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Absorptive Capacity – One Size Fits All?

A Firm-level Analysis of Absorptive Capacity for Different Kinds of Knowledge

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Non-technical summary

Since Cohen and Levinthal (1989;1990) published their seminal work on "absorptive capacity", i.e. a firm's ability to "identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1989; p. 569), a lot of empirical and theoretical work has been devoted to analyzing the absorptive capacity of firms. However, the lack of a direct empirical measure of absorptive capacity has not only caused some problems with the comparability of research results, but has also led to little research "on the process by which absorptive capacity is developed" (Lane et al., 2002; p. 5).

In this paper we try to fill the gap by empirically analyzing the determinants of absorptive capacity of innovative firms. To be more precise, we empirically analyse the effect of R&D activities, human resource and knowledge management, and the organisation of knowledge sharing within a firm on the absorptive capacity of innovative firms for three different types of knowledge. These three types of knowledge are knowledge from a firm's own industry, knowledge from other industries, and knowledge from research institutions.

Using data from the German innovation survey of 2003 we show that the determinants of absorptive capacity differ significantly with respect to the type of knowledge absorbed for innovation activities. In particular we find that the R&D intensity does not significantly influence absorptive capacity for intra- and inter-industry knowledge. However, it does have a positive impact on the exploitation of knowledge generated by public research institutions. In addition, we show that these differences also exist with respect to other determinants of absorptive capacity, in particular the share of high-skilled employees. Our findings complement studies by Gradwell (2003) and Mangematin and Nesta (1999), which suggest that differences in absorptive capacity for tacit and codified knowledge exist at the firm-level. Other findings are that absorptive capacity for all three types of knowledge is path-dependent and firms can influence their ability to exploit external knowledge by encouraging individuals' involvement in innovation projects and knowledge sharing.

Because the differences between the factors influencing absorptive capacity for intra-industry, inter-industry, and scientific knowledge were so pronounced we suggest taking them into account in future studies dealing with absorptive capacity. This should be done by choosing the proxies for absorptive capacity used in the analysis on the basis of the type of knowledge relevant for the study.

Absorptive Capacity- One size fits all?

A Firm-level analysis of absorptive capacity for different kinds of knowledge.

Tobias Schmidt[1]

The paper empirically analyses the effect of R&D activities, human resource and knowledge management, and the organisation of knowledge sharing within a firm on the absorptive capacity of innovative firms for three different types of knowledge, namely absorptive capacity to use knowledge from a firm's own industry, knowledge from other industries and knowledge from research institutions. Using data from the German innovation survey we investigate how firms are able to exploit knowledge from external partners for successful innovation activities. The estimation results show that the determinants of absorptive capacity differ with respect to the type of knowledge absorbed for innovation activities. In particular we find that the R&D intensity does not significantly influence absorptive capacity for intra- and inter-industry knowledge. Additionally, our results suggest that absorptive capacity is path-dependent and firms can influence their ability to exploit external knowledge by encouraging individuals' involvement in a firm's innovation projects.

Keywords: absorptive capacity, R&D, innovation management, innovation survey

JEL: O30, L20, D83

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1 Introduction

Since Cohen and Levinthal (1989;1990) published their seminal work on "absorptive capacity", a lot of empirical and theoretical work has been devoted to analyzing the absorptive capacity of firms. However, the use of the concept of absorptive capacity has not been limited to the firm level, it ranges from the level of the individual to that of entire nations (see Van Den Bosch et al., 2003; Narula, 2004). These levels are intertwined, as a nation's absorptive capacity depends on that of the its organizations and the absorptive capacity of an organization depends on that of its individuals (Cohen and Levinthal, 1990). The absorptive capacity concept has proven to be flexible enough to be used not only for different units of analysis but also in many fields of research, e.g. industrial organization, strategic management, international business and technology management (see Zahra and George, 2002, for an overview). Despite this wide application of the concept and various modifications of its specific features[1], absorptive capacity has been used in most cases as a firm's ability to "identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1989; p. 569).

The empirical operationalization of the concept has not been that focused, though, mainly because it is hard to construct good measures of absorptive capacity from the available information.[2] One reason for this is the lack of a paper trail for the acquisition of external knowledge which could be tracked and used by researchers. A solution to this problem is the use of surveys. Surveys can and have been used for research on absorptive capacity at the firm level. Even with surveys, however, researchers are not able to measure absorptive capacity directly because it is - despite its relatively simple definition - a fuzzy concept; practically no one can give a straightforward indication of his or her level of absorptive capacity. Using surveys thus requires developing an empirical concept of absorptive capacity. Popular proxies that have been used to capture absorptive capacity in recent empirical studies on the innovation and cooperation behavior of firms include R&D budgets, -stocks, and -intensities (Belderbos et al., 2004; Cassiman and Veugelers, 2002; Oltra and Flor, 2003; Stock et al., 2001), following up on the arguments presented by Cohen and Levinthal (1989). Other proxies and measures (primarily used by researchers from the field of business administration) include organizational structure and practices, like incentive systems and human resource and knowledge management, (Lenox and King, 2004; Van Den Bosch et al., 1999; Vinding, 2000) and "production line performance in

1 Zahra and George (2002), for example, cite Mowery and Oxley (1995), who define absorptive capacity as a set of skills needed to deal with tacit knowledge.

2 Among others, Becker and Peters (2000; p.11) state: "The empirical measurement of absorptive capacities of firms is difficult."

terms of labour productivity and conformance quality" (Mukherjee et al., 2000; p. 157).

The lack of a direct empirical measure of absorptive capacity has not only caused some problems with the comparability of research results[3]; it has also led to little research "on the process by which absorptive capacity is developed" (Lane et al., 2002; p. 5). This research shortage on the determinants of absorptive capacity was stressed not only by Lane et al. (2002), who reviewed about 180 papers citing Cohen and Levinthal (1998,1990), but also by Veugelers (1997). She writes that "More work is needed to identify specific firm characteristics generating this absorptive capacity" (p.314). Mahnke et al. (2005) also state that there is a lack of empirical literature on how a firm can increase its absorptive capacity.

In this paper we try to fill the gap by empirically analyzing the determinants of absorptive capacity of innovative firms. In order to be able to construct a more direct measure of absorptive capacity than previous studies, we propose a focus on the results of absorptive capacity instead of on the inputs that are assumed to build absorptive capacity. Using data from the German innovation survey ("Mannheim Innovation Panel"), we are able to assess whether firms' innovations incorporate or are based on knowledge obtained from external partners. We argue that firms that introduce innovations, which are based on external knowledge, necessarily have the ability to exploit knowledge from external sources, thus evincing absorptive capacities. We are therefore able to investigate this component directly and separately from the other two components of absorptive capacity (identification and assimilation of knowledge)[4]. However, a firm which is able to exploit external knowledge usually also has the ability to identify and assimilate it.

The paper also contributes to the existing literature by including measures for the existence of human resource and knowledge management and the organization of knowledge sharing within a firm. We also analyze the differences among these and other measures with respect to exploiting knowledge from within a firm's industry, knowledge outside its industry and knowledge generated by research institutes.

The following section will give a more detailed review of the literature on the determinants of absorptive capacity. In section three we will outline the data and empirical setup used before presenting the results in section four. The paper ends with a discussion of the findings and suggestions for future research.

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3 Zahra and George (2002; p. 186) highlight this problem by writing: " … it is unclear if these measures [of absorptive capacity] converge to capture similar attributes of the same construct, …"

4 Zahra and George (2002; p. 199) argue: "Substantial differences exist among these dimensions, which allow them to coexist and be measured and validated independently.", when talking about the three dimensions of absorptive capacity.

2 Absorptive Capacity in Related Literature

In this section we review relevant literature on absorptive capacity for our study.[5] We'll first take a closer look at the definitions of absorptive capacity, in particular with respect to the three components of absorptive capacity (identification, assimilation and exploitation). Afterwards we'll focus on the determinants of absorptive capacity found in the literature and then discuss some of the findings for the acquisition and exploitation of different kinds of knowledge. The whole review is restricted to the application of the absorptive capacity concept at the firm level.

2.1 The components of absorptive capacity

Absorptive capacity at the firm level is relatively simple to define. Essentially, it is a firm's ability to deal with external knowledge. According to the highly influential definition offered by Cohen and Levinthal (1989), it is firms' ability to "identify, assimilate and exploit knowledge from the environment" (p. 569). Other authors have used some modifications of the concept (see Zahra and George, 2002, for an overview) but have still retained the notion that absorptive capacity is not a one-dimensional concept, consisting rather of various skills and dimensions. Lane and Lubatkin (1998) use the three components proposed by Cohen and Levinthal (1990) for their study on the prerequisites of a firm's ability to learn from another. Van Den Bosch et al. (2003) also suggest defining absorptive capacity as having three components "the ability to recognize the value of external knowledge, assimilate it, and apply it to commercial ends." (p. 280).

There has been some discussion about whether there are more than the three components of absorptive capacity proposed by Cohen and Levinthal. For instance, Zahra and George (2002) expand the concept by introducing an additional component -- transformation of knowledge -- which is "a firm's capability to develop and refine the routines that facilitate combining existing knowledge and the newly acquired and assimilated knowledge" (p. 190). However, they do retain the other three components. This additional component is definitely worth considering for analysis, as it explicates an aspect of the process of knowledge usage that has been implicitly assumed by other authors. In order for external knowledge to be exploited effectively, it has to be transformed in order to be used by various actors within the enterprise. Then again, it can be argued that the transformation dimension need not be made explicit, as it is an integral part of the "exploitation" component.

5 More extensive reviews have been compiled by Daghfous (2004), Van Den Bosch et al. (2003), and Zahra and George (2002).

Moving away from the ability-based concept of Cohen and Levinthal, Van Den Bosch et al. (1999) analyze absorptive capacity along the dimensions of efficiency, scope and flexibility. This does not replace the ability-based definition but rather supplements it. Efficiency, for example, is defined as the costs and economies of scale associated with a certain level of identification, assimilation, and exploitation of external knowledge.

2.2 Determinants of absorptive capacity[6]

The application of the absorptive capacity concept in various fields and at various levels of analysis has led to the identification of a whole array of factors which are assumed to influence absorptive capacity. Most of these determinants come from theoretical considerations and empirical studies on the usage and management of knowledge in R&D or innovation processes. These factors can be assigned to the following three groups[7]:

a) R&D activities

Cohen and Levinthal, (1989) focus mainly on the role of R&D expenditures in building absorptive capacity and point to the dual role R&D plays in the innovation process of firms: building absorptive capacity and generating new knowledge and innovations. Many other scholars have thus used R&D-related measures and approaches to model absorptive capacity at the firm level.[8] Among them are:

- R&D expenditure: R&D intensity (R&D expenditure/total sales) (Stock et al., 2001; Rocha, 1999; Cantner and Pyka, 1998) and level of R&D investment (Leahy and Neary, 2004; Grünfeld, 2003)
- Continuous R&D activities (Oltra and Flor, 2003; Becker and Peters, 2000)
- Existence of an R&D lab (Becker and Peters, 2000; Veugelers, 1997)

6 Daghfous (2004) gives an overview on the determinants of the components of absorptive capacity.

7 There is a fourth group of determinants that will not be discussed in this paper. It includes networks and alliances with external partners and the knowledge environment in general. (see, for example, Caloghirou et al., 2004; Nonaka and Takeuchi, 1995; Lim, 2004). Our focus is on internal factors only.

8 Lane and Lubatkin (1998) offer one of the few studies that calls the use of measures of absorptive capacity based on R&D spending into question.

b) Related prior knowledge and individuals' skills

In their 1990 paper Cohen and Levinthal, expand the concept and argue that absorptive capacity is path-dependent because experience and prior knowledge facilitate the use of new knowledge. As a consequence, absorptive capacity is cumulative. This cumulative nature of absorptive capacity has not been taken into account by many empirical studies but has been extensively discussed in the literature on knowledge and spillovers[9], which are closely related to absorptive capacity.

The cumulative nature of knowledge may also be related to another determinant of absorptive capacity: employees' level of education. The more education and training an employee receives, the higher his or her individual ability to assimilate and use new knowledge will be. As firms' absorptive capacities depend on those of their employees, the general level of education, experience and training their employees have has a positive influence on firms' level of absorptive capacity. Rothwell and Dodgson (1991) found that (small) firms need well-educated technicians, engineers and technological specialists to access knowledge from outside their boundaries. Frenz et al. (2004) take this into account in their analysis by including the share of scientists and engineers in total employees as well as training expenditures in their model.

In this context the presence of so-called "gatekeepers" play an important role in determining absorptive capacity. Vinding (2000) submits that gatekeepers, whose role is to create a language which can be understood by different departments, improve a firm's absorptive capacity through knowledge sharing. Gradwell(2003) stresses that gatekeepers' intermediary role involves screening the environment for knowledge and transforming the relevant knowledge so it can be understood by other employees. Cohen and Levinthal (1990) also introduce two types of gatekeepers, acting either as a "boundary spanner" within the firm or as an interface between the firm and its environment.

c) Organizational structure and human resource management practices

A firm's absorptive capacity is not the simple sum of its employees' abilities as Cohen and Levinthal (1990) argue. According to them, it depends on the ability of an organization as a whole to stimulate and organize the transfer of knowledge across departments, functions, and individuals. This aspect of absorptive capacity has been incorporated into many studies: It has been shown that the absorptive capacity of a firm is determined by its expertise in stimulating and organizing knowledge sharing (Van Den Bosch et al., 1999) and the similarity of any two cooperating firms' systems for doing so (Lane and Lubatkin, 1998). Daghfous (2004) review yields that the organizational structure of a firm and cross-

9 Some of this literature is cited in Cohen and Levinthal (1990) and Daghfous (2004).

functional communication have been found to improve absorptive capacity if they lead to improved knowledge sharing among departments and individuals within a firm (see also Welsch et al., 2001; Van Den Bosch et al., 1999, 2003; Lane and Lubatkin, 1998). In addition, according to Daghfous (2004), organizational culture has a positive influence on the level of absorptive capacity if it provides incentives for knowledge diffusion through the empowerment of employees and managers. Gradwell (2003) points to the strong influence of close networks and relationships within firms in stimulating the transfer of tacit knowledge.

Closely related to organizational structure and knowledge sharing is human resource and knowledge management. To name a few examples, forming workgroups made up of actors from different departments, stimulating job rotation, managing proposals submitted by employees, and encouraging employees to read and monitor relevant literature and developments can certainly help facilitate the flow of knowledge (Mahnke et al., 2005; Jones and Craven, 2001; Cohen and Levinthal (1994). Human resource management can also help to stimulate learning through reward systems and training (Mahnke et al., 2005; Daghfous, 2004) These actions lead to higher individual absorptive capacities and, consequently, to a higher capacity of the organization as a whole. Williamson (1967) argues that information gets lost or at least distorted if it is transferred through different layers of hierarchy. Thus, direct contact among employees from different departments, units and the like should lead to a more efficient transfer of knowledge and a subsequently higher absorptive capacity.

The structure of an organization and the tools and incentives it employs to stimulate knowledge exchange and learning are usually determined by the management of the firm. However, its role in building absorptive capacity goes beyond setting the organizational structure and culture. Lenox and King (2004) show, for example, that managers need to take part in the sharing and provision of knowledge to build absorptive capacity. This knowledge sharing can occur in the form of internal seminars or promotional brochures.

The determinants from all three groups have largely been treated as independent of each other. Nonetheless, it is feasible to assume that they are at least to some degree interrelated. Moreover, most of the determinants are complements rather than substitutes. As a firm’s ultimate goal is to put acquired knowledge to good use -- i.e. turn it into new and innovative products and processes -- it has to ensure that all three components of absorptive capacity are built up and not just a single one. To give an example: A firm employing gatekeepers, which bring relevant knowledge into the firm, but lacking a system to provide that knowledge to those who can apply it to commercial ends obviously has the ability to identify relevant knowledge but cannot exploit it. It would thus fall into the category of firms with absorptive capacities but would fail to realize any advantages from this. Hence, its aim should be to build all of the components of absorptive capacity instead of a single one and invest accordingly in more than just one of the determinants described above.

The review of the literature leads us to formulate the following hypothesis, which will be tested empirically:

H1: R&D activities are not the only building blocks of absorptive capacity. The organization and stimulation of knowledge transfer within a firm as well as the employment of qualified personnel play a critical role in determining the absorptive capacity of firms.

2.3 Absorptive capacity for different kinds of knowledge

The determinants of absorptive capacity discussed above focus on the firm at the receiving end of the knowledge exchange and how its structure and activities increase or decrease absorptive capacity. This is, however, only one side of the coin. Lane and Lubatkin (1998) make the case that a firm might not be able to learn equally from each external firm, arguing that certain characteristics of the "student-firm", i.e. the firm absorbing the knowledge, and of the "teacher-firm" -- the firm providing the knowledge to be transmitted -- have to be similar in order for the student-firm to be able to learn. According to these authors, the ability to learn from an external partner ("teacher") depends, among other things, on "the specific type of new knowledge offered by the teacher." (p. 462) Dussauge et al.(2000) as well as Cohen and Levinthal (1990) conclude that a firm is better able to acquire and use external knowledge from areas it has some prior experience or related knowledge in (path-dependency of absorptive capacity). Becker and Peters (2000) and Nelson and Wolff (1997) argue that firms need higher absorptive capacities for scientific knowledge than for other types of knowledge. Mangematin and Nesta (1999) confirm this result. They find that higher absorptive capacities increase the ability to use more fundamental (as opposed to applied) external knowledge and firms with higher absorptive capacity have more contacts with research institutes than firms with lower absorptive capacities.

All of these findings suggest that there are different absorptive capacities or varying levels of absorptive capacity required for different kinds of knowledge, one distinction being between science-based knowledge and knowledge from the private sector.

Our second hypothesis for the empirical part of the paper is thus:

H2: Different kinds of knowledge are associated with different absorptive capacities.

3 Data and Empirical Implementation

To test the hypotheses mentioned above, we use data from the German innovation survey, the Mannheim Innovation Panel (MIP). This annual survey is conducted by the Center for European Economic Research (ZEW) on behalf of the German Federal Ministry of Education and Research. The methodology and questionnaire of the survey, which is targeted at enterprises with at least five employees, are the same as those implemented in the Community Innovation Surveys (CIS). For our analysis we use the 2003 survey, in which data was collected on the innovation behaviour of enterprises during the three-year period 2000-2002. About 4,500 firms in manufacturing and services responded to the survey by providing information on their innovation activities.[10] Almost 2,000 enterprises indicated that they had introduced at least one product or process innovation in the reference period. We restrict our analysis to firms which introduced innovations between 2000 and 2002 because most of the questions we use to construct our variables are only available for innovating firms, in particular the questions used to construct the dependent variables.

The 2003 MIP questionnaire provides us with data with which we can analyze the factors influencing the absorptive capacities of firms. Since absorptive capacity cannot be measured by a single indicator, we construct our measure using questions regarding impulses from external actors[11] used by firms to develop innovative products and processes.[12] We argue that successfully using such external sources of innovation is a rather direct measure of the exploitation component of absorptive capacity. A firm which is able to pick up impulses from external parties and turn them into innovations is certainly able to exploit external knowledge; it thus possesses absorptive capacities as well.

The firms were also asked to indicate which industries the suppliers and customers, providing these innovative impulses represented during the reference period. We use this information to construct different measures of absorptive capacity for intra- and inter-industry knowledge. To test the hypothesis that knowledge stemming from research institutions and universities requires specific absorptive capacities, we also included a measure of exploitive absorptive capacities[13] for knowledge from research institutes and universities used for developing product and/or process innovations.

10 For a more detailed description of the MIP survey see Janz et al. (2001).

11 Separate questions regarding impulses from customers, competitors, research institutes and universities and suppliers were asked.

12 The questions were phrased as follows: “Were any of the innovations introduced by your enterprise during the three-year period 2000-2002 triggered by new research results?”; “Were any of the innovations introduced by your enterprise during the three-year period 2000-2002 triggered by competitors’ innovations?” , etc.

13 The term “exploitive absorptive capacity” refers to the ability of firms to exploit external knowledge for their innovation activities.

The dependent dummy variables were constructed in the following way:

- *Absorptive capacity (Absorp)*
  One, if one of the absorptive capacities below equals one.
- *Absorptive capacity for intra-industry knowledge (Absorp_intra)*
  One, if at least one of the firm's innovations (in the period 2000-2002) has been developed and successfully implemented because of impulses from customers, suppliers or competitors from the firm's industry (NACE 2).
- *Absorptive capacity for inter-industry knowledge (Absorp_inter)*
  One, if at least one of the firm's innovations (in the period 2000-2002) has been developed and successfully implemented because of impulses from customers or suppliers from industries other than its own (NACE 2).
- *Absorptive capacity for scientific knowledge (Absorp_science)*[14]
  One, if at least one of the firm's innovations (in the period 2000-2002) has been developed and successfully implemented because of impulses from universities or other public research institutes.

The literature review yielded three main groups of determinants for absorptive capacity. In order to analyze their influence on our dependent variables we included the following independent variables in our model:[15]

- *R&D activities*
  We measure the R&D activities of firms along two dimensions: the continuity (continuous vs. occasional) of their R&D engagements and their R&D spending as a share of total turnover. With the first measure (R&Dcon) we try to capture the path dependence of absorptive capacity, as firms which are continuously involved in R&D activities should have developed skills and experience in their specific fields of research. For firms which engage in R&D only occasionally the amount of related prior knowledge can be assumed to be limited or at least less than that of firms performing R&D continuously. We thus expect that firms with continuous R&D are more likely to have absorptive capacities than other firms.
  R&D intensity (R&D_int), measured as share of R&D expenditure in total turnover, is to a large degree a measure of the scope of a firm's R&D commitment. We assume the absorptive capacity of firms to be higher the more they spend on R&D in a given year. We also include R&D intensity as a squared term (R&D_int2). This variable is included because we think that a firm which approaches the technological frontier, thereby researching at the forefront of its field, is no longer able to learn substantially from external parties. Hence, a larger part of R&D spending is targeted at knowledge generation rather than to improving absorptive capacity. In essence, we think

14 We use the term "scientific absorptive capacity" for this concept in the remainder of the paper.
15 Exact definitions of the variables can be found in Table 3 in the appendix.

that R&D intensity does not necessarily influence absorptive capacity linearly, but might rather exhibit a non-linear effect such that firms with very high R&D intensities are less dependent on external impulses with respect to their innovation activities.

- *Related prior knowledge and individuals' skills*
  The existence of related prior knowledge within firms is hard to operationalize with the data we have at hand, as we can not determine in which specific field each firm does its research and possesses previously accumulated skills and experience. This determinant will thus only be represented by the aforementioned variable for continuous R&D (R&Dcon).
  Employee skill level can be fairly easily measured by the amount of employees with higher education degrees as a share of total employees (grads).

- *Organizational structure and human resource management practices*
  The literature provides evidence that the organization of knowledge transfer inside a firm has a positive influence on absorptive capacity. In order to be able to test our first hypothesis we included several indicators of the way knowledge exchange is organized within a firm. These can be divided into two groups: measures intended to stimulate innovation activities and individuals' involvement in knowledge sharing, and collaboration between different departments. Both groups can be seen as determinants of absorptive capacity. While the former provides information on a firm's willingness and efforts to increase knowledge transfer and exploitation (incentives), the latter is a better measure of the actual knowledge transfer occurring between departments (organization); from our point of view, this is the more important determinant of absorptive capacity. We thus include a single indicator of the importance of measures meant to stimulate the involvement of individuals in knowledge sharing (stim_index)[16] and seven variables focusing on different means of collaboration between departments. Two different aspects of collaboration will be investigated: hierarchical and sporadic information provision (mostly involving managers) as well as broad information provision (involving all employees). The former comprises joint development of innovation strategies (col_jointstrat), regular meetings of department heads to discuss innovation-related topics (col_heads), seminars and workshops for innovation projects involving several departments (col_seminar), mutual support of other departments with innovation-related problems (col_mutsup) and temporary exchange of personnel between de-

16 This index is the result of a principal components factor analysis of the importance of nine different methods of stimulating innovation and knowledge transfer. See Table 1 in the appendix for a full list of the methods considered. The methods could not be included separately in the estimation since they were highly correlated with each other and with some of collaboration variables. The results of the factor analysis are presented in the annex.

partments for innovation projects (col_exchange). The latter is represented by informal contact among employees (col_infor), open communication of ideas and concepts between departments (col_opencom).

- *Control variables*

  We also include a number of control variables, most importantly two measures of size: number of employees (ln_emp) and number of employees, squared (ln_emp2). These two variables are meant to capture differences in absorptive capacity among small and large firms. Small firms might not have the same means and opportunities to exploit external knowledge, simply because they cannot risk betting on the wrong horse. Larger firms, on the other hand, often have multiple innovation projects running at the same time and can thus potentially exploit external knowledge better.

  An additional dummy variable is included indicating whether a firm is situated in Eastern Germany (east), as Eastern German firms' innovation behavior still differs significantly from that of Western German firms.[17] It is thus reasonable to assume that absorptive capacity also differs between the two regions.

  To control for industry influences that are not picked up by other variables in the model, we include six industry group dummies[18], with "other manufacturing" being the reference group.

The construction of the dependent variables has two noteworthy implications for the empirical set-up: First, we are not able to observe the level of absorptive capacity directly, but rather only the existence of absorptive capacity. We argue that we will nonetheless be able to at least get a proxy for the level of absorptive capacity by estimating a probit model. We further hold that firms more likely to have exploitive absorptive capacities actually do evince higher levels of absorptive capacity. The second implication is that we have to consider the interdependence among the three measures of absorptive capacity for the different types of knowledge. Since we are allowing firms to have more than one type of absorptive capacity, we have to assume that their possession of one has an influence on the others. What is more, it is reasonable to assume that the determinants of absorptive capacity -- R&D expenditure, for example -- contribute to the accumulation of absorptive capacity for knowledge from universities and businesses alike. This is especially true if the usage and exploitation of different kinds of external knowledge requires the same or very similar competencies and experience. In order to take this interdependence into account in our model, we estimate a trivariate probit model, i.e. a simultaneous system of three equations, instead of

17 See, for example, Rammer et al. (2004) ; Sofka and Schmidt (2004)

18 See Table 2 in the appendix for details.

three separate probits.[19] This will allow us to increase the validity of our estimates.

The full empirical set-up then looks like this:

We first estimate a probit model for absorptive capacity in general:

$$Absorp* = b^{'}X + u \text{ with } Absorp_i = \begin{cases} 1 & if\ Absorp_i * > 0 \\ 0 & otherwise \end{cases}$$

where X is the column vector representing the independent variables outlined above.

In the next step we estimate the following trivariate probit model for the three different types of absorptive capacity:

$$Absorp\_inter^{*} = b_1^{'}X + e_1 \quad \text{with} \quad Absorp\_inter_i = \begin{cases} 1 & if\ Absorp\_inter_i^{*} > 0 \\ 0 & otherwise \end{cases}$$

$$Absorp\_intra^{*} = b_2^{'}X + e_2 \quad \text{with} \quad Absorp\_intra_i = \begin{cases} 1 & if\ Absorp\_intra_i^{*} > 0 \\ 0 & otherwise \end{cases}$$

$$Absorp\_science^{*} = b_3^{'}X + e_3 \quad \text{with} \quad Absorp\_science_i = \begin{cases} 1 & if\ Absorp\_science_i^{*} > 0 \\ 0 & otherwise \end{cases}$$

where the pair-wise correlation of the error terms is not equal to zero:

$$Cov(e_1, e_2) = r_1 \ ; Cov(e_1, e_3) = r_2 ; \ Cov(e_2, e_3) = r_3$$

This model can be solved by employing a maximum-likelihood procedure. To evaluate the likelihood of a certain outcome, the probability of an observation has to be calculated using a trivariate normal probability density function which takes into account $e_1, e_2, e_3, r_1, r_2, and\ r_3$. This poses some problems: It has been shown that standard numerical calculation techniques cannot be used if the normal density function is of an order higher than two.[20] A way to solve this problem involves using simulation techniques. One, which is now implemented in many statistical packages, is the so-called "GHK-Simulator (Geweke-Hajivassiliou-Keane-Simulator)" for multivariate normal distributions[21]. For our model estima-

19 See Greene (2002) on "multivariate probit models".

20 See Glasgow (2001) for a discussion of the topic.

21 Other simulators could also be used. Hajivassiliou et al. (1996) review eleven simulators and find that the GHK is the most reliable method for multivariate normal distributions.

tion we use a procedure developed by Antoine Terracol for the STATA statistical software package (triprobit), which relies on the GHK simulation procedure.[22]

For the model estimation we were able to use 1,650 which indicated that they had carried out innovation activities during the three-year period 2000-2002.

Of the 1,650 observations, 1,177 (71%) have at least one type of absorptive capacity. 575 have at least intra-industry, 956 at least inter-industry and 248 at least scientific absorptive capacity.[23] For those firms that only show one type of absorptive capacity we find a similar distribution. Just 47 firms, or 2.7% of the enterprises in our sample, have only scientific absorptive capacity, while 156 and 463 have only intra-industry and inter-industry absorptive capacities, respectively. 91 of the firms have all three types. The fairly large number of firms having more than one type of absorptive capacity (43% of all firms with absorptive capacity) provides further evidence that the manners in which the three types of absorptive capacity are accumulated are somewhat related and a trivariate probit estimation procedure should be used.

As far as the independent variables are concerned, we find only very few differences between the sample mean and the mean of firms with absorptive capacities. Notable exceptions are the share of employees with higher education, which is about two percentage points higher for firms with absorptive capacity, and the R&D intensity, which is one percentage point higher for the latter group. Additionally, the share of firms with continuous R&D is six percentage points higher for firms with absorptive capacity. The index for stimulating knowledge exchange and innovation activities is also significantly higher for firms with absorptive capacity, but only by two percentage points.

Within the group of firms with at least one type of absorptive capacity, the same variables make a difference between those with scientific absorptive capacity and the other two types. Here, the differences are more pronounced. Firms with scientific absorptive capacity have an average share of employees with higher education of 42% and an R&D intensity of 14.8%. For the mean firm with intra-industry absorptive capacity the numbers read 28% and 7.7%, and for the average firm with inter-industry absorptive capacity they are 30% and 8.7%.

22 The method is known to be sensitive to the number of observations draw in each iteration. We thus tested several different settings. The results only changed as far as the size of the coefficients is concerned, the significance levels and qualitative results stayed the same. The model presented below uses 220 draws instead of the default number of draws which is 25.

23 Additional descriptive statistics can be found in the appendix.

4 Results

The results of our estimation are presented in Table 1. Let us first turn to the standard probit estimation of firms' absorptive capacities (equation 1).

A first striking result is that continuous R&D is significant and positive, while R&D intensity, which is widely used in the related literature as a proxy for absorptive capacity, is not. This indicates that continuous R&D engagement (and not necessarily the level of R&D expenditure) is relevant to absorptive capacity. A firm's current[24] expenditure on R&D is usually not primarily targeted at building absorptive capacity but rather at accumulating new knowledge and developing new products and processes, which might explain our findings. Our results suggest that a firm's current R&D expenditure does not make an ad hoc contribution to the assembly of absorptive capacity; instead, it helps to develop the skills and knowledge necessary to source external knowledge over time. In this sense, absorptive capacity is cumulative. We will argue below that current R&D expenditure can also immediately contribute to exploitive absorptive capacities, but only for specific types of knowledge.

Another explanation for the insignificance of the R&D intensity variables is that firms with higher R&D intensities have a lower demand for external knowledge than firms with lower R&D intensities. The more R&D is done in-house, the more knowledge is generated internally and the less external knowledge is required. It is also quite likely that firms with large in-house knowledge pools would generate more impulses and ideas from within and use less external impulses and ideas for their innovations. In that case firms would have the capacity and capability to use external knowledge in their innovation processes, but simply don't need to do it.[25] If this negative effect on demand for external ideas and knowledge dominates the effect of R&D on absorptive capacity, the R&D intensity would still have a positive effect on absorptive capacity, but it wouldn't show in our estimations.

24 In order to reduce a possible endogeneity bias, we use R&D intensity in the year 2001 instead of that of 2002.

25 They might also not want to do it, if the sourcing of external knowledge is connected with certain costs.

Table 1: Coefficients of Probit and Trivariate Probit Estimation

Variable	Absorptive Capacity (1)	*Intra*-industry Absorp. Cap. (2)	*Inter*-industry Absorp. Cap. (3)	Scientific Absorp. Cap. (4)
R&D activities:				
R&D_int	0.004	-0.002	0.007*	0.014***
	(0.004)	(0.004)	(0.004)	(0.004)
R&D_int2	-0.00001	0.000005	-0.000028*	-0.00005***
	(0.00001)	(0.000014)	(0.000014)	(0.00002)
R&Dcon	0.306***	0.127*	0.222***	0.451***
	(0.078)	(0.076)	(0.073)	(0.089)
Skills/Size:				
grads	0.003**	0.001	0.002	0.010***
	(0.002)	(0.002)	(0.002)	(0.002)
ln_emp	-0.199**	-0.134*	-0.079	-0.099
	(0.090)	(0.079)	(0.076)	(0.087)
ln_emp2	0.023***	0.021***	0.010	0.012
	(0.008)	(0.007)	(0.007)	(0.007)
Collaboration/* Stimulation*:				
col_infor	0.159**	0.218***	0.113	0.096
	(0.076)	(0.072)	(0.144)	(0.088)
col_opencom	0.030	0.102	-0.074	-0.238**
	(0.086)	(0.081)	(0.078)	(0.098)
col_jointstrat	-0.105	-0.138*	-0.022	-0.050
	(0.085)	(0.080)	(0.080)	(0.100)
col_mutsup	0.090	-0.180**	0.122	-0.089
	(0.084)	(0.079)	(0.077)	(0.096)
col_heads	-0.010	0.031	-0.032	-0.123
	(0.080)	(0.076)	(0.075)	(0.096)
col_exchange	-0.275*	-0.092	-0.127	0.117
	(0.150)	(0.147)	(0.140)	(0.160)
col_seminar	-0.009	-0.341***	0.013	0.243**
	(0.116)	(0.110)	(0.105)	(0.220)
stim_index	0.683***	0.293*	0.602***	0.798**
	(0.173)	(0.170)	(0.166)	(0.205)
Observations	1,650		1,650	
X^2	132.73		347.89	
Ald.-Nelson Pseudo R^2	0.137		0.231	
Rho		(2,3): 0.27 ***	(3,4): 0.19***	(2,4): 0.11**

significant at 10%; ** significant at 5%; *** significant at 1%; Robust SEs in parentheses

To investigate whether our results are driven by the choice of measure of R&D intensity, we estimate several additional model specifications. The results, which are reported in column 1 of Table 2, show that, regardless of the measure used for R&D intensity and the inclusion or exclusion of one of the two R&D-related variables, the coefficients of R&D intensity remain insignificant and continuous R&D remains highly significant, providing further evidence that current R&D intensity does not immediately determine the ability of firms to exploit external knowledge.[26]

Table 2: Coefficients of Five Different Probit and Trivariate Probit Estimations[27]

Variable	**Absorptive Capacity**	***Intra*-industry Absorp. Capacity**	***Inter*-industry Absorp. Capacity**	**Scientific Absorp. Cap.**
		Model 1: R&Dcon + R&D_int		
R&D_int	0.004	-0.002	0.007*	0.014***
R&D_int2	-0.00001	0.000005	-0.00003*	-0.00005***
R&Dcon	0.306***	0.127*	0.222***	0.451***
		Model 2: R&Dcon + R&D_int_empl		
R&D_int_empl	0.130	0.211	0.629	1.343**
R&D_int_empl2	-0.167	-0.862	-0.625	-0.708
R&Dcon	0.318***	0.135*	0.255***	0.504***
		Model 3: R&Dcon		
R&Dcon	0.320***	0.121	0.245***	0.504***
		Model 4: R&D_int		
R&D_int	0.007	-0.001	0.009**	0.017***
R&D_int2	-0.00002	0.00001	-0.00003**	-0.0001***
		Model 5: R&D_int_empl		
R&D_int_empl	-0.229	0.085	0.378	0.950
R&D_int_empl2	0.680	-0.682	-0.276	-0.153

A large body of literature has pointed to the positive influence of collaboration and stimulation of knowledge sharing on absorptive capacity, as described in chapter 2. Our results don't totally contradict these findings but raise some doubts about their importance in exploiting external knowledge. Like other studies we find that collaboration between departments has an impact on absorptive capacity, lending support to our first hypothesis. However, only informal contacts have a positive and significant effect on absorptive capacity. The variables representing hierarchical information provision are not or only very marginally sig-

26 We also tested the joint significance of the two R&D intensity variables, but were always able to reject the joined H_0 that both are equal to zero.

27 The models all include the full set of independent variables not related to R&D as well as the variables shown. The full estimation results are available upon request.

nificant. This suggests that it is more important to create a culture and organization that leads to informal knowledge transfer rather than a culture in which information provision is more centralized. One reason for this might be that the diffusion of new knowledge is faster and less prone to distortions through informal networks compared to formal systems (see Williamson, 1967). The insignificance of the other variables is puzzling still, as one would expect that every knowledge exchange regardless of the method used is helping firms to exploit external knowledge.

The measure for methods that try to stimulate employee participation in innovation activities is positively associated with absorptive capacity. This suggests that it is not only necessary increase the knowledge flows between actors inside the firm (mainly through informal contacts), but also to leverage the knowledge of each individual in the innovation process. Almost all the stimulation methods included in the factor analysis are aimed at the involvement of the employees and mangers in the innovation process. These findings confirm, that a firm's absorptive capacity is related to that of its employees.

Further evidence for this result is provided by the importance of higher education for exploitive absorptive capacity .As expected, the share of employees with higher education positively influences the ability of firms to exploit externally available knowledge. This is also true for continuous R&D activities, which we use as an indicator of related prior knowledge. We confirm other studies' findings that both indicators influence firms' absorptive capacities. Our interpretation is that both the related prior knowledge of individuals -- gained through education -- and that of firms, which they have developed through steady R&D investment, positively influences the ability to exploit external knowledge. The positive influence might have something to do with the fact that this related prior knowledge is also necessary to identify and assimilate external knowledge.

We find a significant U-shaped effect of the number of employees on the likelihood that firms have exploitive absorptive capacity. This is surprising, as one would expect the number of employees to always have a positive effect on firms' absorptive capacities: Individuals' absorptive capacity is, after all, part of the firms. Because the U in question (turning point: 75 employees) is very flat, this finding should not be over-interpreted, however. One explanation for the U-shaped relationship might be that very small firms depend more on external knowledge than medium-sized ones. After the turning point of 75 employees is reached, the expected size effect sets in, i.e. every additional employee increases the ability of firms to exploit external knowledge. The demand effect suggested by the insignificance of the R&D intensity (see above), might also be able to explain the U-shaped relationship between the number of employees and absorptive capacity. Very small firms need external knowledge to further exploit their (only) inventions and innovations or to get new ideas for applications of their existing knowledge. After they have reached a certain size (and gained some experience in the market), they are more likely to focus on the exploitation and commercialization of their innovations and internal knowledge, rather than look for new ideas outside their boundaries. This seems to lower the demand for external knowledge by medium size enterprises. If their internal "potential" has been exploited they have to use more external knowledge to grow further.

In essence, we find support for our hypothesis that not only R&D is relevant for the ability to exploit external knowledge. Besides R&D, highly skilled labor as well as knowledge management tools that stimulate the involvement of employees in innovation projects seem to be important. However, only informal contacts, and not as hypothesized almost all collaboration methods, influence the ability to exploit external knowledge positively.

Our results provide evidence supporting our second hypothesis, as we can clearly show that the ability to exploit different types of external knowledge is influenced differently by the factors considered.[28] Most pronounced is the difference between the exploitation of scientific knowledge and knowledge from the business sector. They particularly differ with respect to R&D variables. As mentioned above, there are differences between the effects of R&D intensity on the three different types of absorptive capacity. For scientific knowledge we find a highly significant effect of current R&D intensity; no such effect is evident for the other two types of knowledge. Firms that spend a large amount of turnover on research are usually in greater need of external knowledge and are thus more likely to exploit that knowledge. Additionally, as the share increases they become more and more similar to public research institutes and universities. The more similar firms are, the better they can learn from each other, as Lane and Lubatkin(1998) argue. Their ability to exploit knowledge learned from similar partners also increases, as our results suggest. This similarity argument cannot be made for the other two types of actors providing knowledge, which might explain why we do not find significant signs for intra-industry absorptive capacity and only marginally significant signs for inter-industry absorptive capacity. In the long run, however, R&D seems to be relevant for inter-industry knowledge as well, as the positive effect of continuous R&D suggests. For intra-industry knowledge this variable is also significant, but only slightly.

We again tested the robustness of our model by including different measures of R&D intensity in the estimations. The results remain quite similar to our original model. For scientific absorptive capacity the only more pronounced change we found is the significance of the squared R&D intensity when using the share of R&D employees instead of the share of R&D expenditure. This can be explained by the values the two variables can take. While the R&D intensity based on ex-

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28 Note that the test for the interdependence of the three equations in the trivariate probit shows that the equations are, in fact, not independent, as all Rhos are positive and significant at least at the 95% confidence level.

penditure is not constrained to the interval [0;1][29], that which is based on employees is. If we drop firms with R&D_int greater than one, we get the same result as for R&D_int_empl. For intra-industry absorptive capacity the results differ more than for the other two types. The prominent role of continuous R&D can at least be confirmed in all models.

The results for the three types of absorptive capacity differ not only with respect to R&D-related variables; we also find differences with respect to the extent of collaboration among departments. These factors are only significant for intra-industry and scientific absorptive capacity. This is surprising, as one would expect the exploitation of inter-industry knowledge to also be influenced by collaboration among departments. We argue that the exploitation of inter-industry knowledge for innovations might require less collaboration because a large amount of that knowledge is embodied in products from suppliers and each employee can take the knowledge needed for his or her innovation activities directly from the product. The insignificance and negative significance of some collaboration variables in the equations for intra-industry and scientific knowledge point to the fact that collaboration among departments, as beneficial as it might be for certain enterprise activities, does not necessarily contribute to exploitive absorptive capacity. On the contrary, a firm has to choose how it organizes collaboration with respect to the knowledge it wants to absorb and balance the need to exploit external knowledge with its other needs and goals.

Intra-industry absorptive capacity, for example, is negatively influenced by mutual support among departments. The latter reduces the probability of intra-industry knowledge being successfully exploited in innovations, suggesting that this method does not fit the type of knowledge to be exploited. Mutual support with innovation-related problems is likely to be associated with significant difficulties if different departments are configured distinctly or use procedures not known to others outside of the department, leading to an increase in costs and necessary efforts without leveraging the exploitation of external knowledge. Seminars involving actors from different departments and the development of joint innovation strategies also influence the likelihood that a firm exploits intra-industry knowledge negatively. The method best suited to exploiting intra-industry knowledge is to generate informal contact among employees. This suggests that it is especially beneficial to spread knowledge throughout the whole firm rather than distribute it through formal and more targeted mechanisms. One reason for this might be that knowledge from a firm's own industry can easily be understood by everyone within the firm. Broad dissemination should thus increase the potential use of information for innovation activities. For scientific knowledge the opposite is true: It cannot be easily understood and processed by

29 Note that some firms in our sample out-spend their turnover in financing R&D. They are all from NACE 73, "Research and Development". For firms in that field it is not unusual to have R&D intensity greater than one.

all actors in the company but has to be "translated" into a form that is usable by everyone in the firm. The positive influence of seminars and workshops in the equation for scientific knowledge supports the notion that more translated knowledge implies a higher probability that it can be integrated into the existing knowledge base and utilized in the innovation process. This underscores the role of gatekeepers in the process of building absorptive capacity. In contrast, broad knowledge diffusion reduces the probability of scientific knowledge being exploited. This method is not beneficial since only very few actors inside the firm are able to profit from a more widespread dissemination of knowledge and considerable (opportunity) costs might be involved.

Stimulating employees to get involved in the innovation process as well as knowledge acquisition and distribution is of great importance in determining absorptive capacity for all three kinds of knowledge, as our results suggest. The explanation is straightforward: The more knowledge is screened and the higher the incentives are to use acquired knowledge in the innovation process, the higher the potential to exploit external knowledge.

The differences between the three types of absorptive capacity are not limited to the collaboration and R&D variables, however. While we find a positive and significant coefficient for the share of employees with higher education in the scientific knowledge equation, it is insignificant in the other two equations. Naturally, one would assume that it is easier for employees who have attended university to use knowledge from this domain. They know how to use the knowledge as well as how and where to get it. The level of education does not significantly influence the ability to exploit intra- and inter-industry knowledge. For intra-industry absorptive capacity, size is more important. As in the case of absorptive capacities in general, we find a U-shaped relationship between the number of employees and intra-industry absorptive capacity (turning point: 25 employees). For inter-industry absorptive capacity neither the share of high-skilled labour nor size matters. The differences with respect to high-skilled labour can be explained by varying requirements for the exploitation of external knowledge. One can argue that in order to exploit knowledge from one's own industry, experience is more relevant than a high level of education. Even without a large share of highly educated personnel, firms should be able to exploit knowledge from within their own industries. On the other hand, the exploitation of very sophisticated methods and knowledge produced by public research institutes certainly require a similar kind of advanced training in a particular field. To absorb inter-industry knowledge more general skills in structuring problems and gathering information on previously unknown subjects might be more important than the initial education level of firms' employees.

The positive and significant effect of the dummy for Eastern Germany for intra-industry absorptive capacity is in line with what Sofka and Schmidt (2004) find in analysing first-mover and follower strategies for German firms: Eastern German firms are more often followers than leaders. Eastern German firms are thus more dependent on innovation and knowledge from their market rivals and are consequently more focused on exploiting knowledge from their own industry than Western German firms.

5 Conclusions

In this paper we investigate the determinants of different types of absorptive capacity in innovating firms, using information on external sources that firms have successfully used in developing and introducing innovations. Our first hypothesis was that the existence of exploitive absorptive capacity is not only determined by R&D activities, but also by the organization and stimulation of knowledge transfer within a firm as well as the employment of qualified personnel. In particular, the stimulation of innovation activities and knowledge transfer has proven to be an important building block of exploitive absorptive capacity. This holds for absorptive capacity in general, but also for all three types of absorptive capacity. The same is not true for collaboration among departments on innovation activities. Here we find significant differences between the three types of absorptive capacity and identify methods which hinder the development of absorptive capacities rather than support it. For intra-industry knowledge it seems best to broadly distribute acquired knowledge through informal networks instead of formal channels. The exploitation of scientific knowledge, on the other hand, requires a less broad distribution, but depends on the translation of this knowledge before it is disseminated through seminars and workshops. The specific kind of knowledge from inter-industry sources seems to require less collaboration, as not a single one of the collaboration variables is significant. It is thus feasible to conclude that firms can manage and build absorptive capacity by implementing methods that stimulate knowledge transfer and by providing an organizational framework which improves the flexibility and efficiency of knowledge transfer within their ranks. However, not all types of mechanisms to transfer knowledge are equally suited for the exploitation of specific kinds of knowledge. Due to this, there might not only be a conflict of goals with respect to exploiting external knowledge and other firm goals, but also with respect to the knowledge to be acquired. The influence of stimulation and management of knowledge sharing on absorptive capacity also provides proof of the fact that individuals contribute significantly to the absorptive capacities of firms. Furthermore, it looks like there is indeed a difference between potential and realized absorptive capacity, as proposed by Zahra and George (2002), and that firms can actively try to increase both their actual general and particular absorptive capacities.

Current R&D expenditure as a share of turnover does not influence absorptive capacity, regardless of the measure we use. We find, however, that it helps to build a knowledge stock which contributes significantly to exploitive absorptive capacity. It looks like one face of the "two faces of R&D" (Cohen and Levinthal, 1989) is dominating the other in the short run, i.e. R&D expenditures are predominantly a means of developing new knowledge and innovation rather than of building absorptive capacity. Nonetheless, R&D activities help in the long run to build absorptive capacities. Our results also suggest that R&D activities contribute differently to the accumulation of the three types of absorptive capacity. While it is very important for scientific knowledge, its short-run contribution to exploitive absorptive capacity for business sources is less pronounced. Following the previous argument, this may very well be due to the fact that R&D expenditure contributes faster to the build-up of one type of absorptive capacity than the other, regardless of the intentions behind spending it.

The differences between intra-industry, inter-industry and scientific absorptive capacity are striking and should be taken into account in future studies dealing with absorptive capacity. Researchers should think about what proxies and determinants of absorptive capacity to use, depending on the kind of knowledge firms, individuals, regions or nations have to deal with in their studies. Our results suggest that R&D intensity might not always be the best proxy. What is more, we show that differences exist between knowledge from different industries and from science, complementing other studies by Gradwell (2003) and Mangematin and Nesta (1999), which suggest differences for tacit and codified knowledge.

Future work might also try to further distinguish the types of knowledge to be acquired (and, consequently, the absorptive capacities required). One possible direction would be to investigate the differences in absorptive capacity for domestic and foreign knowledge.

6 Appendix

Table 1: Variables included in the model

Variable	Type	Construction
Absorp	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed because of impulses from at least one of the following sources: customers, suppliers, competitors, universities, research institutions.
Absorp_intra	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed and successfully implemented because of impulses from customers, suppliers or competitors from the firm's industry (NACE 2).
Absorp_inter	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed and successfully implemented because of impulses from customers or suppliers from industries other than its own (NACE 2).
Absorp_science	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed and successfully implemented because of impulses from universities or other public research institutes.
Grads	%	Share of employees with higher education in total employees.
R&D_int	%	Share of R&D expenditure in turnover, 2001
R&D_int2	%	Share of R&D expenditure in turnover, 2001, squared
R&D_int_empl	%	Share of R&D employees in total employees
R&D_int_empl2	%	Share of R&D employees in total employees, squared
R&Dcon	Dummy	One, if firm was engaged in R&D activities continuously
col_infor	Dummy	One, if informal contact among employees were highly important.
col_jointstrat	Dummy	One, if joint development of innovation strategies was highly important.
col_opencom	Dummy	One, if open communication of ideas and concepts among departments was highly important.
col_mutsup	Dummy	One, if mutual support of other departments with innovation-related problems was highly important.
col_heads	Dummy	One, if regular meetings of department heads to discuss innovation-related topics were highly important.
col_exchange	Dummy	One, if temporary exchange of personnel between departments for innovation projects was highly important.

Variable	Type	Construction
col_seminar	Dummy	One, if seminars and workshops for innovation projects involving several departments were highly important.
stim_index	Index	Index based on a question regarding the importance (four-point Likert-scale: “0” not important; “4” highly important”) of nine different methods of simulating innovation and knowledge transfer (stim1-stim9), ranging from monetary incentives for leading employees to incentives to develop one’s own ideas (full list available upon request). Result of principal component factor analysis suggests a single factor with an Eigenvalue greater than one (5.75). Factor loadings after Varimax rotation rescaled between 0 and 1.
Lnemp	Log	Natural logarithm of number of employees
Lnemp2	Log	Natural logarithm of number of employees, squared
east	Dummy	One, if a firm is located in Eastern Germany.
ind_lt	Dummy	One, if a firms is from a low-tech industry.
ind_mlt	Dummy	One, if a firms is from a medium-low-tech industry.
ind_mht	Dummy	One, if a firms is from a medium-high-tech industry.
ind_ht	Dummy	One, if a firms is from a high-tech industry.
serv_lt	Dummy	One, if a firms is from low-tech services.
serv_ht	Dummy	One, if a firms is from high-tech services.

Table 2: List of industry dummies included in the model

Industry Group	**NACE Code**
Other manufacturing	40, 41, 45
Low-tech manufacturing	10-22, 36, 37
Medium-low-tech manufacturing	23, 25-28, 351
Medium-high-tech manufacturing	24 (exc. 244), 29, 31, 34, 35 (excl. 353)
High-tech manufacturing	244, 30, 32, 33, 353
Low-tech services	50, 51, 52, 55, 60-63, 65-67, 70, 71, 74, 75, 90, 92
High-tech services	64, 72, 73

Note: Only those NACE Codes that were present in our sample are listed in the second column.

Table 3: Descriptive statistics

Definition	Variable	Sample	AC [a]	*Intra*-industry AC [a]	*Inter*-industry AC [a]	Scientific AC [a]
Number of observations		1,650	1,177	575	956	248
% of total			68%	33%	56%	14%
Share of R&D expenditure in turnover, in %	R&D_int	7.46	8.69*	7.70	8.66*	14.80***
		(22.27)	(24.75)	(23.00)	(23.17)	(28.50)
Share of R&D expenditure in turnover, squared	R&D_int2	551.19	687.52	587.58	611.30	1028.27
		(5187.4)	(6004.8)	(5756.2)	(5243.9)	(6371.9)
Share of employees with higher education in total employees, in %	grads	27.70	29.57*	27.67	29.66*	42.15***
		(26.83)	(27.41)	(25.50)	(27.54)	(29.69)
Continuous R&D activities	R&Dcon	0.53	0.59***	0.60***	0.60***	0.77***
		(0.50)	(0.49)	(0.49)	(0.49)	(0.42)
Number of employees, logarithm	ln_emp	4.59	4.65	4.95***	4.66	4.68
		(1.89)	(1.97)	(2.11)	(1.97)	(2.26)
Number of employees, logarithm, squared	ln_emp2	24.61	25.49*	28.93***	25.58*	26.95*
		(20.52)	(21.96)	(24.78)	(22.03)	(26.95)
Firm located in Eastern Germany	east	0.32	0.34	0.33	0.34	0.33
		(0.47)	(0.47)	(0.47)	(0.47)	(0.47)
Index for importance of methods of stimulating innovation activities and knowledge transfer	stim_index	0.46	0.48***	0.48***	0.48***	0.52***
		(0.23)	(0.22)	(0.22)	(0.22)	(0.21)

Definition	Variable	Sample	AC [a]	*Intra*-industry AC [a]	*Inter*-industry AC [a]	Scientific AC [a]
Informal contact among employees	col_infor	0.47	0.50*	0.51**	0.50*	0.55***
		(0.50)	(0.50)	(0.50)	(0.50)	(0.49)
Open communication of ideas and concepts among departments	col_opencom	0.46	0.49*	0.47	0.48*	0.47
		(0.50)	(0.50)	(0.50)	(0.50)	(0.50)
Joint development of innovation strategies	col_jointstrat	0.32	0.34	0.31	0.35*	0.37
		(0.47)	(0.47)	(0.46)	(0.48)	(0.48)*
Mutual support of other departments with innovation-related problems	col_mutsup	0.43	0.46*	0.41	0.47**	0.46
		(0.50)	(0.50)	(0.49)	(0.50)	(0.50)
Regular meetings of department heads to discuss innovation-related topics	col_heads	0.36	0.37	0.39	0.38	0.36
		(0.48)	(0.48)	(0.48)	(0.49)	(0.48)
Temporary exchange of personnel between departments for innovation projects	col_exchange	0.06	0.06	0.06	0.06	0.10**
		(0.24)	(0.24)	(0.23)	(0.24)	(0.30)
Seminars and workshops for innovation projects involving several departments	col_seminar	0.12	0.13	0.11	0.14	0.21***
		(0.33)	(0.34)	(0.31)	(0.34)	(0.40)

AC: absorptive capacity; means, standard errors in parentheses

[a] Mean is different from the sample mean at * 10%; ** 5%; *** 1%

Table 4: Regression results from probit (1) and trivariate probit (2)-(4) estimations

Definition	**Variable**	**AC (1)**	***Intra*-industry AC (2)**	***Inter*-industry AC (3)**	**Scientific AC (4)**
Number of employees (logarithm)	ln_emp	-0.199**	-0.134*	-0.079	-0.099
		(0.090)	(0.079)	(0.076)	(0.087)
Number of employees, squared (logarithm)	ln_emp2	0.023***	0.021***	0.010	0.012
		(0.008)	(0.007)	(0.007)	(0.007)
Share of employees with higher education in total employees, in %	grads	0.003***	0.001	0.002	0.010***
		(0.002)	(0.002)	(0.002)	(0.002)
Share of R&D expenditure in turnover, in %	R&D_int	0.004	-0.002	0.007*	0.014***
		(0.004)	(0.004)	(0.004)	(0.004)
Share of R&D expenditure in turnover, squared	R&D_int2	-0.00001	0.000005	-0.000028*	-0.00005
		(0.00001)	(0.00001)	(0.000014)	(0.0002)
Continuos R&D activities	R&Dcon	0.306***	0.127*	0.222***	0.451***
		(0.078)	(0.076)	(0.073)	(0.089)
Informal contacts among employees	col_infor	0.159**	0.218***	0.113	0.096
		(0.076)	(0.072)	(0.144)	(0.088)
Open communication of ideas and concepts among departments	col_opencom	0.030	0.102	-0.074	-0.238**
		(0.086)	(0.081)	(0.078)	(0.098)
Joint development of innovation strategies	col_jointstrat	-0.105	-0.138*	-0.022	-0.050
		(0.085)	(0.080)	(0.080)	(0.100)

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Definition	Variable	AC (1)	*Intra*-industry AC (2)	*Inter*-industry AC (3)	Scientific AC (4)
Mutual support of other departments with innovation-related problems	col_mutsup	0.090	-0.180**	0.122	-0.089
		(0.084)	(0.079)	(0.077)	(0.096)
Regular meetings of department heads to discuss innovation-related topics	col_heads	-0.010	0.031	-0.032	-0.123
		(0.080)	(0.076)	(0.075)	(0.096)
Temporary exchange of personnel between departments for innovation projects	col_exchange	-0.275*	-0.092	-0.127	0.117
		(0.150)	(0.147)	(0.140)	(0.160)
Seminars and workshops for innovation projects involving several departments	col_seminar	-0.009	-0.341***	0.013	0.243**
		(0.116)	(0.110)	(0.105)	(0.220)
Index for importance of methods of stimulating innovation and knowledge transfer	stim_index	0.683***	0.293*	0.602***	0.798**
		(0.173)	(0.170)	(0.166)	(0.205)
Firm located in Eastern Germany	east	0.152**	0.154*	0.122*	-0.050
		(0.076)	(0.072)	(0.070)	(0.093)
Low-tech industries	ind_lt	-0.092	0.143	-0.003	-0.124
		(0.245)	(0.225)	(0.078)	(0.291)
Medium-low-tech industries	ind_mlt	-0.193	-0.315	0.167	-0.183
		(0.239)	(0.222)	(0.205)	(0.288)

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Definition	Variable	AC (1)	*Intra*-industry AC (2)	*Inter*-industry AC (3)	Scientific AC (4)
Medium-high-tech industries	ind_mht	-0.114	0.217	-0.005	-0.120
		(0.237)	(0.215)	(0.201)	(0.275)
High-tech industries	ind_ht	-0.111	0.038	0.055	-0.092
		(0.248)	(0.226)	(0.211)	(0.282)
Low-tech services	serv_lt	-0.311	-0.177	-0.009	-0.291
		(0.232)	(0.214)	(0.197)	(0.277)
High-tech services	serv_ht	0.008	0.094	0.112	-0.147
		(0.259)	(0.235)	(0.221)	(0.295)
Constant		0.417	-0.540*	-0.305	-1.655
		(0.316)	(0.293)	(0.279)	(0.366)
Observations		1,650		1,650	
X^2		132.73		347.89	
Log-likelihood				-2,663.48	
Aldrich-Nelson Pseudo R^2		0.137		0.231	
Rho			(2,3): 0.27***	(3,4): 0.19***	(2,4)0.11**

* significant at 10%; ** significant at 5%; *** significant at 1%; Robust standard errors in parentheses
AC: exploitive absorptive capacity

Table 5: Eigenvalues and Factor Loadings for the Principal Components Factor Analysis

Factor	Eigenvalue	Proportion
1	5.753	1.011
2	0.263	0.046
3	0.071	0.013
4	-0.009	-0.002
5	-0.034	-0.006
6	-0.048	-0.009
7	-0.084	-0.015
8	-0.095	-0.017
9	-0.129	-0.023

Variable	Factor Loadings	Uniqueness
stim1	0.807	0.348
stim2	0.837	0.300
stim3	0.791	0.374
stim4	0.804	0.354
stim5	0.823	0.323
stim6	0.802	0.357
stim7	0.813	0.339
stim8	0.829	0.313
stim9	0.679	0.539

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