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Abstract

In the literature on environmental innovations R&D collaborations have been identified as a critical determinant of a firm's environmental innovation performance. However, the literature suggests that R&D collaboration is not always beneficial. Therefore, a more elaborated analysis of the effects of R&D collaborations on a firm's environmental innovation performance is necessary. This paper investigates the impact of R&D collaborations with different partner types such as customers, competitors, suppliers, universities, governmental research institutes, consultants and other firms within the same firm group on a firm's environmental innovation performance. In addition, this paper addresses the question of whether the diversity of R&D collaboration partners is important for the environmental innovation performance. Firm-level data from 2,337 German service and manufacturing firms are used in the regression analysis. The results suggest that R&D collaboration with suppliers, customers, universities, governmental research institutes, consultants and other firms within the same firm group has a significantly positive impact on a firm's environmental innovation performance, whereas collaboration with competitors has no significant impact. The diversity of R&D collaboration partners has a significantly positive impact on a firm's environmental innovation performance.

Keywords: R&D, collaboration, environment, innovation

JEL Classification: O31, O32

Die Bedeutung von verschiedenen Kooperationspartnertypen für die betriebliche Umweltinnovation

Zusammenfassung

FuE-Kooperationen spielen eine bedeutende Rolle bei der Schaffung von Umweltinnovationen. Allerdings zeigt uns die Literatur, dass FuE-Kooperationen nicht immer vorteilhaft sind. Daher ist eine differenziertere Betrachtungsweise des Einflusses von FuE-Kooperationen auf die Fähigkeit von Unternehmen, Umweltinnovationen hervorzubringen notwendig. Das Papier untersucht diesen Zusammenhang und differenziert dabei nach verschiedenen Typen von Kooperationspartnern wie Kunden, Lieferanten, Universitäten, staatlichen Forschungseinrichtungen, Konkurrenten, Beratern und anderen Firmen innerhalb der gleichen Firmengruppe. Zudem wird der Frage nachgegangen, ob die Diversität von Kooperationspartnern einen Einfluss auf die Umweltinnovationsfähigkeit von Unternehmen hat. Dabei werden Daten von 2 337 deutschen Unternehmen für eine Regressionsanalyse verwendet. Deutlich wird, dass FuE-Kooperationen mit Kunden, Lieferanten, Universitäten, staatlichen Forschungseinrichtungen, Beratern und anderen Firmen innerhalb der gleichen Firmengruppe einen signifikant positiven Einfluss auf die Umweltinnovationsfähigkeit haben. FuE-Kooperationen mit Konkurrenten haben keinen signifikanten Einfluss. Die Diversität von FuE-Kooperationspartnern hat ebenfalls einen signifikant positiven Einfluss auf die Umweltinnovationsfähigkeit.

Schlagwörter: F&E, Kooperation, Umwelt, Innovation

JEL-Klassifikation: O31, O32

1 Introduction

Environmental protection is one of the central issues of our time. Therefore, the driving forces behind environmental innovation are of great relevance for politicians, business management and society in general. For that reason the literature on environmental innovation has investigated the determinants affecting the environmental innovation performance of firms. Among other determinants, collaboration with external partners has been identified as a crucial factor that influences a firm's environmental innovation performance in a positive way (Cainelli et al., 2011;De Marchi, 2012;Horbach, 2008;Horbach et al., 2011).

However, the literature on not environmental-related innovations shows, that R&D collaboration is not in each case beneficial for a firm's innovation performance resulting in the need for a more elaborated analysis of the impact of R&D collaboration on a firm's environmental innovation performance. One important way to have a more sophisticated view on this issue is to analyze the impact of R&D collaboration with different kinds of collaboration partners such as customers, universities or competitors, since every partner type has its individual properties when it comes to collaborative R&D. This approach has often been the subject of interest in the not environment-related innovation literature (Aschhoff, 2008;Belderbos et al., 2004;Bougrain and Haudeville, 2002;de Faria et al., 2010;Su et al., 2009;Un et al., 2010). However, to some degree this literature achieves contradictory results and therefore further research has to be done.

Furthermore, it is important to contribute to the literature on environmental innovation by shedding some light on the question how R&D collaboration with different types of partners affects the environmental innovation performance. This paper therefore supplements the outstanding work of De Marchi (2012) and provides a more detailed look on the contribution of R&D collaboration on a firm's environmental innovation performance in order to offer a solid base for decision making in business management and politics.

This paper also follows the question how the diversity of R&D collaboration partners impacts the environmental innovation performance using an approach similar to Faems et al. (2005). The idea behind this objective can be identified in the different characteristics and knowledge bases among the different partner types. Therefore, R&D collaboration with multiple partners from the same partner type bares the risk that the respective partners provide access to similar or the same information (Burt, 1995;Gomes-Casseres, 1994). However, for the purpose of environmental innovation it is important to have access to a variety of information and resources, fostering the need for a diversity of R&D collaboration partners (Baum et al., 2000).

To sum up, this paper investigates whether R&D collaboration with different partner types has an impact on a firm's environmental innovation performance. While doing so, this paper distinguishes between seven different partner types: customers, suppliers, competitors, consultants, universities, governmental research institutes and other firms within the same firm group. An additional contribution is to follow the question whether the diversity of R&D collaboration partners is important for environmental innovation. Beyond these contributions this paper aims to enrich the ambiguous scientific discussion on the contribution of different R&D collaboration partner types on a firm's innovation performance. Providing additional proof that R&D collaboration in general is important for a firm's environmental innovation performance is the final intention of this research.

To achieve these goals data from the "Mannheim Innovation Panel" (MIP) 2009 are used. This firm-level dataset contains all necessary information on collaboration behavior and environmental innovation activities of German manufacturing and service firms. In total, data from 2337 firms are used in the logistic regression analysis in order to answer the research questions.

The paper is structured as follows. Section 2 describes the theoretical background. The specifics of environmental innovations and the state of the art will be discussed. Furthermore, the individual characteristics of different R&D collaboration partners will be introduced and the research questions will be formulated. Section 3 focuses on methodological issues. The analyzed data and variables will be specified in more detail. Section 4 provides the results of the regression analysis which will be discussed in section 5.

2 Theoretical Background

2.1 The Specifics of Environmental Innovations and the State of the Art

Environmental innovations have differences and similarities compared to other product, process or organizational innovations. In order to identify those differences and similarities one must define environmental innovations in a first step. Following the "Oslo Manual", innovation can be described as "implementing something new or significantly improved" (OECD, 2005: 46 ff.). To adapt this definition to capture environmental innovations one need to add an additional attribute towards sustainability. Therefore, environmental innovations can be described as something new or significantly improved that reduces environmental burdens (Rennings, 2000). It is important to note, that this paper focuses on process-related environmental innovations i.e. innovations that reduce the amount of resources necessary to produce a given amount of output. Product-related environmental innovations i.e. innovations that focus on the improvement of existing products or the invention of new products are not the subject of this paper.

Another important difference of environmental innovations is the existence of positive external effects, since the economic benefits of environmental innovations are complemented by environmental benefits (Carraro, 2000). For example, if a firm introduces a new production process which reduces material use per unit of output, economic as well as environmental benefits occur. From this point of view one can assume, that drivers and determinants of environmental innovations differ compared to other innovations. Therefore, a number of recent studies have stressed the question of the drivers and determinants for environmental innovation (Cainelli et al., 2011;Horbach, 2008;Horbach et al., 2011). For example Horbach (2008) shows that technological capabilities such as knowledge capital have an impact on environmental innovation performance. He also concludes that environmental regulations and environmental management tools are relevant for environmental innovation. The question whether R&D collaboration activities have an impact on a firm's environmental innovation performance has been stressed in past research too. Cainelli et al. (2011) show that collaboration with suppliers and universities have a significant impact on innovation performance. A significant positive effect of collaboration on a firm's environmental innovation performance is also discovered by Horbach et al. (2011). In addition, the literature provides evidence that R&D collaboration activities are even more important than other characteristics such as the size of a firm (Mazzanti and Zoboli, 2005).

Another issue that characterizes environmental innovations is the often more radical nature of those innovations. These radical innovations frequently represent current edge technologies which are often related to a lack of market and technological experience. Uncertainties arise from the absence of established standards for technological solutions or measures of environmental performance (De Marchi, 2012). This perspective suggests that knowledge arising from basic research, such as the research that is done in universities and governmental research institutes is fundamental for environmental innovations.

2.2 Properties of Different Partner types for R&D Collaboration and Research Questions

By now it is common knowledge that innovation is an interactive process. Hence, the linear model of innovation has been replaced by the nonlinear model of innovation with its variety of feedback loops (Kline and Rosenberg, 1986). Those feedback loops suggest that interactions among different partners are crucial for the success of innovative R&D projects (Ahuja, 2000;Gronum et al., 2012;Hallin et al., 2011;Owen-Smith and Powell, 2004).

The literature on R&D collaboration therefore regularly discusses a number of advantages of joint R&D. It is often argued that interactions with external partners such as universities, customers, suppliers or competitors provide access to external knowledge (Teece, 1986). Furthermore, joint R&D is an opportunity to share risks associated to an innovation project which frequently arise due to the uncertainty about the outcome of the project. The costs of R&D such as the costs for laboratory equipment or research personnel can be shared among the involved collaboration partners (Hagedoorn, 2002). The division of labor which might result in an increased efficiency of the involved partners as well as the access to a specialized labor force are further arguments for joint R&D. Collaboration in R&D is also a source of diversity which might result in an improved diversification of a firm (Nelson and Winter, 1982).

However, R&D collaboration does not only provide advantages since one can argue that collaboration is related to transaction costs. Searching for a suitable partner as well as building up trust can be a time-consuming problem (Bleeke and Ernst, 1993). Furthermore, coordination, communication, traveling and the exchange of information among the involved collaboration partners are sources of transaction costs (Koput, 1997). These costs are especially important when it comes to R&D collaboration with spatially more distant partners even if the costs for traveling and communication substantially decreased over the last decades (Gertler, 1995). The transaction costs for the search of a R&D collaboration partner and for building up trust may result in lock-in situations, since the risk to lose the spent resources provides a strong incentive to develop long-term relationships (Fritsch, 2004). Given that leaving old trajectories and pursuing new paths is an important ability in an innovation process, lock-in situations can be a problematic issue. A similar idea is associated to the problem of overembeddedness. Over time, R&D collaboration relationships can be characterized by an increasing amount of trust between the collaboration partners and therefore these relationships can become very strong. Originally innovation oriented relationships may turn into social linkages resulting in inefficient collaboration decisions in the future. Besides, important developments outside the network of R&D collaboration partners can be missed (Broekel and Binder, 2007). Lastly, one can argue, that knowledge spillovers arising from collaborative R&D are not solely beneficial. The specific knowledge base of a firm is often a source of its competiveness and therefore a firm has a strong incentive to protect its knowledge base resulting in a limited willingness to share knowledge (Kesteloot and Veugelers, 1995).

Finally, based on this discussion on the advantages and disadvantages of R&D collaboration the following hypothesis is developed:

H1: Firms collaborating in R&D are more likely to introduce an environmental innovation than firms that do not collaborate.

Despite the discussed advantages and disadvantages of R&D collaboration, a more elaborated view on collaborative R&D is necessary because different characteristics apply for different kinds of collaboration partners. For instance, collaborative R&D with a competitor has a different nature than R&D collaboration with a governmental research institute.

For that reason some of the literature on R&D collaboration investigates the impact of R&D collaboration with different partner types on firm performance (Bougrain and Haudeville, 2002;Brettel and Cleven, 2011;Hsueh et al., 2010).

For example, Hsued et al. (2010) find a positive impact of R&D collaboration with customers and suppliers on a firm's innovation performance, but they do not find significant contribution of R&D collaboration with research institutes. In contrast, Bougrain and Haudeville (2002) discover a significant negative impact of R&D collaboration with suppliers and public research institutes on the success of innovative projects, but no significant impact of R&D collaboration with customers, private research institutes or universities. Different results are discovered by Brettel and Cleven (2011). They show that R&D collaboration with customers, suppliers and universities significantly contributes to the new product development performance of a firm, but they have not found a significant effect of collaboration with competitors or consultants. However, it should be noted that the referred work employs different performance measures which might be an explanation for the demonstrated heterogeneity of results.

In the literature customers are a frequently discussed group of R&D collaboration partners (Aschhoff, 2008;Belderbos et al., 2004;Hsueh et al., 2010;Un et al., 2010). Customers know exactly their wants and needs and therefore they are a valuable R&D collaboration partner (Flores, 1993;Tether, 2002). However, an increasing awareness of the customers about the ecological footprint of their consumption may lead to a credible preference for an environmental friendly production process (Harrison et al., 2005). Hence, customers are likely to have a positive attitude towards R&D collaboration with firms and therefore they are willing to contribute to the environmental innovation process. The knowledge on the preferences of a customer are especially important in the early stages of an innovation project, since this avoids costly changes in the later phases of an innovation project (von Hippel, 1994). Nevertheless, it can be argued, that the preferences of a customer are characterized by tacitness which makes collaboration with customers a difficult task (Nonaka, 1994). This discussion leads to the following hypothesis:

H2_a: Firms that collaborate in R&D with customers are more likely to introduce an environmental innovation than firms that do not collaborate with customers.

Competitors are also a relevant group for R&D collaboration (de Faria et al., 2010;Kang and Kang, 2010;Nieto and Santamaria, 2007), since rivals often have similar needs for developing new innovations (Lhuillery and Pfister, 2009). Competitors can also share costs and risks of an innovation project (Miotti and Sachwald, 2003). Joint R&D provides the opportunity to implement standards in the market and to compete successfully against third-party competitors (Perks and Easton, 2000). R&D collaboration with competitors is also related to some disadvantages since competitors still remain rivals. The knowledge base of a firm is often a source of its competitiveness and therefore the firm has a strong incentive to protect its knowledge which reduces a firm's willingness to collaborate and to share knowledge (Lhuillery and Pfister, 2009). A systematic restriction of knowledge flows among the competing collaboration partners is likely (Hamel, 1991;Oxley and Sampson, 2004). R&D collaboration with competitors is therefore characterized by a possible opportunistic behavior which may reduce the probability of success of an environmental innovation project (Lhuillery and Pfister, 2009). A further argument which reduces the value of R&D collaboration for environmental innovation is the thought, that successful R&D collaboration often needs differences rather than similarities. It remains unclear whether R&D collaboration with competitors has a positive or negative impact on a firm's environmental innovation performance.

H2_b: R&D collaboration with competitors has no significant effect on the probability of a firm to introduce an environmental innovation.

R&D collaborations with suppliers are also commonly discussed in the literature (Belderbos et al., 2004;Bougrain and Haudeville, 2002;Kang and Kang, 2010;Tomlinson, 2010). It is important that suppliers understand the needs of the firms they supply with pre-products. Vice versa it is important that firms understand the requirements of their suppliers. Joint R&D collaboration is a way to account for this thought. Furthermore, suppliers have a strong interest on the success of the firm they supply, since a continuous growth of a firm probably increases the sales of the supplier. Consequently, suppliers are a willing partner for R&D collaboration. Thus their knowledge is relatively easy to access (Hoegl and Wagner, 2005;Littler et al., 1998). Moreover, a firm can share costs and risks of an innovation project with its supplier (Wynstra et al., 2001). Finally, environmental innovations often need changes in raw materials and other inputs used in a production process which makes R&D collaboration with suppliers important. Nevertheless, one should note that intensive R&D collaboration increases the mutual dependency between a firm and its supplier.

H2_c: Firms collaborating in R&D with suppliers are more likely to introduce an environmental innovation than firms that do not collaborate with suppliers.

Environmental innovations frequently require leading-edge knowledge. This kind of knowledge is often a result of basic research, such as the research that is done at universities and governmental institutes. Therefore, scientific institutions are an important partner for joint R&D (Marques et al., 2006). Access to results of basic research is especially important for more radical environmental innovations. The knowledge base of scientific institutions is also characterized by a multidisciplinary variety (Henard and McFadyen, 2006). Collaboration with universities and governmental research institutes is also characterized by a limited potential for conflicting interests compared to other collaboration partners such as competitors. As a result, one can assume that scientific institutions are likely to share their knowledge (Lane and Lubatkin, 1998). However, one should note that research at scientific institutions is traditionally not focused on the requirements of a firm's innovation process (Drejer and Jorgensen, 2005). This leads to the following two hypothesizes:

H2_d: Firms collaborating in R&D with universities are more likely to introduce an environmental innovation than firms that do not collaborate with universities.

H2_e: Firms collaborating in R&D with governmental research institutes are more likely to introduce an environmental innovation than firms that do not collaborate with governmental research institutes.

Independent consultants are also potential partners for R&D collaboration (Brettel and Cleven, 2011;de Faria et al., 2010;Zeng et al., 2010). Standing outside of the firm, consultants have a different perspective on the processes in the firm in contrast to the internal labor force which may become very familiar with the firms internal processes over time (Bruce and Jevnaker, 1998). Furthermore, consultants have a heterogeneous nature since they can provide a variety of technological and market-related knowledge (Alam, 2003;Knudsen, 2007). Therefore, consultants can be a valuable R&D collaboration partner for environmental innovation projects.

H2_f: Firms collaborating in R&D with consultants are more likely to introduce an environmental innovation than firms that do not collaborate with consultants.

In this paper, the final group of R&D collaboration partners for environmental innovation are other firms within the same firm group. Firms within the same form group often have similar needs for environmental innovation and the lower level of competition makes cheating behavior less likely.

H2_g: Firms that collaborate in R&D with other firms within the same firm group are more likely to introduce an environmental innovation than firms that do not collaborate with other firms within the same firm group.

Since the introduced R&D collaboration partner types have different characteristics and knowledge bases, a variety of dissimilar partner types may be important for environmental innovation. Collaboration with multiple R&D collaboration partners from the same partner type may lead to the risk that the different partners provide access to similar or the same information (Burt, 1995;Gomes-Casseres, 1994). Therefore it is important to collaborate with a variety of partner types (Baum et al., 2000). This paper includes the following hypothesis:

H3: Firms with a high diversity of R&D collaboration partner types are more likely to introduce an environmental innovation than firms with a low diversity of R&D collaboration partners.

3 Methodological approach

3.1 Data

For the empirical analysis data from the “Mannheim Innovation Panel” (MIP) gathered in the year 2009 covering firm level data of the 3-year period from 2006 to 2008 are used. This panel was introduced in 1993 and contains survey data on the innovation activities of the German economy. The survey is carried out by the Centre of European Economic Research in cooperation with the Institute for Applied Social Science and the Fraunhofer Institute for Systems and Innovation Research. The annual survey is commissioned by the German Federal Ministry of Education and Research and represents the German contribution to the European Union’s Community Innovation Survey (CIS), which is based on the Oslo Manual (OECD and Eurostat, 1997).

The MIP database is suitable to answer the research questions of this paper, since it contains a considerable amount of relevant information on the collaborative behavior as well as environmental innovation activities and control variables for a large set of German service and manufacturing firms. Furthermore, CIS data from numerous European countries have successfully been used in the economic literature to answer similar research questions (Aschhoff, 2008;Belderbos et al., 2004;de Faria et al., 2010;De Marchi, 2012;Faems et al., 2005;Frenz and Ietto-Gillies, 2009;Horbach, 2008). Finally, the MIP database is suitable, since it contains data from a large number of firms. After cleaning the database from missing values, a total of 2337 firms are included into the analysis. Additionally, information about environmental innovation behavior of the surveyed firms are only available for a limited number of years and therefore panel estimation methods are not used.

3.2 Variables

3.2.1 Indicator of Environmental Innovation

The literature on environmental innovation shows multiple ways to measure the environmental innovation performance. One common way to measure the environmental innovation performance as well as innovation performance in general is to use the patent output of a firm (Nameroff et al., 2004;Petruzzelli et al., 2011). However, a drawback of patent data for measuring innovation performance is that firms often do not patent smaller incremental innovations. There is also a varying propensity to patent innovations across different industries and regions. This may result in a biased estimation of the environmental innovation performance. Therefore, in this paper self-reported data from the MIP are used in order to capture environmental innovation performance of a firm. The respective literature has already proven that self-reported data are suitable for measuring environmental innovation performance (De Marchi, 2012;Horbach, 2008) as well as innovation performance in general (Brettel and Cleven, 2011;Chang, 2003;Kim and Park, 2008).

The 2009 MIP questionnaire asked whether the firm introduced an innovation with environmental benefits such as the reduction of air pollution or soil pollution in the period of 2006 to 2008. It is also important to note that the environmental benefits are related to the production process of the firm and not to the firm's products.

In this paper the dependent variable EnvironInno is a binary variable which takes the value 1 if the firm introduced any kind of environmental innovation. Otherwise EnvironInno is 0.

3.2.2 Indicators of R&D Collaboration Activities

The central issue of this paper is to investigate the question whether R&D collaboration with different partner types has a positive impact on the probability that a firm introduces an environmental innovation. Therefore, a number of collaboration measures are necessary. The 2009 MIP questionnaire asked whether a firm has collaborated for innovation activities in the period from 2006 to 2008. Furthermore, the questionnaire provides seven different partner types for innovation collaboration including firms within the same enterprise group, customers, suppliers, competitors, consultants, universities and governmental research institutes. The questionnaire also asks whether the particular collaboration partner was located in Germany, Europe, United States, China/India or any other country.

Therefore, in this paper a number of binary variables are used to assess the innovation collaboration activities of a firm by partner type. The variable CoopFirmGroup equals 1 if the respective firm collaborated for innovation activities with another firm within the same enterprise group during the period between 2006 and 2008. On this occasion it is not relevant whether the collaboration partner was located on Germany or any other part of the world. If the firm did not collaborated with other firms within the same firm group in this period, CoopFirmGroup is 0. Analog to this approach the variables CoopCustomer, CoopSupplier, CoopCompetitor, CoopConsultant, CoopUniversity and CoopGovInstitute capture the innovation collaboration activities with customers, suppliers, competitors, consultants, universities and governmental research institutes.

Additionally the variable CoopAnyKind is introduced. CoopAnyKind takes the value 1 if the firm collaborates with any kind of partner for innovation activities. Otherwise CoopAnyKind is 0. This variable is introduced in order to analyze the question whether R&D collaboration itself increases the probability that a firm introduces an environmental innovation.

The final independent variable that is used in this paper to analyze the impact of R&D collaboration activities on environmental innovation performance is CoopPartnerDiv. CoopPartnerDiv is an interval-scaled variable that captures the variety of R&D collaboration partners a firm uses for innovation activities. CoopPartnerDiv takes the value 0 if the respective firm does not collaborate. CoopPartnerDiv equals 1 if the firm collaborates with 1 of the introduced partner types. Accordingly, CoopPartnerDiv is 2 if the firm collaborates with 2 different partner types and so on. The maximum value of CoopPartnerDiv is 7 since the MIP distinguishes between 7 partner types. This variable is necessary to answer the question whether the diversity of partner types for R&D collaboration has an impact on a firms environmental innovation performance.

3.2.3 Control Variables

To control for a variety of firm characteristics a number of control variables are included into the regression analysis. The current innovation research stream often controls for firm size since the relationship between firm size and innovative performance of a firm is discussed in the relevant literature for many decades now (Schumpeter, 1939). Large firms can use economies of scale in R&D and have the option to spread innovation-related risks over a number of R&D projects. Larger firms also have access to a larger pool of financial resources giving them an advantage compared to smaller firms (Veugelers, 1997). Finally, one can argue that larger firms are more likely to acquire necessary complementary resources such as raw materials or specialized materials, to make the environmental innovation project a success (Teece, 1986;Tripsas, 1997). By the same token smaller firms may outperform larger competitors in terms of speed and flexibility (Bower and Christensen, 1995). Therefore the variable size is used in this paper to capture the size of a firm using the number of employees.

It is important to control for internal R&D activities of a firm because firms pursuing R&D activities accumulate knowledge which is necessary for environmental innovation more efficiently. It is also argued that if a firm conducts R&D regularly it is more likely that this firm detects an idea for an environmental innovation. The binary variable InternRD describes whether a firm has performed internal R&D activities during 2006 and 2008.

A similar idea applies for the variable FuEIntens which captures the R&D intensity measured by the total R&D expenditures as a share of turnover. It is assumed that firms with a high R&D intensity accumulate knowledge more efficiently and are more likely to absorb external knowledge for innovative projects.

The absorptive capacity of a firm does not only depend on a firm's internal R&D efforts or the R&D intensity. It is also argued that a firm's absorptive capacity depends on the human capital (Cohen and Levinthal, 1990). Therefore, it is important to include the human capital into the regression analysis. The variable HumCap captures the human capital as the proportion of employees who have an university degree or other higher education qualification. The higher the share of highly qualified employees, the higher the chance that a firm can absorb and exploit external knowledge for environmental innovation.

One characteristic that applies particularly for innovation related studies in Germany is the idea that innovation activities of East German firms still differ from West German firms (Aschhoff et al., 2006). To control for this regional characteristic the binary variable ost is introduced. Ost equals 1 if the firm is located in Eastern Germany. If the firm is located in West Germany, ost equals 0.

Finally, a number of industry dummies are included to control for industry effects which is by now a common practice in the innovation-related literature (Veugelers, 1997). These dummies capture a variety of industry-specific dimensions such as technological opportunities, appropriability regimes or the emergence of dominant designs along the technology life cycle. Table 1 provides an overview on the industries included in this analysis.

Table 1:
Overview of the composition of the sample by industry

Industry	Freq.	Percent	Cum.
Mining	48	2.05	2.05
Food, tabacco	104	4.45	6.50
Textiles	59	2.52	9.03
Wood, paper	158	6.76	15.79
Chemicals	86	3.68	19.47
Plastics	84	3.59	23.06
Glass, ceramics	53	2.27	25.33
Metals	175	7.49	32.82
Machinery	152	6.50	39.32
Electrocal equipment	109	4.66	43.99
Medical and other instruments	113	4.84	48.82
Transport equipment	67	2.87	51.69
Furniture	43	1.84	53.53
Energy, water	128	5.48	59.01
Wholesale	110	4.71	63.71
Retail, Automobile	52	2.23	65.94
Banking, insurance	75	3.21	69.15
IT, telecommunications	87	3.72	72.87
Technical services	234	10.01	82.88
Other services	352	15.06	97.95
Real estate, renting	48	2.05	100.00
Total	2,337	100.00	

An overview of all relevant variables employed in this paper is displayed in table 2.

Table 2:
Definition of variables

	Variable	Description	Scale of measure
Dependent variable	EnvironInno	Firm introduced an environmental innovation - 1 if yes, 0 if no	Binary
Independent variables	CoopFirmGroup	Collaboration with other firms within the same firm-group - 1 if yes, 0 if no	Binary
	CoopCustomer	Collaboration with customers - 1 if yes, 0 if no	Binary
	CoopSupplier	Collaboration with suppliers - 1 if yes, 0 if no	Binary
	CoopCompetitor	Collaboration with competitors - 1 if yes, 0 if no	Binary
	CoopConsultant	Collaboration with consultants - 1 if yes, 0 if no	Binary
	CoopUniversity	Collaboration with universities - 1 if yes, 0 if no	Binary
	CoopGovInstitute	Collaboration with governmental research institutes - 1 if yes, 0 if no	Binary
	CoopAnyKind	Firm collaborates with any kind of partner - 1 if yes, 0 if no	Binary
	CoopPartnerDiv	Number of collaboration partner types	Interval
Control variables	InternRD	Internal R&D activities - 1 if yes, 0 if no	Binary
	size	Number of employees	Interval
	HumCap	Proportion of employees who have an university degree or other higher education qualification - in intervals	Ordinal
	FuEIntens	Total R&D expenditure as a share of turnover - values over 0.15 truncated to 0.15	Interval
	ost	Firms from the 'new' German Länder (from East Germany) - 0 if Western Germany, 1 if Eastern Germany (Including Berlin)	Binary
	Industry	Dummy variables for 23 industrie sectors	Binary

3.3 Model

Due to the fact that the dependent variable EnvironInno is a binary variable taking the value 1 if the firm introduced an environmental innovation between 2006 and 2008 or the value 0 if the firm did not introduced an environmental innovation, a limited dependent variable model is used for the regression analysis. A logit model is employed to verify the research questions of this paper.

In total four different models are estimated. Model 1 represents the basic model including all introduced control variables. Model 2 adds the variable CoopAnyKind in order to answer the research question whether collaboration in general increases the probability that a firm introduces an environmental innovation. Model 3 adds the seven different collaboration partner type dummies to analyze the contribution of the different kinds of collaboration partners to a firm's environmental innovation performance. Finally model 4 includes the variable CoopPartnerDiv.

Before running the regression analyses the data were tested for multicollinearity but no indications for a multicollinearity problem were discovered.

4 Results

This section describes the results of the logit analysis in order to test the 9 hypotheses introduced in section 2. Table 3 displays the regression results of the 4 regression models.

Model 1 is the basic model which includes only the control variables. As expected, the coefficients for InternRD and size are positive and significant. The variable HumCap which captures the share of highly qualified employees is significant and negative suggesting that a high share of highly qualified employees reduces the chance of a firm to introduce an environmental innovation. The variables FuEIntens and ost have no significant effect on a firm's environmental innovation performance. The industry dummies are also included. For the purpose of clarity they are not reported in detail. The industry dummies in model 1 are all insignificant expect technical services (coeff = -0.9979; P < 0.05) and other services (coeff = -0.5935; P < 0.10).

Model 2 includes the control variables and the variable CoopAnyKind which was introduced in order to answer the question whether collaboration in general contributes to the environmental innovation performance as stated in hypothesis H1. The coefficient of CoopAnyKind is highly significant and positive suggesting that R&D collaboration with any kind of partner increases the probability of a firm to introduce an environmental innovation. Therefore, model 2 supports hypothesis H1.

The main focus of this paper is to analyze the impact of R&D collaboration with different partner types on the environmental innovation performance. Therefore, hypotheses H2_a to H2_g were introduced. Hence, model 3 includes the control variables and the R&D collaboration dummies for the seven different partner types. As anticipated, the coefficients for the variables CoopFirmGroup, CoopCustomer, CoopSupplier, CoopConsultant, CoopUniversity and CoopGovInstitute are positive and significant. This indicates that R&D collaboration with other firms within the same firm group, customers, suppliers consultants, universities and governmental institutes increases the probability to introduce an environmental innovation. The coefficient for the variable CoopCompetitor is not significant suggesting that R&D collaboration with competitors has no noticeable impact on a firms environmental innovation performance. These results support the hypotheses H2_a to H2_g.

Table 3:
Regression results (logit model; dependent variable = EnvironInno)

	Model 1	Model 2	Model 3	Model4
CoopPartnerDiv				0.458***
				(0.064)
CoopFirmGroup			1.018***	
			(0.212)	
CoopCustomer			0.352**	
			(0.178)	
CoopSupplier			0.350*	
			(0.190)	
CoopCompetitor			0.291	
			(0.199)	
CoopConsultant			0.479**	
			(0.214)	
CoopUniversity			0.312*	
			(0.186)	
CoopGovInstitut			0.478**	
			(0.221)	
CoopAnyKind		1.826***		
		(0.232)		
InternRD	1.594***	-0.038	0.748***	0.725***
	(0.162)	(0.266)	(0.207)	(0.200)
size	0.000***	0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
HumCap	-0.041*	-0.058***	-0.053**	-0.054**
	(0.021)	(0.022)	(0.022)	(0.021)
FuEIntens	-1.538	-1.244	-2.524	-3.207*
	(-1.691)	(-1.698)	(-1.839)	(1.757)
ost	-0.031	-0.012	0.005	0.001
	(0.096)	(0.098)	(0.098)	(0.098)
Industry	Yes	Yes	Yes	Yes
Constant	-0.413	-0.390	-0.414	-0.409
	(0.305)	(0.306)	(0.308)	(0.308)
Pseudo R-Square	0.0909	0.1129	0.1124	0.1096
Observations	2337	2337	2337	2337
prob > chi2	0.0000	0.0000	0.0000	0.0000
log likelihood	-1458.1489	-1422.8857	-1423.6656	-1428.1439

Standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

The final model is model 4. This model includes the control variables as well as the variable CoopPartnerDiv. This model aims to answer the question whether the diversity of R&D collaboration partners has an impact on the environmental innovation performance of a firm as stated in hypothesis H3. As expected, the coefficient for CoopPartnerDiv is significant and positive. This suggests that a greater variety of R&D collaboration partners promotes the probability that a firm introduces an environmental innovation. Hypothesis H3 is therefore supported.

5 Discussion and Conclusions

Despite a high interest of policy makers and customers on eco-friendly production processes of goods and services, a surprisingly low number of studies have tried to investigate the contribution of R&D collaboration on a firm’s environmental innovation performance in a more elaborated way. This paper investigates the impact of R&D collaboration with different kinds of partners on the environmental innovation performance of German manufacturing and service firms using a large data set from the 2009 Mannheim Innovation Panel.

One of the main results is the strong evidence, that R&D collaboration has a significant positive impact on the probability that a firm introduces an environmental innovation. This result is consistent with the literature on environmental innovations (Cainelli et al., 2011;De Marchi, 2012;Horbach, 2008) as well as the literature on other types of innovations such as product innovations (Belderbos et al., 2004;Nieto and Santamaria, 2007;Un et al., 2010).

Another important contribution of this paper is to distinguish R&D collaboration according to different partner types. Each partner type has its individual characteristics to contribute to a firm’s environmental innovation performance. For example, R&D collaboration with suppliers allows to ensure eco-friendly inputs for a firms production process. Also, the basic research knowledge as well as the variety of knowledge of the scientific institutions fosters the probability that a firm introduces environmental innovations. Moreover, due to R&D collaboration, customers can reveal their preferences for environmental friendly production process of the goods they consume. Therefore, this paper shows that other firms within the same firm group, customers, suppliers, consultants and scientific institutions such as universities and governmental research institutes are important partners for environmental innovation.

R&D collaboration with competitors has no significant effect on the environmental innovation performance of a firm. This is probably due to the competitive nature that provides an incentive for the involved collaboration partners to withhold vital information (Hamel, 1991;Lhuillery and Pfister, 2009;Oxley and Sampson, 2004). This result is in line with the literature on not environment related process innovations since Su et al.

(2009) as well as Tomlinson (2010) find no significant effect of R&D collaboration with competitors on a firm's process innovation performance.

The complex nature of environmental innovations (Andersen, 2002;Theyel, 2006) demands for a variety of knowledge inputs. This paper shows that firms with a larger variety of R&D collaboration partners are more likely to introduce environmental innovations then firms with a lower variety of R&D collaboration partners. Again, these findings are concordant with the literature. Faems et al. (2005) show similar results using the example of product innovation performance.

Hence, it can be conclude that R&D collaboration for environmental innovation is not beneficial per se. A more elaborated view on collaboration interactions is necessary in order to sufficiently describe and optimize R&D collaborations. Firms that collaborate in R&D for environmental innovation therefore have to consider with which partner types they collaborate as well as to make sure a sufficient amount of variety.

Still, this study has its limitations that leave some space for further research. There is literature investigating the impact of R&D collaboration on product innovation claiming that there is an inverted U-shape relationship between collaboration efforts and a firms product innovation performance (Kang and Kang, 2010), meaning that an increase in collaboration activities has a positive impact on innovation performance only up to a certain level. A further increase of R&D collaboration reduces the innovation performance probably due to increasing transaction costs. This implies the question on the existence of an optimal level of collaboration activities. This work does not search for an inverted U-shape relationship between collaboration and environmental innovation performance, since the binary nature of the variables used in this paper to capture collaboration does not allow for such an analysis. Therefore, further research should close this gap. An additional limitation of this work is the focus on environmental innovations in a firm's production process. This paper does not capture environmental innovations for the products of a firm. However, eco-friendly products are important for customers especially if the eco-friendly feature of a product delivers added value to the customer (Kammerer, 2009). Further research can therefore provide a great contribution by filling this gap.

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