*, co-editor of the *Spanish Economic Review* and member of the editorial board of the *Journal of the European Economic Association*, the *Journal of Industrial Economics*, *Strategic Organization,* the *European Management Review* and the *Review of Economics and Business*. He recently co-edited a book on the relation between mergers and acquisitions and innovation (M&A and Innovation: The Innovation Impact, Edward Elgar 2006) and has been a consultant to the European Commission and the Belgian government on matters of innovation policy and to several companies on matters of (innovation) strategy.

CREi
Centre de Recerca
en Economia Internacional

Ramon Trias Fargas, 25-27 - 08005 Barcelona
Tel: 93 542 13 88 - Fax: 93 542 28 26
E-mail: crei@crei.cat
http://www.crei.cat

PVP: 6,00 €

UNIVERSITAT POMPEU FABRA
Generalitat de Catalunya