# Managing knowledge spillovers: The impact of absorptive capacity on innovation performance[§]

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**Abstract**

This paper investigates how a firm's absorptive capacity mediates the impact of knowledge spillovers on innovation performance. Our basic hypothesis is that those firms with higher absorptive capacity are able to manage knowledge spillovers more efficiently, and ultimately more likely to transform them into innovative outcome. Additionally, we seek to understand how key contingencies in the external knowledge environment do influence the relationship between absorptive capacity, knowledge spillovers and innovation performance. We find empirical support to our theoretical hypotheses by using a panel data of more than 2200 innovating firms drawn from the Community Innovation Survey (CIS) conducted by the Spanish National Statistics Institute.

**JEL Classification**: O30, O32, O33.

**Keywords**: Absorptive capacity, innovation, knowledge spillovers

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*"Ninety-nine percent of everything exciting that happens will happen outside your own research labs" Tom McKillop, CEO of Astra Zeneca.*

## 1/ Introduction

One of the most important changes in the organization of the innovation process within corporations in the last two decades has been the increasing recognition of the importance of external knowledge flows. Firms are gradually abandoning the idea that the generation of new knowledge is mostly an internal process (Arora et al., 2001; Gans and Stern, 2003). In some industries, the boundaries between the knowledge stock of the organization and the external knowledge stock have been blurring. Consequently, the monitoring of external knowledge flows and the ability to absorb them within the organization have become imperative for building sustainable competitive advantage (Teece, 1998).

Cohen and Levinthal (1990)'s seminal contribution highlights that firms cannot benefit from external knowledge flows by simply being exposed to them. Firms need instead to develop the ability to recognize the value of new external knowledge, assimilate it, and apply it to commercial ends. In other words, firms must possess "absorptive capacity". The last decade has witnessed a proliferation of contributions to the concept of absorptive capacity (see, for a survey, Zahra and George, 2002). Theoretical contributions have analyzed the concept of absorptive capacity at different levels: business unit, firm, dyad, and country (Szulanski, 1996; Cockburn and Henderson, 1998; Lane and Lubatkin, 1998; Keller, 1996). Many scholars have recognized that a firm's absorptive capacity is not a goal in itself, but that it moderates important organizational outcomes. For example, Cohen and Levinthal (1990) relates absorptive capacity to, among others, innovative capabilities, innovation performance and expectation formation. Our paper follows in this tradition and investigates the mediating role of absorptive capacity in conditioning innovation performance. That is, how a firm's ability to first recognize external knowledge and then adapt it to its organization routines is mapped into innovation outcomes. An important implication is that heterogeneity in the level of absorptive capacity translates into differences in the benefits from otherwise similar stocks of external knowledge.

Specifically, in this paper we focus on involuntary knowledge flows, *i.e.* knowledge spillovers. Knowledge spillovers arise when part of the knowledge generated by an organization spills over its boundaries and becomes available to other organizations (Nelson, 1959; Arrow, 1962). Several papers have highlighted the importance of knowledge spillovers for strategic decisions at the firm level. For instance, Jaffe (1986) and Bernstein and Nadiri (1988) investigate the impact of spillovers on firms' productivity and performance. Cohen and Levinthal (1990) and Geroski (1995) analyze the effect of knowledge spillovers on firms' incentive to perform R&D. Cassiman and Veugelers (2002) study the relationship between R&D cooperation and spillovers. Finally, Jaffe et al. (1993) and Almeida and Kogut (1999) underline the importance of geographical co-location in order to benefit from knowledge spillovers, whose effects have been shown to decay with distance.[1]

In this paper we seek to improve our understanding of the relationship between knowledge spillovers and absorptive capacity. We argue that absorptive capacity has two effects on knowledge spillovers. First, firms endowed with higher levels of absorptive capacity will be more aware of the existence of knowledge spillovers. For instance, a firm, whose R&D employees have never published in scientific journals, might ignore the existence of specialized journals where a great deal of publicly available knowledge could be sourced. Similarly, a firm actively investigating the possibility of improving its own product can better understand the knowledge embodied in the products launched by its rivals by reverse engineering them. Second, the benefits of the knowledge spillovers that each firm can identify and recognize also depend on its absorptive capacity. Firms with higher levels of absorptive capacity will be able to manage more efficiently external knowledge flows and better integrate them with internally generated flows, such as to advance innovation performance. In other words, we posit that firms with higher levels of absorptive capacity extract more value from otherwise similar stocks of knowledge spillovers. The latter effect is what we refer to as "the mediating role of absorptive capacity".

As a further refinement of our theory and using the insights from the literature, we explore how some key contingencies in the external knowledge environment influence the relationship between absorptive capacity, knowledge spillovers and innovation performance. In particular, we focus on two types of contingencies: the degree of turbulence and the level of appropriability. We argue that the mediating role of absorptive capacity is much more pronounced in turbulent environments vis-à-vis more stable ones, and in environments with strong legal protection of intellectual property.

[1] After the seminal work of d'Aspremont and Jaquemin (1989), spillovers have been mostly modeled as exogenous in the theoretical industrial organization literature. Recently, some authors have incorporated the important role of absorptive capacity as a necessary condition for benefiting from the spillovers (Kamien and Zang, 2000).

Drawing on a sample of more than 2200 Spanish innovative firms we find evidence that firms endowed with more absorptive capacity both enjoy more knowledge spillovers, and turn them more efficiently into innovative outcomes. Our data also suggest that the role of absorptive capacity strongly depends on the contingencies of the external knowledge environment.

Our paper contributes to the empirical literature on absorptive capacity and its impact on different innovation outcomes. Cohen and Levinthal (1989) argue that the desire to assimilate external know-how creates a positive incentive to invest in R&D. They offer indirect evidence of the relationship between innovation performance and absorptive capacity by showing that knowledge spillovers encourage, rather than diminish the investment in R&D. Gambardella (1992), based on several case studies of large US drug manufacturers, concludes that firms with better in-house scientific research programs have exploited more efficiently outside scientific information. Focusing on collaborative linkages in the biotechnology industry, Arora and Gambardella (1994) find that a firm's absorptive capacity plays a crucial role in explaining the number of alliances each firm is establishing. Cockburn and Henderson (1998) show that connectedness to the scientific community is a key factor in driving a firms' ability to recognize and use upstream research and findings. Moreover, connectedness is significantly correlated with performance in drug discovery. Veugelers (1997) using a similar dataset on 290 Flemish firms shows that firms with greater absorptive capacity present greater complementarity between external sources of R&D (e.g., from alliance partner) and internal R&D spending. Summarizing, direct evidence of the impact of absorptive capacity on innovation performance is still scarce. Most of the available evidence does not yet convincingly separate the "two faces of R&D" (Cohen and Levinthal, 1990), i.e. whether successful innovating firms are better at capturing knowledge spillovers, or whether they are simply more productive at R&D than their rivals. We are able to separate the two effects by focusing on how absorptive capacity mediates the impact of knowledge spillovers on innovation performance, and at the same time controlling as well as we can for other drivers of innovation performance, like for instance inputs of the innovation process and firms' innovation ability. This, we believe, constitutes our contribution to the related literature.

The remainder of the paper is organized as follows. Section 2 develops the theoretical underpinnings as well as the hypotheses to be tested. In Section 3, we conduct the empirical analysis. The paper ends with some final remarks.

## 2/ Background theory: knowledge spillovers and absorptive capacity

Innovation is a complex process in which new knowledge is applied to commercial ends. New knowledge is generated typically through a cumulative process in which existing knowledge is transformed, modified and improved. Part of this knowledge reaches the firm from external sources. To be sure, the role of external knowledge flows for the success of the innovation process has long been recognized. Firms that were too much inward looking have been accused to suffer from the so-called "not-invented here" syndrome (Katz and Allen, 1982). However, the importance of external knowledge sources has increased dramatically in the last few years. The cliché that we live in the knowledge economy might be right insofar it refers to the increasing importance of knowledge generated outside the firm's boundaries (Arora et al., 2001).

The increasing availability of external knowledge affects the firm in its role as a user of technology. The strategic imperative is not only to maximize the revenues from the firm's actual stock of knowledge, but also to identify knowledge that is available outside its boundaries. Further, this does not imply that firms can simply rely on outside knowledge flows and need not invest in R&D. As Mowery (1984) has pointed out, a firm is far better equipped to absorb the output of external R&D if it is also performing some amount of R&D internally. Cohen and Levinthal (1990) have highlighted the role of "absorptive capacity".[2] Absorptive capacity is defined as the ability to recognize the value of new external knowledge, assimilate it, and apply it to commercial ends. In shorts, having greater ability to absorb external knowledge flows, implies that the firm can extract more value from such flows. Arora and Gambardella (1994) point out a double role of absorptive capacity; they distinguish between the ability to evaluate external knowledge and the ability to exploit it. Recently, Zahra & George (2002) have introduced a similar distinction between what they call potential and realized absorptive capacity. Potential absorptive capacity enables a firm's receptiveness to external knowledge; realized absorptive capacity reflects a firm's capacity to leverage absorbed knowledge.

Knowledge spillovers constitute a prototypical example of external knowledge sources that the firm could exploit to enhance innovation performance. The concept of knowledge spillovers was pioneered by Nelson (1959) and Arrow (1962) who

[2] Gans and Stern (2001) argue that firms invest in internal R&D to enhance their bargaining power in technology acquisitions. Arora et al. (2005) find only mild empirical evidence to support such a theory.

characterized knowledge as having the feature of a durable public good. The knowledge produced by an innovator is easily "borrowed" by another party, without compensating the former. For instance, Teece (1998) shows that behind the decision of several foreign firms to locate in Silicon Valley lied the aim to benefit from knowledge spillovers. Several authors have documented the importance of knowledge spillovers for strategic decisions at the firm level (Jaffe, 1986; Cohen and Levinthal, 1990; Cassiman and Veugelers, 2002). The amount of knowledge spillovers available to a firm depends on the density of firms' clustering in a given geographical area, the sector, the nature of knowledge, and the legal protection of intellectual property, among other things (Jaffe et al., 1993; Teece, 1986; Saxenian, 1996). Although all firms located in a given geographical area and belonging to a given sector might equally benefit from the presence of knowledge spillovers, in practice, they differ in their ability to identify and exploit such spillovers and, therefore, both the amount and the effect of knowledge spillovers is unequally distributed across the population of firms. Put it differently, absorptive capacity can be a source of a firm's competitive advantage (Barney, 1991).

Our objective in this paper is to address the difficult task of empirically disentangling the "two faces of R&D" (Cohen and Levinthal, 1989). In particular we would like to convincingly show that if a positive impact of absorptive capacity on innovation performance exists, this is not due to the misspecification of controls for innovation ability, innovation productivity, and inputs of the innovation process.

Before proceeding we need first to clarify the drivers of innovation performance. Innovation performance can be thought of as a function of both internally and externally generated knowledge flows. As we argued above the weights have tilted in favor of external knowledge flows in recent years, but this does not imply that internally generated knowledge is not important. Internal knowledge flows are the outcome of the innovation ability of the firm, the efficiency of its innovation process, the inputs poured into the innovation process, among other things.

External knowledge flows come from outside the firm's boundaries. Specifically, our focus here is on knowledge spillovers. As explained above the available stock of knowledge spillovers depends on many industry-specific characteristics. However, the ability of the firm to first recognize and then benefit from these knowledge spillovers depends on its "absorptive capacity".[3] This implies that a

[3] We do not know whether knowledge spillovers have a positive or negative direct effect on innovation performance. For instance, Cassiman and Veugelers (2002) argue that spillovers might have a double role. Incoming spillovers might be beneficial, whereas outgoing spillovers might benefit competitors and then reducing the firm's competitive advantage in innovation.

firm can aim at superior performance in its innovation activity by boosting its ability to recognize and exploit external knowledge flows. Obviously, as Cohen and Levinthal (1989) have suggested the drivers of absorptive capacity are highly correlated with the inputs of the innovation process and the firm innovation ability, and it is probably not easy to estimate their separate effect on firms' innovation performance.

Our strategy here is the following.

First, we assume that absorptive capacity has an effect on innovation performance only when there are external knowledge flows to identify, integrate and exploit. Put it differently, a firm that leaves in a vacuum would not benefit from absorptive capacity. Hence, the way in which we capture the impact of absorptive capacity is through its mediating effect on the impact of knowledge spillovers. Firms with more absorptive capacity benefit more, or loose less, from the presence of knowledge spillovers. Put it differently, absorptive capacity mediates the effect of knowledge spillovers on innovation performance. Following the literature, we can also distinguish between two roles of absorptive capacity (Arora and Gambardella, 1994; Zahra and George). First, absorptive capacity helps the firm to identify more knowledge spillovers. In other words, the amount of knowledge spillovers that the firm can perceive is an increasing function of its absorptive capacity. Second, given the amount of knowledge spillovers identified by the firm, how much it can benefit from them also depends on its absorptive capacity. The former effect is what other scholars have called ability to identify, ability to evaluate or potential absorptive capacity, the latter effect is typically labeled as ability to use, ability to exploit or realized absorptive capacity. Overall, we can conclude that heterogeneity in the level of absorptive capacity translates into differences in the benefits from otherwise similar stocks of external knowledge.

Second, we need to control as well as we can for all other drivers of innovation performance, that is, inputs of the innovation process, ability to innovate, and efficiency of the innovation production function. To be sure, many of the drivers of innovation performance are also drivers of the firm's absorptive capacity. For instance, Cohen and Levinthal (1989) have stressed the dual role of the investment in R&D. It would be unviable to isolate the impact of absorptive capacity on innovation performance if one would have posited a direct effect, like for instance Cockburn and Henderson (1998). In such a case the only available option is to impose ex-ante a different set of proxies that explain absorptive capacity. We believe that absorptive capacity is so intertwined with innovation ability and several inputs of the innovation process that it would be meaningless to proceed in that way, especially with the limitations imposed by our dataset.[4] As explained before, our strategy to isolate the effect of absorptive capacity is by looking at it as mediator of the impact of knowledge spillovers.

The relationship between absorptive capacity, knowledge spillovers and innovation performance crucially depends on some key contingencies in the external knowledge environment. We focus here on two types of contingencies: the degree of turbulence and the level of appropriability.

March (1991) has proposed two broad types of qualitatively different learning activities through which firms divide its attention and resources: exploration and exploitation. Exploration implies search, discovery, experimentation, risk taking and innovation, while exploitation implies refinement, implementation, efficiency of production and selection. In a stable knowledge environment, like a mature single industry, firms have a strong focus on the exploitation of knowledge since the knowledge domain the incumbent firm wishes to exploit is closely related to its current knowledge base. Differently, in turbulent knowledge environments, firms engage more actively in exploration since the relevant knowledge might be distant from their existing stock of knowledge. Hence, in turbulent environments it becomes far more important to monitor external knowledge development and an inward looking attitude is highly penalized. This also translates into the design of the organization within each environment. Certainly, to promote new knowledge absorption in turbulent environments (Van den Bosch *et al.*, 1999), decentralized designs are clearly desirable. On the contrary in stable environments, the exploitation of existing knowledge within the organization leads to a more centralized designs.

In turn, this implies that the role of absorptive capacity is magnified in turbulent environments. Since most of the relevant knowledge is outside the firm's boundaries, knowledge spillovers become more important, and the ability to benefit from them play a crucial role in securing competitive advantage. Another characteristic of a sector is the relevance of a firm's appropriability regime. Appropriability refers to the ability of the firm to protect the advantages of (and benefit from) new products or processes. Appropriability depends among other things on the strength of the protection of intellectual property rights (IPRs) like patents, trade secrets, copyrights, trademarks, etc.. Under a regime of strict protection of IPRs, firms patent their innovations to protect revenue streams arising from innovations. Imitation is more difficult and imitating firms need to incur higher costs to circumvent valid patents. By contrast, under a regime of weak protection of IPRs, firms can preserve their innovation advantages only by

[4] For a rather different view, see for instance Zahra and George (2002).

resorting to different means of protection like secrecy, complexity of routines, control of complementary assets (Teece, 1986). Secrecy, in particular, has been identified as the preferred mode from protecting both product and process innovation by Cohen et al. (2000) in a large survey of manufacturing firms. Patenting is considered a risky strategy because if the regime of protection is not too strong, a patent may provide enabling information for other firms to circumvent the process and yet achieve the desired output. Put it differently, if one of the crucial task of a patent system is to disclose information that can be socially and efficiently used by other players, the risk of imitation when legal protection is weak makes this goal unattainable. In turn, this implies that firms will try to develop mechanisms to protect their innovation which tend to reduce the amount of disclosed information. Hence, knowledge spillovers are inevitable less important in regimes of weak appropriability. Firms anticipate this fact and devote fewer resources to develop their absorptive capacity.

## 3/ Empirical Analysis

### 3.1/ Data

The dataset used in this study is assembled from the Community Innovation Survey (CIS) conducted in Spain in 2000 and a similar survey conducted by the Spanish National Statistics Institute (INE) in 2002 (*Encuesta de Innovación Tecnológica, EIT)*. The purpose of the survey is to collect detailed information about innovation activities of Spanish firms belonging to all sectors of the economy. The database for each year is a stratified sample according to the number of employees and the sector. In particular, the number of employees has been divided into three intervals (from 10 to 49; from 50 to 249 and more than 250).[5] Firms are assigned to 54 different sectors following a Spanish classification called CNAE.[6] The response rate has been quite large (92%). This is not surprising given that Spanish firms have a legal obligation to fulfil questionnaires administered by INE. The final database for the year 2000 is composed of about 16,000 firms, and for the year 2002 of about 26,000. However, we have only considered firms that have answered the questionnaire in both periods and, after removing observations with missing values, we are left with a panel of about 4000 firms. Some diagnostic checks have been performed to assure that the sample we

[5] INE has only sent the questionnaire to firms with more than 10 employees.
[6] In the Appendix we report the correspondence between the sectors of our database (CNAE classification) and those based on the more standard SIC classification.

employ does not suffer any serious selection bias. Slightly more than 55% of the firms of our sample have indicated that they have spent a positive amount of resources in any innovation activity. We consider that the problem we want to analyze is rather meaningless for those firms that have not devoted resources to innovation activities. However, for completeness we also report our results using the full sample of 4000 firms, and correct the estimated coefficients through the Heckman procedure.

Finally, notice that most studies based on CIS data are cross-section. Since we have two waves, we can control more carefully for potential simultaneity problems that affect other studies. Indeed, our dependent variable is innovation performance measured during the period 2002-2004, whereas all our independent variables are constructed from the 2000 survey and therefore refer to the 1998-2000 period.

### 3.2/ Variable definition

Measures of performance

We consider two different measures of performance. INNOV is a dummy that takes the value of 1 if a firm has introduced new or improved products, or new or improved processes. NEWPROD is the percentage of sales due to new or improved products. Both variables are from the 2000-2002 survey.

Knowledge spillovers

In the questionnaire, firms rated the importance of different information sources for innovation on a four-point scale from 1 (high) to 4 (not at all). We focus on 7 sources: suppliers, clients, competitors, universities, other research institutions, specialized journals and meetings. We build an index (SPILLOVER) that varies between 0 (no spillovers) to 1 (maximum spillovers). Notice that this is a firm-specific measure of knowledge spillovers. A similar measure has been used by Cassiman and Veugelers (2002) in their study of R&D cooperation and spillovers based on Belgian CIS data, to which we refer for the discussion of the virtues of this measure vis-à-vis alternative measures proposed in the literature. This measure is likely to be a function of the ability of the firm to identify and recognize external knowledge flows, i.e. its absorptive capacity. Indeed, if a firm cannot identify the presence of external useful information it will naturally tend to classify it as not important. Moreover, to classify anything one has to have the ability to understand the object under scrutiny and compare it with some reference object (March, 1991; Levinthal and March, 1993). We will try to address this problem in two ways: first, by factoring out the effect of absorptive capacity from our measure of knowledge spillovers; second, by using as an alternative measure the sector average level of knowledge spillovers.

Absorptive capacity

The literature has proposed several different measures of absorptive capacity, and none seems to be superior to all others in all circumstances. In their seminal paper Cohen and Levinthal (1990) used R&D intensity, although they argued that the process of building absorptive capacity is cumulative. So, rather than to the actual flow of R&D investment, absorptive capacity more closely relates to the depreciated sum of past investments in R&D. To capture this cumulativeness aspect of absorptive capacity Veugelers (1997) and Cassiman and Veugelers (2002), among others, use the fact that the firm has an R&D department fully staffed (permanent R&D). Alternatively, other authors have used the stock of granted and not expired patents as a natural proxy of the stock of knowledge accumulated by the firm in the past. On a theoretical level, patent stock is an attractive construct for firm absorptive capacity (Silverman, 1999). Each dollar spent on internal R&D may not generate the same amount of knowledge stock. Some research is likely to be unproductive and should not be weighed equally to that which is successful (Hall, Jaffe, and Trajtenberg, 2001). Other papers that have used a similar construct are Stuart (2000) and Cockburn and Henderson (1994). Finally, since absorptive capacity has to do with the ability of the individuals of the organization to assimilate, process and transform external knowledge flows, scholars have also used measures of the firm human capital. For instance, Mowery and Oxley (1995) and Keller (1996) employ investment in scientific and technical training and the number of scientists and engineers. Veugelers (1999) uses the number of doctorates within the R&D department. Following the different suggestions of the literature, we have operationalized our measure of absorptive capacity by constructing a new variable which is the principal component of 1) a dummy which is equal to 1 if the firm has an R&D department fully staffed, 2) the stock of patents, 3) a dummy which is equal to 1 if the firm undertakes training activity for its R&D personnel, and 4) a dummy which is equal to 1 if the firm has a share of researchers over total employees greater than the average of the sector.[7]

[7] As a robustness check, we also have used several alternative definitions of absorptive capacity. Results, available from the authors upon request, are with what we find here. In particular, we have constructed an alternative variable of absorptive capacity by summing up the values of the aforementioned three dummy variables. This generates a score that varies between 0 (no absorptive capacity) to 3 (strong absorptive capacity). We have also use a dummy that takes the value of 1 if the above sum is greater or equal than 2, and zero otherwise, to identify firms with a sufficiently high level of absorptive capacity.

In order to capture empirically the mediating role of absorptive capacity, we cross our proxy for a firm's absorptive capacity with our measure of knowledge spillovers (HABSCAP*SPILLOVER). We also control for a direct effect of knowledge spillovers on innovation performance.

Innovation ability and inputs of the innovation process

We need to control as well as we can for other possible drivers of innovation performance. If innovation is the outcome of the innovation process, to predict such an outcome one has to consider the inputs and the innovation production function (i.e. the ability to innovate). The standard input of the innovation process is the amount - in this case, the flow - of investment in R&D (INTERNAL R&D, which is measured in a log scale). Innovation performance will also depend on the ability of the R&D department. We proxy this ability with the same two variables that we also used in our measure of absorptive capacity, that is, the training of R&D personnel (TRAINING, which is the log of the actual expenditure), and the share of researchers over total employees (R&D SKILL). Finally, for the sake of completeness we also control for the stock of patent. Although we argued that the stock of patents is a valid construct for absorptive capacity, it might also capture the firm's innovation ability (firms with greater ability have obtained more patents).

Turbulent knowledge environments

Turbulent knowledge environments are those environments where the underlying knowledge base is under a process of continuous evolution and change. By identifying the degree of knowledge turbulence at the sector level, we attempt to address the fact that some industries may experience greater technological ferment that may drive both the importance of absorptive capacity and the opportunities to benefit from knowledge spillovers. We define as turbulent sectors those in which the rate of increase in the share of sales due to new or improved products is higher than the economy average rate of increase (TURBULENT).

Sectors with strong IPRs

Firms rated on a four-point scale the effectiveness of four different methods for protecting IPRs: patents, utility models, trademarks and copyrights. We summed up the

We have to mention that these alternative measures of absorptive capacity show a correlation greater than 0.8 with the variable based on the principal component analysis. Thus, it is not surprising the consistency of the results found.

four scores, and standardized such as the resulting index varies between 0 (minimum protection) and 1 (maximum protection). Finally, we average the firm level index at the sector level. See also Cassiman and Veulegers (2002). Sectors with strong IPRs are those having a score higher than the average of the economy (APPROPRIABILITY).

Control variables

We use the number of employees in a log scale (SIZE) as a control for firm size. We use a dummy (NEW) that signals whether a firm is of new creation or not. To control for the degree of competitiveness in a sector we use the Herfindahl index (HERFINDAHL). We introduce a variable that accounts for the existence of factors that hinder the innovation process (INNOVATION COSTS). Firms rated on a four-point scale the importance of the following constraints to innovation activity: a) excessive risk, b) large sunk investment, and c) short pocket. We normalize the sum to vary between 0 and 1. Finally, following Cassiman and Veugelers (2002), we control for the ability of the firm to protect its innovation using strategic tools like lead time, design complexity and secrecy (STRATEGIC PROTECTION). This is again a normalized sum of three scores (for the importance of lead time, design complexity, and secrecy) that varies between 0 and 1.

### 3.3/ Descriptive evidence

Table 1 offers a first cut to the data by comparing means across different subsets of our sample firms. Panel A shows that firms with higher absorptive capacity value the importance of external knowledge flows more than firms with less absorptive capacity. This suggests that our measure of knowledge spillovers might indeed be related to the firm's level of absorptive capacity. The remaining panels explore the effect of absorptive capacity on innovation performance. Panel B shows that firms with higher absorptive capacity are more innovative independently of the measure we use. Panel C indicates that among the firms that declare that external knowledge flows are important (larger than the mean of the sector), firms with higher absorptive capacity extract more benefits in terms of innovation performance from such knowledge flows. Panel D and panel E show that that those firms with high absorptive capacity and that state that knowledge spillovers are important are able to generate more innovative output in those sectors where it is particularly desirable for such firms to have great potential for absorption of external knowledge flows, i.e. turbulent sectors and/or sectors where IPRs are particularly strong.

**Table 1. Test of means of the main variables**

| | | | |
|---|---|---|---|
| **PANEL A (THE PRESENCE OF ABSORPTIVE CAPACITY** | | | |
| | The firm has a level of absorptive capacity greater than the sector it belongs | The firm has a level of absorptiv capacity smaller than the sector i belongs | ***p*-value** |
| Level of knowledge spillovers greater than the sector average | 0.478 | 0.154 | 33.578 (0.000) |
| **PANEL B (THE EFFECT ON INNOVATION PERFORMANCE)** | | | |
| | The firm has a level of absorptive capacity greater than the sector it belongs | The firm has a level of absorptive capacity smaller than the sector it belongs | ***p*-value** |
| DNEWPROD=1 | 0.351 | 0.180 | 9.311 (0.000) |
| DINNOV=1 | 0.632 | 0.442 | 9.373 (0.000) |
| **PANEL C (THE MEDIATING EFFECT)** | | | |
| | The level of knowledge spillovers and of absorptive capacity are greater than the sector average | The level of knowledge spillovers an of absorptive capacity are respectivel greater and smaller than the sector average | ***p*-value** |
| DNEWPROD=1 | 0.355 | 0.182 | 8.813 (0.000) |
| DINNOV=1 | 0.637 | 0.451 | 8.657 (0.000) |
| **PANEL D (TURBULENT SECTOR)** | | | |
| | The level of knowledge spillovers and of absorptive capacity are greater than the sector average GROWTH=1 | The level of knowledge spillovers an of absorptive capacity are greater tha the sector average GROWTH=0 | ***p*-value** |
| DNEWPROD=1 | 0.416 | 0.333 | 2.837 (0.004) |
| DINNOV=1 | 0.735 | 0.601 | 4.587 (0.000) |
| **PANEL E (STRONG APPROPRIABILITY)** | | | |
| | HABSCAP=1 DSP=1 APPROPR=1 | HABSCAP=1 DSP=1 APPROPR=0 | ***p*-value** |
| DNEWPROD=1 | 0.442 | 0.196 | 9.056 (0.000) |
| DINNOV=1 | 0.743 | 0.443 | 10.944 (0.000) |

Note: P-values in parentheses and correspond to the Mann-Whitney tests. All the dummy variables used in the Table are based on the definition given in the text (Section 2).

### 3.4/ Econometric Analysis

Multivariate regression techniques are used to extend the previous descriptive analysis. We consider the following specification:

$$\begin{Bmatrix} INNOV \\ NEWPROD \end{Bmatrix} = a + b_1 R\&D\ SKILLS + b_2 INTERNAL\ \ R\&D + b_3 TRAINING + b_4 NUMPATENT + b_5 STRATEGIC\ \ PROTECTION + b_6 COST + b_7 SPILLOVER + b_8 HABSCAP * SPILLOVER + b_9 SIZE + b_{10} NEW + b_{11} HERFINDAHL + e$$

We use as dependent variables our two measures of innovation performance: INNOV and NEWPROD. Remember that these two variables are drawn from the 2000-2002 survey, whereas all variables in the right hand side come from the 1998-2000 survey. Since INNOV is a dummy (whether the firm innovate or not), and NEWPROD is a share and varies between 0 and 100, we use a Probit and a Tobit estimation, respectively.

The results are shown in Table 2. In the first two columns we report the estimations for the subsample of firms that have invested a positive amount of money in innovation activity. This is not the set of innovative firms (which is clearly a smaller subset of such firms). In principle, we think that it makes little sense to investigate the mediating role of absorptive capacity on innovation performance for firms that do not run any R&D activity. However, since we select our sample on a threshold, i.e. whether the firms invest or not in R&D, our results might suffer from some sort of estimation bias. As a robustness check, we also estimate our two innovation performance equations using a selection model (Greene, 1993). A first equation controls for the binary decision of investing or not in R&D activity, whereas a second equation reproduces our basic regression for the subset of firms with positive investment in R&D. The results of the Heckman probit are reported in the last two columns of table 2.[8] We have a total of 3986 firms of which only 2265 spend a positive amount in R&D.

[8] We do not report the selection equation in the table since we do not believe it is very interesting in itself. In addition to some of the exogenous variables described in the text we have also included controls for total export activity and total investment.

**TABLE 2**

| | INNOV[1] | NEWPROD[1] | INNOV[2] | NEWPROD[2] |
|---|---|---|---|---|
| | -0.110 | -1.554 | -0.086 | 0.001 |
| R&D SKILLS | -1.210 | -0.520 | -0.900 | 0.010 |
| | 0.036$^{***}$ | 2.068$^{***}$ | 0.043$^{***}$ | 0.046$^{***}$ |
| INTERNAL R&D | 5.790 | 9.080 | 4.920 | 4.640 |
| | 0.025 | -0.963 | 0.040 | -0.047 |
| TRAINING | 0.420 | -0.480 | 0.660 | -0.720 |
| | 0.000 | 0.047 | 0.000 | 0.000 |
| NUMPATENT | -0.260 | 1.300 | -0.310 | 0.160 |
| | 0.383$^{***}$ | 12.244$^{***}$ | 0.397$^{***}$ | 0.365$^{***}$ |
| STRATEGIC PROTECTION | 4.080 | 4.220 | 4.210 | 3.950 |
| | -0.068 | -3.530 | -0.057 | -0.045 |
| COST | -0.720 | -1.100 | -0.590 | -0.440 |
| | 0.438$^{***}$ | 8.392 | 0.528$^{***}$ | 0.083 |
| SPILLOVERS | 2.790 | 1.500 | 2.810 | 0.410 |
| | 0.414$^{***}$ | 10.186$^{***}$ | 0.348$^{***}$ | 0.333$^{***}$ |
| HABSCAP*SPILLOVER | 3.570 | 2.630 | 2.580 | 2.450 |
| | 0.098$^{***}$ | -0.107 | 0.097$^{***}$ | 0.028 |
| SIZE | 4.490 | -0.150 | 4.390 | 1.220 |
| | -0.139 | -0.321 | -0.160 | -0.084 |
| NEW | -0.860 | -0.060 | -0.980 | -0.500 |
| | -0.001$^{**}$ | 0.076 | -0.001 | 0.001 |
| HERFINDAHL | -0.370 | 1.180 | -0.480 | 0.640 |
| | -0.906$^{***}$ | -36.833$^{***}$ | -1.014$^{***}$ | -1.360$^{***}$ |
| CONSTANT | -5.840 | -6.710 | -5.400 | -6.700 |
| Number of obs. | 2265 | 2265 | 3986 | 2265 |
| R2 | 8.72 | 2.84 | | |
| | -1417.595 | -5442.361 | -2150.47 | -1980.67 |
| LR test | (0.000) | (0.000) | (0.000) | (0.000) |

[1] ***p-value 0.01, ** p-value 0.05, *p-value 0.10. P-values in parentheses. See the definition of the variables in the text.

[2] We have conducted Heckman probits with a selection equation for positive innovation expenses. For the specification with NEWPROD we have used a dummy variable that takes the value of 1 if NEWPROD is greater than the mean of the sector to which the firm belongs.

First of all, notice that knowledge spillovers have a positive and significant impact on innovation performance. So, firms that enjoy more knowledge spillovers are more innovative. Second, firms with higher levels of absorptive capacity benefit more from knowledge spillovers. Indeed, our cross variable (HABSCAP*SPILLOVER) is positive and highly significant. Hence, one can conclude that other things equal, knowledge spillovers have a direct and positive impact on innovation performance, and the magnitude of this positive effect is amplified by the firm absorptive capacity. Put it differently, firms with higher levels of absorptive capacity are more innovative because they exploit more efficiently the flow of external knowledge. The signs of the other variables seem plausible. A larger investment in R&D (flow) generates a higher chance to obtain an innovation. This effect is significant across all our specifications. Other measures of innovation ability do not show up significant. Strategic protection and firm size are positively and significantly related to innovation performance. That is, firms that have made larger use of strategic protection and bigger firms are more likely to show better innovation performance.

As we discussed above, one virtue of our measure of knowledge spillovers is that it is firm specific. So, it already incorporates the fact that not all firms are exposed to the same amount of spillovers even if they compete in the same sector and/or geographic area. However, such a firm specific measure of knowledge spillover is likely to be correlated to firm variables, most notably among them, the firm level of absorptive capacity. Firms with greater absorptive capacity will show up a larger amount of firm specific knowledge spillovers. To check for this possibility we have run a regression in which we used as dependent variable our measure of knowledge spillovers and as explanatory variable our construct for absorptive capacity. Moreover, we have controlled for sector and geographical location through a vector of dummy variables for 54 sectors and a vector of dummy variables for 51 Spanish provinces. As suggested by the literature knowledge spillovers tend to be localized and their importance decays with distance (Henderson et al., 1993). The results from such regression show that absorptive capacity has a positive, substantial effect on knowledge spillovers (0.593 with p-value of 12.54). Although we do not believe that this relationship between our measures of knowledge spillovers and absorptive capacity invalidates our previous findings, we have also tried to control for it. We followed two routes. First, we have used the results of the regression described above to factor out the impact of absorptive capacity from our measure of knowledge spillovers (orthogonalization). We then have used the orthogonalized measure of knowledge spillovers to run our two regressions. Second, we have used the sector average of knowledge spillovers instead of our firm specific measure. In this case, all firms belonging to the same sector experiment the same level of knowledge spillovers. Results of these additional estimations are reported in the Appendix. It is comforting to observe that our results are pretty robust to these different measures of knowledge spillovers.

Finally we analyze whether absorptive capacity plays a different role depending on contingencies of the environment. We have argued that absorptive capacity should play a more crucial role in those sectors with greater knowledge opportunities and those with stricter protection of IPRs. Table 3 addresses the role of absorptive capacity in turbulent knowledge sectors and table 4 in sectors with higher appropriability. The two tables are identical to table 2 with only one additional regressor. We have added a cross variable (ABSCAP*SPILLOVER*TURBULENT) as the product of ABSCAP, SPILLOVER, and TURBULENT in table 3. If this term turns out positive it implies that absorptive capacity is more important to turn knowledge spillovers into innovative products in those sector with a more turbulent and creative environment. In table 4 we have added a cross variable (ABSCAP*SPILLOVER*TURBULENT) as the product of ABSCAP, SPILLOVER, and APPROPRIABILITY. If this term shows up positive it implies that absorptive capacity is more important to turn knowledge spillovers into innovative products in those sectors with stricter enforcement of IPRs.

**TABLE 3**

**Turbulent knowledge sectors**

| | INNOV[1] | NEWPROD[1] | INNOV[2] | NEWPROD[2] |
|---|---|---|---|---|
| R&D SKILLS | -0.105 | -1.451 | -0.082 | 0.003 |
| | -1.150 | -0.490 | -0.860 | 0.030 |
| INTERNAL R&D | 0.037*** | 2.071*** | 0.043*** | 0.046*** |
| | 5.830 | 9.100 | 4.930 | 4.630 |
| TRAINING | 0.025 | -1.010 | 0.040 | -0.048 |
| | 0.420 | -0.500 | 0.650 | -0.750 |
| NUMPATENT | 0.000 | 0.051 | 0.000 | 0.000 |
| | -0.240 | 1.380 | -0.270 | 0.190 |
| STRATEGIC PROTECTION | 0.381*** | 12.104*** | 0.395*** | 0.358*** |
| | 4.050 | 4.170 | 4.180 | 3.870 |
| COST | -0.063 | -3.504 | -0.052 | -0.043 |
| | -0.670 | -1.090 | -0.530 | -0.420 |
| SPILLOVER | 0.417*** | 7.891 | 0.503*** | 0.071 |
| | 2.660 | 1.410 | 2.680 | 0.350 |
| ABSCAP*SPILLOVER | 0.330*** | 8.194** | 0.268** | 0.305** |
| | 2.720 | 2.040 | 1.930 | 2.190 |
| ABSCAP*SPILLOVER*TURBULENT | 0.251** | 5.997** | 0.245** | 0.100 |
| | 2.140 | 1.860 | 1.950 | 0.940 |
| SIZE | 0.101*** | -0.078 | 0.100*** | 0.030 |
| | 4.610 | -0.110 | 4.520 | 1.280 |
| NEW | -0.132 | -0.133 | -0.154 | -0.082 |
| | -0.810 | -0.020 | -0.950 | -0.490 |
| HERFINDAHL | -0.001 | 0.057 | -0.001 | 0.001 |
| | -0.590 | 0.880 | -0.690 | 0.410 |
| CONSTANT | -0.905*** | -36.181*** | -1.010*** | -1.346*** |
| | -5.830 | -6.590 | -5.370 | -6.630 |
| Number of obs. | 2261 | 2261 | 3982 | 3982 |
| R2 | 8.87 | 2.88 | | |
| LR test | -1412.746 | -5434.501 | -2145.755 | -1978.921 |
| | (0.000) | (0.000) | (0.000) | (0.000) |

[1] ***p-value 0.01, ** p-value 0.05, *p-value 0.10. P-values in parentheses. See the definition of the variables in the text.

[2] We have conducted Heckman probits with a selection equation for positive innovation expenses. For the specification with NEWPROD we have used a dummy variable that takes the value of 1 if NEWPROD is greater than the mean of the sector to which the firm belongs.

## TABLE 4
## Sectors with high appropriability

| | INNOV[1] | NEWPROD[1] | INNOV[2] | NEWPROD[2] |
|---|---|---|---|---|
| R&D SKILLS | -0.066 | 0.463 | -0.042 | 0.049 |
| | -0.720 | 0.160 | -0.440 | 0.500 |
| INTERNAL R&D | 0.037*** | 2.059*** | 0.043*** | 0.046*** |
| | 5.820 | 9.160 | 4.950 | 4.620 |
| TRAINING | 0.039 | -0.308 | 0.054 | -0.034 |
| | 0.650 | -0.150 | 0.880 | -0.520 |
| NUMPATENT | -0.001 | 0.030 | -0.001 | 0.000 |
| | -0.500 | 0.820 | -0.600 | -0.200 |
| STRATEGIC PROTECTION | 0.360*** | 10.649*** | 0.372*** | 0.333*** |
| | 3.800 | 3.700 | 3.900 | 3.570 |
| COST | -0.088 | -4.252 | -0.078 | -0.067 |
| | -0.930 | -1.340 | -0.800 | -0.660 |
| SPILLOVER | 0.420*** | 7.031 | 0.507*** | 0.058 |
| | 2.670 | 1.270 | 2.710 | 0.290 |
| HABSCAP*SPILLOVER | -0.014 | -10.320** | -0.084 | -0.118 |
| | -0.090 | -2.070 | -0.520 | -0.700 |
| HIGHABSCAP*SPILLOVER*APPROPRIABILTY | 0.557*** | 25.118*** | 0.564*** | 0.562*** |
| | 4.520 | 6.440 | 4.530 | 4.520 |
| SIZE | 0.105*** | 0.337 | 0.105*** | 0.039* |
| | 4.790 | 0.480 | 4.720 | 1.670 |
| NEW | -0.114 | 1.521 | -0.141 | -0.050 |
| | -0.700 | 0.280 | -0.880 | -0.300 |
| HERFINDAHL | 0.000 | 0.101 | 0.000 | 0.002 |
| | -0.150 | 1.570 | -0.260 | 0.920 |
| CONSTANT | -0.959*** | -39.407*** | -1.065*** | -1.425*** |
| | -6.160 | -7.210 | -5.680 | -6.980 |
| Number of obs. | 2265 | 2265 | 3986 | 3986 |
| R2 | 9.37 | 3.23 | | |
| F test | -1407.477 (0.000) | -5421.022 (0.000) | -2140.199 (0.000) | -1970.629 (0.000) |

[1] ***p-value  0.01, ** p-value 0.05, *p-value  0.10. P-values in parentheses. See the definition of the variables in the text.

[2] We have conducted Heckman probits with a selection equation for positive innovation expenses. For the specification with NEWPROD we have used a dummy variable that takes the value of 1 if NEWPROD is greater than the mean of the sector to which the firm belongs.

Table 3 and 4 suggest that absorptive capacity is a more important source of competitive advantage in those sectors characterized by higher degrees of knowledge turbulence and stricter enforcement of IPRs, respectively. Indeed, we observe a positive and significant coefficient for the variable ABSCAP*SPILLOVER*TURBULENT, which is meant to capture the distinguished effect of absorptive capacity in those sectors that are defined turbulent (TURBULENT=1). Similarly, the coefficient of ABSCAP*SPILLOVER*APPROPRIABILITY is positive and significant, implying that absorptive capacity plays a more crucial role in those sectors that enjoy a stricter enforcement of IPRs. These results are confirmed once we control for possible problems created by the sample selection (last two columns of Tables 3 and 4).

## **4**/ Conclusions

Cohen and Levinthal (1989) have opened up a rich research path by defining the concept of absorptive capacity and describing its importance for understanding firms' performance in innovation. However, they have also pointed out that absorptive capacity and innovation ability are so intertwined that it is very difficult to estimate separately their impact on innovation performance. In this paper we do so by arguing that absorptive capacity mediates the impact of knowledge spillovers of innovation performance. Firms endowed with more absorptive capacity are better equipped at identifying the presence of knowledge spillovers and exploiting them efficiently.

Our results suggest that absorptive capacity is indeed a source of competitive advantage. In other words, this paper shows that it pays dividends, in terms of innovative performance, for firms to invest in enhancing their absorptive capacity. Moreover, we have found that absorptive capacity is even more critical in turbulent knowledge sectors and sectors with stricter enforcement of IPRs. In the knowledge-based economy, where large part of the relevant knowledge comes from outside the firm's boundaries, this is a particularly important message for practitioners.

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