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REGULAR ARTICLE

Role of human resource practices in absorptive capacity and R&D cooperation

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Abstract This paper reconceptualises absorptive capacity as a strategic human resource construct and analyses its role in determining R&D cooperation and innovation in firms. In spite of widespread consensus on the role of absorptive capacity in innovation, the literature has so far concentrated only on traditional R&D and human capital based indicators of absorptive capacity. Furthermore, most firm-level studies investigating this relationship are cross-sectional in nature and there is need for longitudinal evidence. Employing the IAB Establishment Panel Survey on about 1200 private sector establishments in Germany during 2007–2011, we apply a structural model that links firms' human resource practices, R&D collaboration strategies and finally their innovation outcome. Findings from the first stage of the empirical analysis suggest that adoption of employment practices positively affects horizontal, institutional and consulting-based R&D cooperation, while compensation programs positively affect only horizontal R&D cooperation. In the second stage, the effect of cooperative R&D conditioned upon human resource practices on innovation performance is examined. Results indicate that firms having institutional and consulting-based R&D cooperation relationships are more often associated with higher incremental product, process and new-to-market innovation, whereas the effect is relatively weaker in case of horizontal R&D cooperation.

Keywords Absorptive capacity · Compensation programs · Employment practices · Human resource management · Innovation · R&D cooperation

JEL classification J21 · J24 · J33 · L20 · M12

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1 Introduction

The resource-based view of the firm attributes differences in performance across firms to the heterogeneity in their resources and capabilities (Wernerfelt 1984; Barney et al. 2001). Beside investments in physical and tangible assets like machinery, infrastructure and other financial assets, firms' resource endowments may vary with regard to investment in intangible assets like R&D, expenditures that underlie organizational practices, and investments with respect to human capital. On the micro level, human capital is extensively discussed as the basis for firms' competitive advantage, performance and technological innovation and measured in terms of recruitment of high-skilled workers, career paths of employees, mobility of star scientists and geography of labor inputs (Kim and Marschke 2005; Song et al. 2003; Audretsch and Stephan 1996; Almeida and Kogut 1999; Breschi and Lissoni 2001; Simonen and McCann 2008; Boschma et al. 2009). Human capital is also linked to the literature on "absorptive capacity" (Cohen and Levinthal 1990) showing that firms' innovative capabilities and learning abilities are enhanced by their existing stock of human capital (Lofstrom 2000; Minbaeva et al. 2003; Hatch and Dyer 2004).

Although the importance of human capital is greatly acknowledged in the above studies, in a world with rapidly changing knowledge boundaries, firms cannot rely solely on internal human capital stock to be on par with latest technological requirements. Efficient interaction with external knowledge networks and successfully broadening the scope of acquisition, assimilation and absorption of external knowledge are equally important. Building on this cue, several authors examine the complementarity between human capital and external collaboration to explain firms' performance, by estimating human capital using stock-based indicators such as share of hired experts in total workforce (Song et al. 2003), share of employees in R&D or with high level of qualification and skill (Rothwell and Dodgson 1991), share of trained employees (Muscio 2007) and accumulation of on-the-job experience (Cooper et al. 1994). Most of these studies verify that greater human capital stock combined with external knowledge is a necessary condition for greater firm performance. However, the human resource mechanism through which access to external knowledge results in greater performance is seldom discussed. To be able to successfully "integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (Teece et al. 1997, p. 516), firms are required to continuously develop and upgrade their knowledge base, that is, the knowledge embedded in the minds of their human resources. External acquisition of R&D experts can be one aspect, the other may work through implementation of human resource management (HRM) practices that aim at increasing employees' competencies, learning, creative-thinking (Huselid 1995; Lane and Lubatkin 1998), motivation and commitment (Lawler 1971; Lazear 1999), their ability to effectively absorb and utilize external knowledge and promote knowledge sharing within and between organizations (Laursen and Mahnke 2001). Such practices not only increase the absorptive capacity of the employees, thereby firms' overall knowledge stock and internal capabilities, but also provide conditions for building and managing social capital and increasing firms' innovative capabilities. Yet, research in this direction has been surprisingly scarce.

The present paper addresses this caveat of existing research by considering HRM as an important strategic asset in organizational value creation and development of absorptive capacity, that is necessary for systematically managing external knowledge embedded in R&D cooperation relationships and stimulating innovation performance. By definition (Ichniowski et al. 1995), human resource management encompasses employment practices as well as incentive and compensation schemes. However, the state-of-the-art literature on HRM is constrained on two major grounds which this article attempts to address. The first criticism relates to a methodological limitation, while the second considers a conceptual drawback. The methodological issue is based on the fact that most of the existing studies are cross-sectional in nature and therefore do not take into account the potential simultaneity between adoption of human resource practices and performance indicators. In other words, better performing firms are more likely to adopt relatively better human resource practices than low performing firms which might systematically bias the estimation results. In order to account for this identification problem, it is therefore essential to consider a time horizon and then estimate the relationship between the two using a CDM-type structural model.

The second limitation lies in the fact that although HRM practices contribute to the internal human capital development and value creation in firms, they are not explicitly considered as determinants of firm-level absorptive capacity in explaining its relationship with firms' innovation and cooperation decisions. While acknowledging the importance of external knowledge linkages, especially in the form of inter-firm R&D collaboration in organizational performance, innovation studies have so far considered "appropriability" and "spillovers" only with respect to firms' R&D activities. However, most of these studies consider absorptive capacity as a stock-based resource rather than a "dynamic capability" that needs to be continuously invested upon. In contrast, studies in strategic management literature have emphasized on the importance of 'relative' absorptive capacity (Prahalad and Bettis 1986; Lane and Lubatkin 1998) and organizational similarities among partner firms as the most important criteria for alliance-formation. Yet, the extensive construct of organizational absorptive capacity has been particularly overlooked (Zahra and George 2002) in analysing conditions for benefiting from external collaboration. These concerns are reconfirmed by Lane et al. (2006) who suggest that "absorptive capacity should be empirically explored in non-R&D contexts using metrics that capture each dimension of the absorptive capacity process in a manner appropriate for that context." In order to have a holistic understanding, it is therefore essential to also consider internal organizational settings and human resource practices firms continuously employ to create knowledge, learning and absorptive capacity.

On this basis, the novelty of the paper lies in recognising absorptive capacity as a human resource construct that provides sufficient appropriability and spillover conditions for collaboration and innovation decisions in firms. Furthermore, attention is given to the methodological limitations in earlier studies by considering a longitudinal data and using structural model. Subsequently, drawing inspiration from the resource-based view of firm (RBV), strategic management (SM) and industrial organization (IO) literature, the paper provides a broader definition of absorptive capacity incorporating firms' human resource practices and address the following two research questions using data for private-sector German establishments during 2007–2011.

1. *Do human resource practices determine the likelihood of firms' having R&D collaboration and the choice of cooperation partners?*

2. *Does such cooperative R&D conditional on human resource practices contribute to firms' incremental and new-to-market innovation performance?*

The remainder of the article is organized as follows: Section 2 gives the conceptual background and formalization of the hypotheses. Section 3 introduces the data and construction of the variables. Section 4 describes the empirical strategy used to test the hypotheses. Section 5 summarizes main results and Section 6 concludes the paper with implications for policy intervention.

2 Background

2.1 Human resource practices and absorptive capacity

Successful innovation requires development of new knowledge that can be acquired through external sources, developed internally or both. In the context of internal knowledge building and knowledge management, firms' human resource practices present an important attribute. Human resource practices are traditionally defined in the strategic management and human resource management literature as organizational programs that allow employees to draw on knowledge and competencies inside and outside the firm in an efficient way (Lado and Wilson 1994, Huselid 1995, Ichniowski and Shaw 1999, Vinding 2006, Laursen and Mahnke 2001). Usually, they constitute a) employment practices like internal and external training programs, delegation of responsibility, job rotation, provision of quality workshops, and b) performance related incentive and compensation schemes. These human resource practices are found to enhance employee trust and loyalty, increase their productivity, abilities to cooperate and exchange knowledge and foster intra- and inter-organizational learning (Lane and Lubatkin 1998). Prior research incorporating human resource practices looks at sectoral, demographic, institutional and managerial factors that affect the degree and extent to which these practices are adopted and implemented across firms and their subsequent impact on individual and firm performances (Laursen and Mahnke 2001; Addison et al. 2004; Simonen and McCann 2008; Osterman 1995; Collins and Clark 2003). Advanced literature on HRM has also introduced the notion of high involvement work practices as a system of human resources practices to enhance employees' levels of skill, intrinsic motivation, productivity and empowerment (Huselid 1995; Guthrie 2001).

Looking next at the literature on absorptive capacity, following Cohen and Levinthal's (1990) seminal paper researchers have come up with different variants of the concept in explaining organizational knowledge stock and performance. Absorptive capacity has been defined in terms of traditional R&D variables such as in-house R&D expenditure (Cohen and Levinthal 1990), new product development (Stock et al. 2001), publications and co-authorship (Cockburn and Henderson 1998), patents (Zhang et al. 2007), external interactions such as R&D cooperation relationships (Tsai 2001), years of experience (Cooper et al. 1994) or optimal cognitive distance (Nooteboom et al. 2007). It has also been related to human capital indicators such as acquisition of research personnel (Song et al. 2003), share of trainees in total workforce and firm's prior knowledge base and education-skill composition (Rothwell and Dodgson 1991).

Studies in strategic management have shifted focus from the traditional indicators to organizational forms and routines, social integration mechanisms and potential and realized absorptive capacity (Lane and Lubatkin 1998; Van Den Bosch et al. 1999; Zahra and George 2002; Vinding 2006). Lane and Lubatkin (1998), for example, define absorptive capacity as a dyad-level learning phenomenon and claim that a firm's ability to absorb and learn from external knowledge depends not only on R&D-related activities but on the extent to which its knowledge-processing systems, organizational structures and dominant ideologies are similar to the partner firm. Van Den Bosch et al. (1999) consider organization forms (functional form, divisional form, matrix form) and combinative capabilities (system capabilities, coordination capabilities, socialisation capabilities) as main determinants of absorptive capacity, ceteris paribus the level of prior knowledge. Zahra and George (2002, p. 198) propose a multi-dimensional definition of absorptive capacity based on the dynamic capabilities view of the firm and highlight the importance of "organizational routines and strategic processes by which firms acquire, assimilate, transform and exploit knowledge by transforming acquired knowledge". Murovec and Prodan (2009) provide a direct measure of organizational absorptive capacity by distinguishing between demand-pull and science-push theories and test this using a cross-national structural model. Similar studies are conducted by Jensen et al. (2007), Jansen et al. (2005), Vega-Jurado et al. (2008) and Camison and Fores (2010) who redefine absorptive capacity in terms of organizational mechanisms, coordination capabilities, informal processes of learning, managerial knowledge and social integration mechanisms.

Evidently, human resource practices and absorptive capacity have been studied in isolation quite extensively in the literature. However, the prospect of human resource practices as an antecedent of absorptive capacity has been seldom discussed. As Foss et al. (2005, p. 3) point out, "in spite of the size and richness of the literature on absorptive capacity, the notion itself remains a label for a complex interaction of behaviors, organizational practices and knowledge bases in firms, much of which is not well understood". Thus it becomes increasingly important to disentangle the extensive construct of organizational absorptive capacity and identify the mechanism of knowledge creation and utilisation in firms. One of the primary sources of organizational absorptive capacity is rooted in the abilities and motivation of its human resources. Subsequently, implementation of HRM practices are fundumental to promoting individual learning, combinative capabilities, facilitating knowledge flows and absorptive capacity. For example, human resource practices in the form of internal and external training programs continuously upgrade employee skills and combinative capabilities, allowing them to keep up with latest technological developments and market needs. Given that investment in human resources is not easily imitated, firms often provide continuous training to employees in the form of technical workshops and skill improvement programs that increase functional efficiency and produce greater returns in the long run. Employment restructuring programs such as quality workshops and job rotation allow for decentralization of responsibilities, integration of functions and distribution of localized knowledge across individuals and departments (Ichniowski and Shaw 1999; Jensen and Meckling 1992; Inkpen 1996; Kase et al. 2009). Cross-functional teams result in interactive open communication between department leaders and regular employees, social integration and greater combinative capabilities of firms (Kogut and Zander 1992). This is one aspect of HRM, which shall henceforth be referred to as employment practices. The other aspect incorporates performance-based reward systems and flexible payments that foster employee satisfaction and curb opportunistic behaviours (Coriat and Dosi 1998), providing incentive for greater efforts, increased efficiency and organizational knowledge building (Bollinger and Smith 2001). Minbaeva et al. (2003) propose the implementation of "intellectual capital enhancing HRM" such as compensation programs to induce appropriate behaviour and motivation in employees, which would ultimately help employees to break invisible barriers to career growth and enhance knowledge transfer. Taken together, these practices enhance employee abilities as well as employee motivation and contribute significantly to individual as well as organizational absorptive capacities. However, existing research still does not explicitly consider HRM as a determinant of absorptive capacity and its role in firms' collaboration and innovation strategies.

2.2 R&D cooperation and human resource practices

Over the past few decades, there is a steady growth in the number of studies on inter-firm relationships in the form of strategic alliances, supply-chain cooperation, public-private collaborations, research joint ventures, and virtual company networks. Openness towards knowledge sharing usually involves two levels of commitment; one being willingness to participate in strategic alliances to avail complementary benefits related to marketing, sales or other non-R&D related functions, and the other being collaboration in product and process development or completion of an innovation. Prior studies find that firms with external knowledge linkages benefit from exploiting similar/complementary knowledge and internal resources (Shan et al. 1994; Lee et al. 2001; Becker and Dietz 2004; Cantner and Meder 2007), positive internalization of spillovers (Kaiser 2002), increased efficiency through economies of scale and scope (D'Aspremont and Jacquemin 1988), reduced transaction and organizational costs and increased capabilities and strategic endowments (Prahalad and Hamel 1993), which subsequently influence their innovation (Nooteboom et al. 2007).

In the context of R&D cooperation, four main areas of interest are highlighted in the literature (Veugelers 1997; Becker and Peters 2000; Hagedoorn 2002; Cassiman and Veugelers 2002; Kaiser 2002; Vinding 2006): a) what factors determine a firm's R&D collaboration strategies, that is, whether or not to form cooperation networks for research and development, b) what determines the choice of appropriate cooperation partners, c) how to efficiently manage external knowledge networks, and d) how efficient utilization of cooperation networks is complemented by absorptive capacity and how that subsequently affects firm performance. With regard to determinants of firms' R&D cooperation strategies and partner selection, a diverse range of paradigms exists. For example, industrial organization literature suggests complementarity of resources, own R&D activities, magnitude of research spillovers, appropriability mechanism and presence of high-skilled researchers (Richardson 1972; D'Aspremont and Jacquemin 1988; Kaiser 2002; Belderbos et al. 2004; Cassiman and Veugelers 2002; Simonen and McCann 2008) as major determinants of research collaboration. Richardson (1972, p.895), in a seminal article, introduces the concept of capabilities and blurring firm boundaries and argues that "firms are not islands but are linked together in patterns of co-operation and affiliation. Planned co-ordination does not stop at the boundaries of the individual firm but can be effected through co-operation between firms“. D'Aspremont and Jacquemin (1988) employ a theoretical model of imperfect competition to show that investment in own R&D builds absorptive capacity, maximizes incoming spillovers and minimizes outgoing spillovers, thereby ultimately affecting R&D cooperation decisions. Kaiser (2002) empirically tests whether R&D expenditures affect the propensity of firms to form a research joint venture and finds that on average cooperating firms invest more in R&D than non-cooperating firms. However, there exists significantly weak but positive effect of horizontal spillovers, on the probability of R&D cooperation but no effect on the choice of vertical or mixed cooperation. Similarly, Franco and Gussoni (2010) find that firms who are better able to maximize incoming spillovers and minimize knowledge leakage will prefer a mix of heterogeneous collaboration partners over a single partner relationship. Belderbos et al. (2004) explore the heterogeneity in firms' partner-selection strategies and find significant differences with respect to incoming spillovers and R&D intensity between horizontal, vertical and institutional cooperation. Other studies on the choice of R&D cooperation partners have been conducted by Mowery et al. (1996), Boschma (2005), Cantner and Meder (2007) who find technological proximity/overlap, managerial tools and individual incentives as main determinants of R&D cooperation partners. Miotti and Sachwald (2003) find complementary R&D resources to be the determining factor, and, Muscio (2007) finds significant effects of R&D employment, skilled human capital and innovative activities on the choice of cooperation partner in firms. Studies in strategic management literature emphasize on the importance of 'relative' absorptive capacity (Prahalad and Bettis 1986; Lane and Lubatkin 1998) and organizational similarities among partner firms as the most important criteria for alliance-formation.

Evidently, R&D cooperation is extensively studied within multiple strands of literature encompassing multiple dimensions of organizational theories. The current study contributes to this knowledge pool by drawing inspiration from the RBV and dynamic capabilities (DC) theories of the firm to determine the role of HRM practices in R&D collaboration strategies. Looking first at employment practices such as job-training, restructuring of responsibilities and external acquisition of labor, it is expected that firms providing greater training and employability conditions are more willing to engage in cooperation relationships to be better able to exploit and absorb complementary knowledge of their partners than firms with lower investment in human capital. For example, while employee training increases cost efficiency on the one hand, it also influences learning capabilities in employees through upgrading of skills and competencies regarding latest technological developments and market needs. As firms are confronted with new challenges, continuous investment in employee training creates new skills and competencies, thereby contributing significantly to organizational knowledge stock. New hiring allows firms to select from a pool of qualified personnel a set of employees that provide perfect fit to organizational requirements and innovation strategies. Employment restructuring such as job rotation, quality workshops and cross-functional teams increases discretionary efforts of employees (Becker and Huselid 1998) by allowing them to be responsible for planning and controlling their own tasks. Taken together, technical and creativity-enhancing job training along with diverse employment practices promote knowledge sharing and skills which in turn leads to higher absorptive capacity. This enables firms to transform resources and capabilities from external knowledge sources into innovation (Stock et al. 2014).

Therefore, such employment practices are expected to be an important determinant of firms' R&D cooperation strategies, irrespective of the type of collaboration partner.

In this respect, the paper draws distinction between three types of R&D cooperation relationships- cooperation with other private establishments (horizontal), cooperation with universities and research institutes (institutional), and cooperation with consulting firms (consultation-based). This categorization of R&D partners is in-line with Tether (2002, p. 952) who highlight cooperation for innovation beyond the supply chain and claim that "customers and supplies apart, firms can engage in co-operative arrangements for innovation with several other types of partner; these include competitors, universities, consultants, research institutes, research and technology organizations, and other associations". Since the IAB Establishment Panel Survey provides information on cooperative arrangements with competitors, universities/research institutes and consultants, attention is restricted to these three types of R&D cooperation and the following hypothesis is put forward:

Hypothesis 1: Adoption of employment practices positively affects R&D cooperation with other private firms, research institutes and universities as well as consultation-based firms.

With respect to incentive and compensation-based programs as determinants of cooperation, however, significant differences are expected between R&D cooperation with private establishments, with research institutes and with consulting firms. The literature on outgoing spillovers provides mixed reviews on the effect of firms' appropriability conditions on the probability of cooperation. While on the one hand, greater protection in the form of intellectual property rights, patents and copyrights serves as a shield against value misappropriation (Cassiman and Veugelers 2002), it also reduces the scope of acquisition and assimilation of external knowledge on the other (Lopez 2008). Incentive and compensation schemes such as performance bonuses and profit sharing align the interests of employees with that of the firm and motivate workers to put additional efforts into tasks and individual performance. Therefore firms often resort to employment protection in the form of higher flexible payments, bonuses and performance-based incentives to ensure job motivation and retention on part of the employees. However, such a reward system is likely to have different effects on the probability of R&D cooperation relationships depending on the types of partners. For example, in case of private cooperation or cooperation with competitors having symmetric knowledge profile and innovation activities, employee protection is crucial given the high risks associated with employee turnover and poaching. Since private firms frequently collaborate for innovation with competitors to exploit complementary resources and rivals' competencies (Hamel et al. 1989), employee retention particularly at the level of managers and R&D professionals becomes increasingly important. This might not be relevant when the cooperation partner is a research institute or consulting firm. Private firms tend to cooperate with universities and academia for basic and long-term strategic research particularly in pre-competitive technologies (Tether 2002), while collaboration with consultants results in the provision of applied knowledge, specialist skills and market information. Thus, institutional and consulting-based R&D cooperations are significantly different from horizontal cooperations in organizational settings, risk involved, knowledge and employment portfolio, and appropriation mechanism.

Consequently, provision of higher flexible payments and performance-based rewards to high-skilled R&D personnel are more likely to be associated with cooperation with private establishments than with research institutes or consulting firms. Accordingly, the following hypothesis is put forward:

Hypothesis 2: Compensation programs positively affect R&D cooperation only with competitors and other private firms.

2.3 Human resource practices, R&D cooperation and innovation performance

The effect of human resource practices on firm performance has been subjected to extensive discussion in the past few decades. Previous literature in the fields of industrial organization and strategic management claim that human resource practices in the form of high-performance work practices improve employee skills and competencies, their motivation to perform and reduce turnover by ensuring loyalty and commitment. This in turn encourages greater individual and firm performance, measured mostly in terms of productivity (Huselid 1995; Datta et al. 2005), turnover and financial performance (Huselid 1995), sales growth and stock growth (Collins and Clark 2003), and innovation performance (Laursen and Foss 2003; Vinding 2006; Chen and Huang 2009). With regard to R&D cooperation and firm performance, theoretical predictions and empirical evidence suggest that R&D cooperation enables firms to internalize incoming spillovers (D'Aspremont and Jacquemin 1988; Kaiser 2002), reduce cognitive distance between partners (Nooteboom et al. 2007), lower operational risks and maximize market control (Teece 1980), increase efficiency (Kogut 1988) and consequently innovation performance. Most of these studies find a positive impact of R&D cooperation relationships on firm performance, with significant differences within industries (Fritsch and Lukas 2001), between types of cooperation partners (Belderbos et al. 2004; Cassiman and Veugelers 2005), and measures of performance used (Becker and Dietz 2004; Okamuro 2007).

While existing literature analyzes in isolation the direct impact of human resource practices on the one hand and R&D cooperation on the other hand in firm performance and innovation, no attempt is made so far to consider how R&D cooperation conditioned upon firms' HRM practices affect innovation performance. What is investigated so far is the interplay between firms' absorptive capacity measured in terms of R&D activities and external knowledge sources and how they affect development and introduction of new products or processes to the market. Few studies also extend the concept of absorptive capacity to a human capital framework and test the joint effect of human capital and openness to external knowledge on firm performance. Vinding (2006), for example, uses data on manufacturing and service firms from two Danish databases- DISKO (Danish acronym for 'The Danish Innovation System - A Comparative Analysis) and IDA (Integreret Database of Arbejdsmarkedsforskning) and shows that human resource practices adopted within the firm combined with external knowledge promotes the ability to innovate. Simonen and McCann (2008) investigate innovation in firms by looking at the geography of human capital acquisition. On the same note, Lee et al. (2001), Escribano et al. (2009) and Gao et al. (2008) examine the influence of managerial networks and internal capabilities on innovation.

Other studies on the importance of human capital and human resource practices in firm performance are proposed by Ichniowski et al. (1995), Huselid (1995), Laursen and Foss (2003, 2012), Collins and Clark (2003), Collins and Smith (2006), and Chen and Huang (2009), all of which find a positive relationship albeit to various degrees. This can be one aspect; the other channel might work through the contribution of expected R&D cooperation conditional on HRM and other firm characteristics to innovation. Increased knowledge absorption and diffusion capabilities in employees, through implementation of human resource practices, can be expected to augment incremental and new-to-market innovation performance of firms having external R&D collaboration relationships. This follows from the theoretical understanding that greater absorptive capacity allows for efficient utilization of external knowledge, resulting in firms' increased likelihood of introducing new or improved products or services to the market. Accordingly, the final three hypotheses explore the effects of variation in cooperative R&D predicted by firms' human resource programs on innovation output, distinguishing between incremental product, process and new-to-market innovation.

Hypothesis 3a: R&D cooperation conditioned upon HRM positively affects incremental product innovation.
Hypothesis 3b: R&D cooperation conditioned upon HRM positively affects incremental process innovation.
Hypothesis 3c: R&D cooperation conditioned upon HRM positively affects new-to-market innovation.

3 Data and variable description

The empirical analysis is based on data from the IAB Establishment Panel, which is a representative employer survey on corporate indicators of investment, employment practices and innovation activities at establishment-level. The data is carried out orally by way of personal interviews and consists of information on innovation firms across all sectors in Germany. The sample covers over 15,000 establishments having at least one employee liable to social security and the annual response rates to the surveys vary between 63% and 73% (Fischer et al. 2008). The IAB Establishment Panel has been in existence in western Germany since 1993 and in the east since 1996 and covers information from 1993 to 2011. Information collected includes (Acs and Audretsch 1987) general data on the participating establishment such as total number of employees, ownership structure, operational investments, sales, sectoral affiliation, employee representation (Addison et al. 2004) employment structure such as educational background of employees, skill mix, employment groups, vacancies, operational working hours, personnel movement and recruitment, (Almeida and Kogut 1999) human resource practices such as training, advanced training measures, employee participation in profits and capital, vocational traineeships, salaries and wages, and (Audretsch and Stephan 1996) innovative activities and R&D cooperation. The current analysis is conducted using survey data from 2007 to 2011 since information on the main variables of interest viz. R&D, cooperation structure and innovation activities of establishments is available from

2007 onwards and only for three data points (2007, 2009 and 2011). All explanatory variables used in the analysis are lagged by 2-years in the estimation, and therefore the first year of estimation is 2009. Due to the construction of the lagged variables and exclusion of the missing values, the final sample consists of about 1200 innovating firms for each time period and the analysis is run on 1658 observations. To some extent, the availability of only 3 waves of firm-level data from the IAB may hinder drawing inference on the long-term causal relationship between HRM, R&D cooperation and innovation. However, alternate data sources such as the Community Innovation Survey and its corresponding Mannheim Innovation Panel for Germany provide very little to no information on the main variables of interest, HRM and human capital indicators. Therefore given the objective and scope of the current paper, detailed information is drawn from the IAB Establishment Panel and considerable attention paid to the choice of econometric models for estimating causal links. The following section provides an overview of the variables used in the analysis (see Table 7 in Appendix for detailed description of the variables).

3.1 Measures of absorptive capacity

Two measures of absorptive capacity are provided, the first one based on human resource practices and the second using traditional measure.

> *Measure 1:* As previously mentioned, human resource practices are categorized into two groups: (i) Employment practices, where establishments are asked if they have supported training courses in the current year and their choice is indicated by a binary variable (yes/no). Furthermore, establishments are asked if they have offered other/advanced on-the-job training such as external or internal training courses, seminars and workshops, initial skill adaptation training, training in self-learning, employment restructuring such as job rotation and quality workshops. Each of these variables is reported with a yes/no and therefore indicated by dichotomous variables. This measure also includes information on hired personnel and is given by a binary variable indicating whether an establishment has hired qualified high-skilled personnel during the first half of the current year; (ii) Compensation programs, which indicate whether establishments offer additional financial incentives (mostly performance-based) for employees and is given by two binary variables, profit-sharing and staff sharing arrangements for employees. Since the questionnaire consists of 11 binary variables corresponding to HRM practices, Pearson's linear correlation coefficient is not ideal. Instead, tetrachoric correlation suited for binary variables is conducted which allows for subsequent conceptual grouping of the HRM variables into constructs of two (see Table 5 in Appendix). Based on this conceptual understanding, the two main variables of interest are created simply by taking the mean of all HRM variables relating to employment practices and compensation programs respectively and then re-binarising them on a scale of 0–1. The procedure significantly reduces the number of regressors in the estimations and provides better comparability and interpretative ease within a discrete choice model framework.

Measure 2: Following existing literature, a second measure of absorptive capacity is provided that reflects firm's willingness to undertake innovation activities. In that sense, R&D intensity is calculated as the ratio of full-time R&D employees engaged fully and partially in R&D related job duties to the total number of employees in each establishment.

3.2 Measure of skill and educational background

Skill structure and educational background of employees are given by two variables viz. share of skilled blue collar and white collar workers requiring a vocational education and share of qualified white collar employees requiring a university degree in the total workforce.

3.3 Measure of physical investments

Establishments are asked to indicate (yes/no) whether they have made operational investment in one or several of the areas such as real estate, information and communications technology, electronic data processing, production facilities and transportation systems. Each of these are denoted by binary variables, and then recoded as a single variable for overall operational investment.

3.4 Measure of innovative activities

For innovation output, commonly-used indicators are employed, such as whether the enterprise has improved or further developed a product or service (measure for incremental product innovation), whether the establishment has developed or implemented procedures that have improved production processes or services (measure for incremental process innovation) and whether the enterprise has offered a completely new product or service to the market (measure for new-to-market innovativeness). Each of the three variables is indicated by binary values.

3.5 Measure of R&D cooperation

The measure for R&D collaboration, given by whether or not research and development is carried out in cooperation with others, is indicated by a binary variable (0/1). Furthermore, establishments who cooperate in R&D are asked to specify the kind of cooperation partners they have: other private establishments and competitors ('horizontal'), universities or research institutes ('institutional'), or consulting firms ('consulting'). Each of these three variables is given by dichotomous variables.

3.6 Control variables

A wide range of establishment-level, industry-level and market-level control variables are included in the analysis. Drawing on the literature that finds a significant relationship between firm size and the probability of conducting R&D (Cohen et al. 1987;

Cohen and Klepper 1996), establishment size is used to control for the level of R&D activities and is given by the natural logarithm of total workforce. Sector affiliation of establishments is given by 2-digit NACE industry classification and included in the analysis as dummies (for construction of aggregated sector dummies, see Table 6 in Appendix). Additional controls, such as whether establishment belongs to east/west Germany, whether establishment is part of a multi-establishment and whether the establishment is an individually-owned firm or a partnership are included. New hiring is given by a binary variable denoting whether the establishment has hired new staff in the previous year. Establishments are asked to assess the overall technical state of the plant in terms of technology, machinery, office equipment on a scale of 1–5 with 1 being state-of-the-art and 5 being obsolete. Finally, pressure from competition that the establishment has to deal with is added as a market-level control and is denoted by a categorical variable ranging from 1 to 4 with 1 being no competitive pressure and 4 being substantial pressure from external competition.

4 Methodology

In order to determine the relationship between firms' R&D cooperation strategies and human resource practices, and subsequently the effect of R&D collaboration conditioned upon human resource practices on innovation performance, a two-step structural modelling is adopted as the suitable estimation technique. The procedure draws inspiration from the CDM model (Griffith et al. 2006) and attempts to understand the effect of R&D cooperation conditioned upon HRM and other firm characteristics on innovation output. Subsequently, the first stage of the equation is estimated as follows:

$$\begin{aligned} Cooperation_{i,t} &= \beta_1 + \beta_2 Employment_{i,t-2} + \beta_3 Compensation_{i,t-2} \\ &+ \beta_4 R\&D_{i,t-2} + \beta_5 Z_{i,t} + \epsilon_{i,t} \end{aligned} \tag{1}$$

where $Cooperation_{i,\ t}$ represents three binary equations, each represented by a dummy variable for each type of cooperation- horizontal, institutional and consulting respectively. $Employment_{i,\ t-2}$, $Compensation_{i,\ t-2}$ *and* $R\&D_{i,\ t-2}$ denote 2-years lagged variables on employment practices, compensation programs and R&D intensity respectively. $Z_{i,\ t}$ indicates the additional core and supplementary variables and $\epsilon_{i,\ t}$ is the unobserved error term. The main independent variables of interest are lagged by 2 years for two reasons. *First*, to reduce the potential simultaneity problem within a discrete choice model setup in the sense that while greater investment in human resource practices increases the likelihood of having a research collaboration, firms cooperating in R&D are also more likely to invest more in human resource practices. *Second*, R&D cooperation decisions requires past information on market and firm characteristics, which makes it necessary to use data from previous years to estimate collaboration strategy in the current year.

Earlier studies (Belderbos et al. 2004; Carboni 2010) find that the choice of a collaboration partner is not independent of another. In other words, the probability of having one type of cooperation partner is correlated with that of having the other type(s), therefore not accounting for such systematic correlations would produce biased results. Belderbos et al. (2004) employ a multivariate probit estimation in order to account for such systematic correlations among different cooperation partners. Kaiser (2002) uses a nested multinomial logit model in order to incorporate a sequential process, where firms decide whether to collaborate in R&D in the first stage and whom to collaborate with in the second. This specification implies that the second stage of the decision making process matters for the first stage, which might not be appropriate given that firms decide simultaneously upon research cooperation and the type of partners. Franco and Gussoni (2010) use a multinomial logit estimation assuming that the probability of choosing one type of collaboration partner is stochastically independent from the probability of choosing other types of partners. However, a potential problem with this approach is that in the presence of possible interdependencies between R&D cooperation strategies, estimates may turn out to be inefficient. This is indeed the case in this context, as it is highly likely that the three cooperation strategies are not independent of each other (see Table 8 in Appendix for correlation table). The multivariate limited dependent variable technique proposed by Belderbos et al. (2004) accounts for such pair-wise correlation and therefore has been employed in this analysis. Consequently, it takes the following form:

$$\begin{aligned} y^*_{i,k} &= x_{i,k}\beta_k + \omega_{i,k} \\ y_{i,k} &= \begin{cases} 1, & if\ y^*_{i,k} > 0 \\ 0, & otherwise \end{cases} \end{aligned} \tag{2}$$

where $i = 1, \ldots\ldots, N$ denotes the unit of analysis establishments and k stands for the number of cooperation strategies, which in this case corresponds to 3. $y^*_{i,k}$ is the set of unobserved latent variables. The assumption for multivariate probit model is that each observed variable $y_{i,\ k}$ will take the value 1 if and only if the underlying latent variable is positive. β_k is the vector of parameters to be estimated, $x_{i,\ k}$ is the set of explanatory variables, and $\omega_1\omega_2\omega_3$ N $(0, \Sigma)$ are the corresponding error terms, with Σ being the covariance matrix of error terms. Solving this system of equations requires a maximum likelihood estimation technique (Cappellari and Jenkins 2003) using the Geweke-Hajivassiliou-Keane (GHK) simulator that calculates the joint probabilities of all possible combinations. As robustness check, univariate logit models with exclusive cooperation categories are estimated, for private only, university only, consulting only and mixed type (see Table 4 in Appendix).

The second stage of the structural model for analysing the conditional effect of R&D on innovation is conducted in two steps. *First*, the linear predicted probabilities for R&D cooperation strategies determined by human resource practices are extracted from the multivariate probit estimation (eq.1). Next, these predicted probabilities are implemented in the final innovation equation instead of the raw values to estimate the probability of introducing an innovation. This procedure is similar to the three-stage CDM model of R&D expenditure, innovation output and productivity, except that in this case, sample selection bias is not a concern given the binary nature of the variables. This allows for estimating the model only in two steps. The method also ensures that the predictions for cooperation-types are not systematically related to innovation output (simultaneity) and therefore accounts for unobserved heterogeneity that might determine R&D cooperation relationships. Additionally, it also allows for a better understanding of the contribution of expected R&D cooperation conditional on HRM to innovation performance. However, one disadvantage of using predicted values for interdependent R&D cooperation partners in a single equation framework is that it introduces multicollinearity into the system. In order to obtain unbiased estimated coefficients, therefore, individual estimations are conducted for each type of collaboration partner. Also, given the potential drawback associated with identification when considering highly significant variables from first-stage estimation in the second step, none of the main variables relating to human resource practices and R&D intensity are included in the innovation model.

An added concern with respect to unobserved heterogeneity may arise when analyzing data on time series cross-section or panel due to time-invariant individual effects. Two methods that are usually employed in order to address this issue are fixed effect and random effect models. Fixed effect model assumes the individual-specific effect to be constant over time, while the random effect model treats this unobserved heterogeneity as randomly drawn from the underlying probabilistic distribution. For the current analysis, random effects model is employed, assuming that the individual effects are uncorrelated with the regressors. The reasons for such a model specification are as follows. *First*, estimates computed using a fixed-effect model for a panel can be biased over short periods (Heckman 1981a) which may not a problem for random-effects. Since the analysis covers only three waves during 2007–2011, the random effect model is clearly the favored approach. *Second*, a fixed-effect model does not include estimation of the time-invariant components, which may be a serious limitation in this case. *Finally*, it can be assumed that the sampled cross-sectional units of the IAB establishment panel are drawn from a large population. Following these arguments, simple probit estimations using random effects, panel adjusted standard errors and time dummies are used, that compares the probability of firms coming up with product, process or new-to-market innovation with that of firms being non-innovative.[1]

Incorporating these econometric issues, eq. 3 presents the second specification of the structural model.

$$Innovation_{i,t} = \beta_1 + \beta_2 Cooperation_{pred} + \beta_3 X_{i,t} + u_{i,t} \tag{3}$$

where $Innovation_{i,\ t}$ represents corresponding innovation variables: incremental product, process and new-to-market, and $Cooperation_{pred}$ denotes predicted probabilities for cooperation. $X_{i,\ t}$ indicates additional core and supplementary variables and $u_{i,\ t}$ is the unobserved error term.

5 Results and discussion

The pattern of R&D cooperation among the firms in the final pooled sample is presented in Table 1. Of the 1658 cases, about 89% are in R&D cooperation, as compared to 11% with no R&D cooperation. Among the R&D cooperation established, 8.81% are exclusively with other private enterprises or market competitors, 19.18% are with university or research institutes only and 4.70% are with consulting firms only.

[1] The Hausman test confirms the use of a random-effect model since the null hypothesis on the difference in coefficients not being systematic cannot be rejected.

Table 1 Distribution of R&D cooperation types for the final sample

Cooperation type	Number of cases	% of total sample
No cooperation	187	11.28
Cooperation	1471	88.72
- Private only	146	8.81
- University/Institutional only	318	19.18
- Consulting only	78	4.70
- Mixed cooperation	929	56.03
Total Sample for 2007–2011	($N = 1658$) ($n = 1170$)	

Evidently, most R&D cooperations are mixed (56.03%), implying that majority of the firms cooperating in R&D has more than one collaboration partners.

Next, following the empirical strategy previously mentioned we start by estimating the first stage of the structural model (eq. 1) on the relationship between human resource practices as a measure for firms' absorptive capacity and R&D cooperation. Column 1 of Table 2 presents the marginal effects obtained from probit estimation with binary R&D cooperation variable, while column 2–4 present the estimated coefficients from the multivariate probit analysis with heterogeneous collaboration partners. When considering the binary measure of R&D cooperation, R&D intensity is found to be a significant predictor implying that firms associated with greater R&D activities are more likely to be in a R&D cooperation relationship. However, none of the HRM-based absorptive capacity measures provides strong evidence. Furthermore, the overall fit of the model indicates poor predictability thus reinforcing the importance of considering heterogeneity in R&D cooperation relationships. Subsequently, results from the multivariate probit estimation are presented in Table 2, which provide significantly improved model fit and confirm the drawback associated with aggregating varied cooperation strategies into a single indicator.

First, looking at the likelihood ratio (LR) test for the various combinations of R&D cooperation strategies, interdependency is confirmed. This finding reaffirms the choice of the estimation strategy, which assumes significant pair-wise correlation among different cooperation partners, rather than considering them as independent choices. *Second*, lagged employment practices are found to strongly explain R&D cooperation, regardless of the type of collaboration. This establishes the previous claim that, human resource practices are aimed at increasing employee productivity and capabilities, and therefore firms' overall knowledge stock and absorptive capacity. Hence, these should be significant for all types of R&D collaboration strategies, showing support for hypothesis 1. Compensation and incentive programs on the other hand, are found to only explain R&D cooperation, albeit weakly, with private firms and competitors but not with any other type of collaboration partner. This result is also in-line with the theoretical arguments, that oftentimes compensation and incentive payments are offered to R&D employees when there is a higher risk of employee mobility and poaching between firms. This risk of labor turnover and increased outgoing spillovers is greatest in case of horizontal R&D cooperation where firms with similar knowledge profile, employability conditions and appropriation mechanism operate in unison. Therefore,

Table 2 Heterogeneity in R&D cooperation strategies

	Binary Cooperation	Private cooperation	University cooperation	Consulting cooperation
$\text{Employment}_{t\text{-}2}$	0.092*	0.567***	0.891***	0.543***
	(0.052)	(0.207)	(0.221)	(0.206)
$\text{Compensation}_{t\text{-}2}$	0.042	0.185*	0.050	0.156
	(0.028)	(0.112)	(0.128)	(0.112)
R&D $\text{intensity}_{t\text{-}2}$	0.140**	0.758***	0.783***	0.111
	(0.059)	(0.219)	(0.272)	(0.209)
Size	0.009	−0.041	0.175***	0.089***
	(0.008)	(0.026)	(0.033)	(0.027)
University share	0.001	0.004*	0.011***	0.001
	(0.001)	(0.002)	(0.003)	(0.002)
Skilled share	0.001	0.002	0.005**	−0.002
	(0.001)	(0.002)	(0.002)	(0.002)
Operational investment	0.017	0.141	0.093	0.089
	(0.027)	(0.109)	(0.123)	(0.116)
Constant		−0.512***	−1.595***	−0.974***
		(0.194)	(0.225)	(0.195)
Sector dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes

Dummy DV(s). Cluster-adjusted standard errors in parentheses $*p < 0.10$ $**p < 0.05$ $***p < 0.01$. N = 1658, $n = 1170$

Univariate probit (column 1), Multivariate probit (column 2, SML draws = 100)

Wald chi2 = 55.26* (243.09***), Log pseudolikelihood = −545.58 (−3071.86)

Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi2 (Almeida and Kogut 1999) = 70.41***

private firms having an effective payment and employee retention system are more likely to cooperate in R&D with other competing firms, as compared to firms who have none. The finding provides support for hypothesis 2, while no such effect is found for institutional or consulting cooperation. This is because private firms cooperate with universities and academic institutions for undertaking basic research while collaborations with consultant companies are often associated with exchange of applied knowledge and market information. These types of exchanges seldom involve high risk of employee poaching and violation of intellectual property rights, given the very different knowledge portfolios and appropriation mechanism involved. Taken together, these findings suggest the possibility of relationships that is yet to be documented in the innovation and strategic management literature. In other words, where Cohen and Levinthal (1990), Lane and Lubatkin (1998), Zahra and George (2002) provide a process perspective of absorptive capacity pertaining to intra-organizational learning, our reconceptualization and results empirically verify the overlap between organizational structures and employment practices on the one hand and external knowledge management on the other. As Lane et al. (2006, p. 847) point out, “such a capability approach that focuses on both organizational structure and knowledge content as distinctive and integral components of absorptive capacity, rather than one that merely focuses on the “what” of knowledge, is critical in understanding how organizations acquire, assimilate, and exploit knowledge”, this finding forms the first significant contribution of the paper.

With regard to R&D intensity measured in terms of R&D employees, it is found to have a significant and positive impact on horizontal cooperation with private establishments and cooperation with universities and research institutes, but none with respect to consulting firms. The results might stem from the fact that consulting firms are more often associated with marketing and advertising innovation, and not necessarily scientific research unlike private firms or universities. When cooperating with other private firms or research institutes with similar basic knowledge spectrum, it is more likely that firms with higher degrees of R&D intensity are able to gain greater benefit from exploiting complementary knowledge of their partners than firms with less R&D intensity. However when the cooperation partner is a consulting firm, cooperation agreements might be solely based on risk-sharing or marketing rather than exploitation of complementary assets relating to research and development.

With respect to other explanatory variables and controls, emphasis is first placed on the employment structure of the establishment. A greater share of employees having a university degree in total workforce is found to be significantly and positively associated with cooperation with private as well as research institutes, while no such effect is obtained with respect to consulting cooperation. Additionally, higher share of skilled workers in the workforce is found to significantly explain cooperation with research institutes and universities. Both these findings indicate the importance of human capital stock in firms’ economic decisions and effective management of social capital. Next, size of the establishment measured in terms of workforce strength is found to be an important criterion for R&D cooperation, implying that larger establishments on average tend to cooperate more on R&D. However, significant differences are observed between private cooperation and institutional and consulting-based cooperation. This again relates to the literature on firm size, R&D activities and performance (Acs and Audretsch 1987; Pavitt et al. 1987; Cohen et al. 1987) which provides mixed evidence. Overall firm size is found to have a negligible impact on R&D intensity of business units when inter-industry differences are controlled for. Moreover, share of R&D employees, rather than aggregated employee stock, is more likely to be associated with research collaboration with private firms as is the case here. Finally, no significant effect of physical investment, investment in ICT, electronic data processing and production facilities is found on the probability of having R&D cooperation.

For the second stage of the structural model (eq. 3) on the conditional effect of R&D cooperation on innovation, results are reported in Table 3. Considering three measures of innovation- incremental product, incremental process and new-to-market innovation, individual probit estimations are conducted, first with predicted binary cooperation without distinguishing between types of cooperation partner (Model 1), and second with predicted probabilities for each of type of collaboration partner (Model 2- Model 4). Starting with the binary cooperation variable, evidence suggests that variation in R&D cooperation predicted by human resource practices and R&D intensity significantly explain all types of innovation performance of establishments. However, the marginal effects obtained from individual probit estimations indicate that the conditional probabilities of incremental process and new-to-market innovation increase by

Table 3 Marginal effects for Innovation performance

	Product				Process				New-to-market			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Pred. binary coop.	0.417**				1.339***				1.031***			
	(0.212)				(0.311)				(0.309)			
Pred. private coop.		0.029				0.150**				0.221***		
		(0.040)				(0.063)				(0.058)		
Pred. university coop.			0.040*				0.180***				0.126***	
			(0.021)				(0.032)				(0.031)	
Pred. consulting coop.				0.092**				0.389***				0.228***
				(0.043)				(0.063)				(0.062)
Hiring	0.030*	0.037**	0.026	0.024	0.012	0.034	−0.010	−0.015	0.044	0.059**	0.030	0.031
	(0.018)	(0.017)	(0.018)	(0.018)	(0.028)	(0.028)	(0.029)	(0.028)	(0.027)	(0.027)	(0.028)	(0.028)
East/West	0.055***	0.055***	0.052***	0.045***	0.090***	0.097***	0.078***	0.047*	0.004	0.019	−0.005	−0.022
	(0.016)	(0.017)	(0.016)	(0.017)	(0.027)	(0.028)	(0.027)	(0.028)	(0.026)	(0.026)	(0.026)	(0.026)
Techstate	−0.033***	−0.035***	−0.033***	−0.032***	−0.119***	−0.124***	−0.115***	−0.113***	−0.062***	-0.064***	-0.061***	-0.061***
	(0.012)	(0.012)	(0.012)	(0.011)	(0.017)	(0.017)	(0.017)	(0.017)	(0.016)	(0.016)	(0.017)	(0.017)
Legalform	−0.009	−0.007	−0.014	−0.012	−0.007	−0.001	−0.031*	−0.023	0.020	−0.019	−0.036**	−0.028
	(0.010)	(0.010)	(0.010)	(0.010)	(0.017)	(0.018)	(0.018)	(0.018)	(0.017)	(0.017)	(0.018)	(0.018)
Status	0.039**	0.043**	0.038**	0.037**	0.071***	0.087***	0.060**	0.054**	−0.014	−0.002	−0.021	−0.021
	(0.017)	(0.017)	(0.018)	(0.018)	(0.026)	(0.026)	(0.026)	(0.027)	(0.025)	(0.025)	(0.025)	(0.025)
Competition	0.030***	0.032***	0.030***	0.028***	0.052***	0.058***	0.049***	0.044***	0.015	0.019	0.013	0.011
	(0.009)	(0.009)	(0.009)	(0.009)	(0.016)	(0.016)	(0.016)	(0.016)	(0.015)	(0.015)	(0.015)	(0.015)
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wald chi2	110.25***	109.39***	115.13***	117.96***	116.07***	105.76***	123.82***	131.63***	42.38***	46.57***	47.60***	45.29***
Pseudo R2	0.12	0.11	0.11	0.12	0.06	0.06	0.07	0.07	0.02	0.03	0.03	0.03

Univariate probit model with dummy dependent variable(s)

Delta-method standard errors in parentheses, $*p < 0.10$ $**p < 0.05$ $***p < 0.01$

Number of observations = 1658, Number of firms = 1170 more than 70% as compared to product innovation, in response to a one unit change in R&D cooperation.

Looking next at the different types of R&D cooperation, significant differences in innovation performance are observed for private, institutional and consulting cooperation. With respect to product innovation, predicted cooperative R&D with research institutes and consulting firms are found to significantly impact the likelihood of coming up with incremental product innovation; while no such effect is found with regard to horizontal cooperation. This finding could either indicate that variation in private R&D cooperation predicted by HRM practices have no significant effect on product innovation, or that such cooperation in general has a positive effect on product innovation but not through HRM. However, in the case of incremental process and new-to-market innovation, all three types of cooperation are found to have strong and positive impacts, supporting hypothesis 3b and 3c. In principle, these results provide a similar consensus regarding the relationship between research collaboration and firm performance, in-line with the works of Kaiser (2002), Cassiman and Veugelers (2002) and Belderbos et al. (2004). However, where this research differs from existing studies is in the way R&D cooperation on innovation is measured, taking into account possible simultaneity bias and unobserved heterogeneity. Additionally, it provides fresh evidence on the effects of expected R&D cooperation conditioned upon HRM on innovation performance, thus forming the second major contribution of the paper.

With regard to the control variables, hiring of new staff in the previous year increases firms' human capital stock and R&D activities and thereby is found to significantly affect incremental product innovation. Regional geography is found to determine innovation performance, in the sense that establishments belonging to West Germany are found to innovate more than East German firms. However, the effect is most pronounced for product and process innovation while no such east-west differences are obtained for new-to-market innovation performance. Overall technical state of the plant in terms of technology, machinery, office equipment is considered to be a strong determinant of innovation, and the negative significant relationship suggests that establishments with obsolete technologies innovate less than establishments that are on par with latest technological requirements. Finally, firms with multiple business units are found to innovate more than single establishment firms, while substantial pressure from external competition motivates firms to continuously innovate and improve upon already existing products and processes.

6 Concluding remarks and policy implications

"As competition becomes more knowledge-based, a firm must develop a thorough understanding of its own knowledge, the processes by which it converts knowledge to capabilities, and the capacity of those capabilities to meet the demands of its environment" (Lane and Lubatkin 1998, p. 474). To this end, researchers have extensively used absorptive capacity to explain the process of identification, assimilation and utilization of knowledge to gain competitive advantage. However, despite growing interest, many conceptual and empirical ambiguities have remained due to diversity of its underlying components, antecedents and unsystematic measurement of outcomes (García-Morales et al. 2011). The current paper addresses these concerns in three major ways: *First*, using Zahra and George's (2002) definition as a point of departure, we contribute to the reconceptualization of absorptive capacity by emphasizing on firms' human resource practices and organizational settings employees operate in. In so doing, we move away from an exclusive R&D (Cohen and Levinthal 1990) and human capital (Rothwell and Dodgson 1991; Vinding 2006) focus of absorptive capacity to a broader "dynamic capability" outlook by considering employment practices and compensation mechanisms. *Second*, emphasis is placed on the role of human resource practices as an antecedent of absorptive capacity in managing external knowledge. In providing sufficient spillovers and appropriability conditions for research collaboration, we confirm the importance of firms' human resource and knowledge management practices in alliance-formation and partner selection that has been mostly overlooked in existing literature. *Finally*, the conditioned effect of research collaboration on firms' incremental and new-to-market innovation outcome is examined to empirically verify whether greater absorptive capacity results in firms' increased likelihood of introducing new or improved products or services to the market through efficient utilization of external knowledge.

The analysis uses IAB Establishment Panel on around 1200 German private-sector establishments for a period of 2007–2011 and a two-stage structural model to account for possible simultaneity bias. In the first stage, distinction is drawn between horizontal, institutional and consulting cooperation partners and a multivariate probit model is estimated assuming interdependency of collaboration strategies. In the second stage, the effect of cooperative R&D conditioned upon HRM is estimated on product, process and new-to-market innovation performance. In other words, evidence is provided for the effects of HRM through cooperative relationships on innovation, and not their direct impacts on innovation. Confirming theoretical expectations, firms' human resource practices are found to play a major role in determining R&D cooperation and partner selection. Specifically, adoption of employment practices is found to positively affect R&D cooperation, irrespective of the type of partner, while compensation programs are found to positively affect R&D cooperation only with private firms. Finally, cooperative R&D with research institutes and consulting firms are found to significantly impact the likelihood of coming up with incremental product, process and new-to-market innovation, whereas the effect is relatively weaker in case of horizontal R&D cooperation.

Findings from this paper not only contribute to the theoretical understanding of human resource practices as major determinants of absorptive capacity and innovation in cooperation relationships, but also provide implications for policy intervention. *First*, by defining absorptive capacity as employment practices and compensation programs, the main practical implication derived is that investment solely in R&D and capital resources is not sufficient for innovation in inter-firm linkages. It is also essential to know when, how and to what extent should firms adopt strategies that improve employee competencies and capabilities as well as build social capital and innovative capabilities. Looking at statistics for Germany, the Federal Institute for Vocational Education and Training reports that the dual system of vocational education has made an important contribution in keeping the youth unemployment rates across the country low. However, the overall picture is significantly different when considering investment in human capital in private sector firms, with the rate of company-sponsored training decreasing by 0.8% in 2012 as compared to the previous year thus reporting the lowest level of in-company training since 1999. Given the necessity of human capital and employee resources in building and upgrading absorptive capacity, managing external knowledge linkages and building innovative capabilities in firms, policy should therefore focus on providing greater access to training, employment restructuring, better employability conditions and incentive-compensation schemes for employees to improve innovation performance especially in research collaborations. Finally, results from the empirical analysis indicate that cooperation with private firms, universities and consultation-based firms are important for process and new-to-market innovation and less so for product innovation. Consequently, policy should aim at greater investment in absorptive capacity of employees that increase their motivation, interpersonal skills and dynamic creativity to be able to derive substantial benefits from R&D collaboration relationships, especially in terms of explorative innovation performance.

While the study provides interesting insight into the black box of firms' human resource practices in determining social capital and innovation, it also advances scope for further analysis. *First*, even though human resource practices and compensation programs are found to positively influence R&D cooperation across different partner-types, it can be expected that there exist sectoral differences depending on how technologically advanced a sector is. For example, firms in high-tech sector might be associated with greater horizontal cooperation than firms in the low-tech sector. This is because high-tech firms might find it essential to better exploit complementary knowledge and R&D resources of the rivals in order to extend their network structure. Similar differences are also expected with respect to knowledge-based, ICT-based and supply-dominated firms. *Second*, the sample presented here consists of innovation firms. This might be a reason to expect that the sample suffers from a "sample-selection" bias. Given the nature of the dependent variables used in the analysis, a Heckman correction (Heckman 1979) is not possible. However, one can think of using Generalized Linear Latent and Mixed Model (GLLAMM, Rabe-Hesketh et al. 2002) in order to account for the potential limitation. *Finally*, given that both are somewhat different proxies of firm-level absorptive capacity, it can be expected that there exists a strong complementarity between employment practices and compensation programs. Following this line of thought, a complementarity analysis between different measures of human resource practices is being conducted in a succeeding study using the adoption-productivity approach suggested by Cassiman and Veugelers (2002).

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Compliance with ethical standards The manuscript is original and has not been published nor is under consideration for publication elsewhere.

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

Table 4 Univariate probit model with exclusive R&D cooperation categories

	Only private	Only university	Only consulting	Mixed cooperation
Employment$_{t-2}$	−0.850***	−0.545**	−0.668**	1.199***
	(0.298)	(0.235)	(0.336)	(0.216)
Compensation$_{t-2}$	0.013	−0.095	0.077	0.166
	(0.164)	(0.131)	(0.193)	(0.114)
R&D intensity$_{t-2}$	−0.349	−0.326	−1.146***	0.753***
	(0.328)	(0.262)	(0.414)	(0.215)
Size	−0.160***	0.023	−0.088**	0.064**
	(0.041)	(0.029)	(0.043)	(0.028)
University share	−0.009***	−0.001	−0.003	0.007***
	(0.003)	(0.003)	(0.003)	(0.002)
Skilled share	−0.001	0.001	−0.006**	0.003
	(0.002)	(0.002)	(0.002)	(0.002)
Operational investment	−0.017	−0.070	−0.021	0.149
	(0.142)	(0.123)	(0.194)	(0.111)
Constant	0.179	−0.773***	−0.461	−1.401***
	(0.267)	(0.221)	(0.282)	(0.206)
Sector dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Wald chi2	74.75***	27.89***	32.84***	111.50***
Pseudo R2	0.08	0.02	0.05	0.06

Cluster-adjusted standard errors in parentheses *p < 0.10 **p < 0.05 ***p < 0.01. N = 1658, n = 1170

Table 5 Tetrachoric correlation on 11 binary human resource practices and grouping

Profit share	1										
Staff share	0.6061	1									
External training	0.1489	0.0256	1								
In-company training	0.0653	0.0772	0.1753	1							
On-the-job	0.1093	0.1341	0.2486	0.5465	1						
Lectures	0.1281	−0.0049	0.4876	0.3276	0.456	1					
Job rotation	0.1813	0.2557	0.1478	0.3886	0.6635	0.3117	1				
Self study	0.1544	0.255	0.235	0.3969	0.4169	0.4446	0.3579	1			
Quality workshop	0.1782	0.204	0.2048	0.3631	0.5096	0.3505	0.4485	0.3766	1		
Other	0.0145	−0.0972	0.1366	0.3667	0.1884	0.3047	0.2996	0.2884	0.2673	1	
Hired personnel	0.0808	0.0926	0.3754	0.3563	0.2238	0.3474	0.2358	0.216	0.1772	0.2055	1

Table 6 Industrial classification and subsequent generation of sector dummies

Current sector affiliation	Dummies generated
Agriculture/forestry	Primary sector (base group)
Mining/energy	Manufacturing
Food/luxury	Construction and engineering
Textiles/clothing	Trade, repair and transport
Paper/printing	Financial and insurance services, ICT, real estate
Wood sector	Other services, organizational and public administration
Chemical sector	
Plastics industry	
Glass/stones/ore extraction	
Metal production	
Recycling	
Metal goods/steel production	
Engineering	
Vehicle engineering	
Other vehicle production	
Electrical engineering	
Precision engineering/optics	
Furniture/jewelry/toys	
Main building sector	
Building/installation	
Car-rent/−reparation/gas-station	
Wholesale trade	
Retailing/reparation	
Traffic	
Financial sector	
Insurance	
Data processing	
Research/development	
Judiciary/advertising	
Realties/ flats	
Renting	
Educational institutions	
Health/social	
Waste-management	
Culture/sports/entertaining	
Other services	
Organizations	
Civil service/social insurance	
Other civil services	
Others	

Table 7 Variable description

Variables	Definition
Employment	Index of employment practices. Average of the scores for all items calculated and recoded on a scale of 0–1, 1 being highly provided and 0 otherwise
Compensation	Index of compensation schemes. Average of the scores for all items calculated and recoded on a scale of 0–1, 1 being highly provided and 0 otherwise
R&D intensity	Ratio of employees engaged fully and partially in R&D to the total number of employees in the establishment
Skilled share	Share of skilled blue-collar and white-collar workers requiring vocational education in total workforce
University share	Share of qualified white-collar employees requiring university degree in total workforce
Operational investment	Operational investment made in one or several of the areas such as real estate, ICT, electronic data processing, production facilities and transportation system.
	Average of the scores for all items calculated and recoded on a scale of 0–1, 1 being highly provided and 0 otherwise
Incremental product innovation	1 if establishment has improved or further developed a product or service, 0 otherwise
Incremental process innovation	1 if establishment has developed or implemented procedures that have improved production processes or services, 0 otherwise
New-to-market innovation	1 if establishment has offered a completely new product or service to the market, 0 otherwise
Cooperation	1 if research and development is carried out by the establishment in cooperation with others, 0 otherwise
Private cooperation	1 if research and development is carried out by the establishment in cooperation with other private establishments and competitors, 0 otherwise
University cooperation	1 if research and development is carried out by the establishment in cooperation with universities or research institutes, 0 otherwise
Consulting cooperation	1 if research and development is carried out by the establishment in cooperation with consulting firms, 0 otherwise
Establishment size	Natural logarithm of total workforce
Sector affiliation	Dummies corresponding to NACE 2-digit industry classification
New hiring	1 if establishment has hired new staff in the previous year, 0 otherwise
East/west Germany	1 if establishment belongs to West Germany, 0 otherwise
Technical state	Overall technical state of plant (technology used, machineries, office equipments), on a scale of 1–5 with 1 being state-of-the-art and 5 being obsolete
Legal form	Legal form of organization of enterprise, 1 if individually-owned, 2 if partnership, 3 if limited partnership, 4 if capital corporation, 5 if public corporation, 6 if others
Establishment status	1 if multiplant establishment, 0 otherwise
Competition	Pressure from market/external competition, categorical variable ranging from 1 to 4 with 1 being no competitive pressure and 4 being substantial pressure

Table 8 Correlation table

Binary coop.	1																										
Private coop.	0.3737*	1																									
University coop.	0.5677*	0.1114*	1																								
Consulting coop.	0.3105*	0.1358*	0.1791*	1																							
Product innov.	-0.0297	-0.0172	0.0082	0.1014*	1																						
Process innov.	0.0325	0.0369	0.0457	0.1014*	0.2808*	1																					
New-to-market in.	0.0504*	0.0618*	0.0768*	0.1093*	0.1817*	0.2455*	1																				
R&D lag	0.1017*	0.1343*	0.1145*	-0.011	-0.1606*	-0.0539*	0.0519*	1																			
Empl. lag	0.0845*	0.0640*	0.2065*	0.1347*	0.0890*	0.1625*	0.0782*	-0.1038*	1																		
Comp. lag	0.0349	0.0387	0.0486*	0.0791*	0.0829*	0.1059*	0.0404	-0.1297*	0.1711*	1																	
Size	0.0454	-0.0263	0.1849*	0.1468*	0.1274*	0.2039*	0.0560*	-0.3107*	0.5035*	0.2059*	1																
University share	0.1168*	0.1190*	0.1843*	0.0274	-0.1093*	-0.0365	0.0476	0.5891*	0.0437	-0.0189	-0.1028*	1															
Skilled share	-0.0333	-0.0549*	-0.0459	-0.0217	0.0936*	0.0379	-0.0530*	-0.4299*	0.0218	0.0714*	0.1274*	-0.6125*	1														
Op. invest	0.0311	0.0258	0.0850*	0.0679*	0.1036*	0.1293*	0.0375	-0.1160*	0.2008*	0.0870*	0.2895*	0.0116	0.0353	1													
Hiring	0.0208	-0.0138	0.0905*	0.0713*	0.0445	0.0444	0.0563*	-0.0483*	0.1710*	0.0306	0.3340*	0.0730*	0.0357	0.1819*	1												
West	-0.0409	-0.1226*	0.0195	0.0812*	0.0871*	0.0945*	0.0056	-0.1137*	0.1319*	0.0919*	0.2914*	-0.1324*	-0.0748*	-0.0111	0.0742*	1											
Tech state	-0.0565*	-0.0439	-0.0890*	-0.0517*	-0.0453	-0.1662*	-0.1059*	-0.1282*	-0.0975*	-0.0104	-0.0382	-0.1281*	0.0735*	-0.0993*	-0.0393	0.0217	1										
Legal form	0.1069*	0.0332	0.1890*	-0.0029	-0.1147*	-0.0275	-0.0347	0.2756*	0.1275*	-0.0997*	0.2465*	0.3738*	-0.1507*	0.0512*	0.1601*	0.0292	-0.0418	1									
Status	0.0122	-0.028	0.0871*	0.0221	0.0875*	0.1224*	0.0069	-0.0632*	0.1686*	0.1296*	0.3375*	0.0642*	-0.0319	0.0641*	0.1070*	0.1789*	-0.0262	0.1755*	1								
Competition	0.0192	0.0106	-0.009	0.0665*	0.1726*	0.1177*	0.0376	-0.2657*	0.1111*	0.1888*	0.1520*	-0.2023*	0.1661*	0.0696*	-0.0242	-0.0019	0.0791*	-0.2354*	0.0786*	1							
Primary	-0.0732*	-0.0257	-0.1068*	-0.0373	0.0348	0.0228	0.0243	-0.2262*	-0.0237	0.0042	0.029	-0.2725*	0.1299*	0.0224	0.0284	-0.0269	0.0628*	-0.1350*	0.0388	0.1049*	1						
Manufacturing	-0.0275	0.0015	-0.0103	-0.0067	0.0601*	0.0559*	0.011	-0.1809*	0.0754*	0.1503*	0.1880*	-0.1546*	0.0984*	0.0600*	-0.022	-0.0175	0.0408	-0.1280*	0.0501*	0.1442*	-0.3191*	1					
Construction	0.0063	-0.0357	0.0254	0.0793*	0.1390*	0.0512*	0.0037	-0.1911*	0.0397	0.0727*	0.1265*	-0.1446*	0.1825*	0.0211	-0.033	0.0148	0.0873*	-0.1570*	0.0098	0.1333*	-0.3681*	-0.0907*	1				
Trade-transport	-0.0341	0.0297	-0.045	-0.0021	0.0225	-0.013	0.0541*	0.1466*	-0.1011*	0.0284	-0.2337*	0.1722*	-0.1659*	-0.0530*	-0.0590*	0.046	-0.0821*	-0.0638*	-0.0477	-0.0550*	-0.1352*	-0.1451*	-0.1673*	1			
Financial	0.0924*	0.0551*	0.1082*	-0.0036	-0.1697*	-0.0456	-0.0251	0.5859*	-0.0700*	-0.1009*	-0.2024*	0.4334*	-0.3187*	-0.029	-0.0129	0.0058	-0.1254*	0.2832*	0.0025	-0.2370*	-0.1962*	-0.2105*	-0.2428*	-0.0892*	1		
Other service	0.0935*	0.0311	0.0882*	-0.0445	-0.1410*	-0.0745*	-0.0339	0.0730*	0.1085*	-0.1833*	0.0605*	0.1913*	-0.1057*	-0.0519*	0.1042*	0.0016	-0.0539*	0.3501*	-0.0463	-0.2154*	-0.1732*	-0.1859*	-0.2145*	-0.0788*	-0.1143	1	

Correlation Matrix: Correlations greater than or equal to 0.05 (in absolute terms) are significant ($p < 0.05$)

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