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What drives innovation output from subsidized R&D cooperation?—Project-level evidence from Germany

Michael Schwartz [a,*], Francois Peglow [b], Michael Fritsch [a,c], Jutta Günther [a]

[a] Halle Institute for Economic Research, P.O. Box 11 03 61, 06017 Halle (Saale), Germany
[b] Max Planck Institute for Demographic Research, Konrad-Zuse-Str. 1, 18057 Rostock, Germany
[c] Friedrich Schiller University Jena, School of Economics and Business Administration, Carl-Zeiss-Str. 3, 07743 Jena, Germany.

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ABSTRACT

Using a large dataset of 406 subsidized R&D cooperation projects, we provide detailed insights into the relationship between project characteristics and innovation output. Patent applications and publications are used as measures for the innovation output of an R&D project. We find that large-firm involvement is strongly positively related with the number of patent applications, but not with the number of publications. Conversely, university involvement has positive effects on projects' innovation output in terms of the number of publications but not in terms of patent applications. In general, projects' funding as measure of projects' size is an important predictor of the innovation output of R&D cooperation projects. No significant effects are found for the number of partners as (an alternative) measure of projects' size, for spatial proximity between cooperation partners, for the involvement of a public institute for applied research, and for prior cooperation experiences. We derive conclusions for the design of R&D cooperation support schemes.

1. Introduction

Systemic innovation theory emphasizes that technological innovation is the result of a division of innovative and creative labor (Freeman, 1987; Nelson, 1993; Lundvall, 1992). From this perspective, the locus of technological innovation resides not only within the boundaries of the firm, but particularly emerges in an exchange process between different organizations, such as private firms, universities, research laboratories, suppliers, and customers. Inter-organizational R&D cooperation is also relevant according to the resource based view of the firm that focuses on firms' technological capabilities in R&D cooperation ventures (Belderbos et al., 2004; Mowery et al., 1998; Sachwald, 1998). Based on this recognition, innovation policy in many countries has implemented measures designed to initiate, facilitate and accelerate cooperative R&D, particularly between scientific institutions and industry (Muldur et al., 2006).

Given this policy shift towards stimulating R&D cooperation, there exists surprisingly little empirical evidence how cooperative R&D could and should be supported by public policy. A large part of research in this area has been devoted to the impacts of R&D cooperation on the performance of the partners involved (e.g., Belderbos et al., 2006; Kim and Park, 2008; Miotti and Sachwald, 2003; Negassi, 2004; Okamuro, 2007). There is also considerable empirical evidence available with respect to the questions 'why to cooperate' and 'with whom' (e.g., Arza and López, 2011; Arranz and de Arroyabe, 2008; Barge-Gil, 2010; Cassiman et al., 2010; Brockhoff et al., 1991; De Faria et al., 2010; Okamuro et al., 2011; Miotti and Sachwald, 2003). However, only few studies have analyzed the relationship between the characteristics of cooperative R&D projects and their innovation output. Exceptions for such analyses on the project level are recent contributions by Branstetter and Sakakibara (2002), Bizan (2003) and Petruzzelli (2011).

Bizan (2003) investigates the success of 142 government-supported research alliances between high technology firms from the United States (US) and Israel. These cooperative R&D projects were funded by the Israeli-US Bi-national Industrial Research and Development Foundation (BIRD). The success of the R&D projects was evaluated in terms of technical results and time to commercialization (first commercial sale after achieving technical success). According to this analysis, the most influential factors for the success of a cooperative R&D project were its budget size, the length of the cooperation, the complementarities of the partners and whether or not the cooperating firms have been related through ownership ties. Branstetter and Sakakibara (2002) related the characteristics of a consortium to its research productivity measured in terms of patent applications based on panel data

* Corresponding author. Tel.: +49 345 7753 794; fax: +49 345 7753 743.
E-mail addresses: Michael.Schwartz@iwh-halle.de (M. Schwartz), peglow@demogr.mpg.de (F. Peglow), m.fritsch@uni-jena.de (M. Fritsch), Jutta.Guenther@iwh-halle.de (J. Günther).

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from 145 Japanese government-sponsored R&D consortia. Whereas the technological proximity of participants affected the outcomes positively, the degree of product market proximity was found to be negatively associated with the performance of an R&D consortium. However, both studies are restricted to inter-firm R&D cooperation and do not include cooperation between academic institutions and industry. Petruzzelli (2011) uses 796 university–industry joint patents from European universities and assesses the impact of several factors on the innovative output of these collaborations (measured as citations received by the joint patents). Amongst others, the analysis reveals positive effects of prior cooperation and of geographical distance between the partners and projects' innovative outcome.

The present paper analyzes the output of cooperative innovation projects, many of them with universities and other public research institutes involved. All the 406 R&D cooperation projects on our sample benefited from financial support by the Free State of Saxony (Germany) between 2000 and 2006. Our analysis provides important insights into the relationship between the innovation output of publicly-funded R&D cooperation projects and specific project characteristics. The data set allows us to account for several key variables that may shape the innovation output of R&D cooperation projects which have not been available in previous studies. More specifically, we investigate the impact of project duration, project scale, differences in the composition of cooperation partners, experiences of cooperation partners from prior (subsidized) cooperation, spatial proximity between project partners, and the commercialization range of the project outcomes on the innovation output of R&D cooperation projects. We also control for possible impacts of the specific technological field of R&D cooperation projects.

Defining the criteria for judging the 'success' of an R&D project is a difficult task since individual R&D projects may be rather specific with regard to their primary objectives (e.g., Arranz and de Arroyabe, 2008). These objectives might differ between the partners or types of partner within project consortia, such as private firms, academic institutions, or government organizations. While university researchers may consider R&D projects as successful if they generate new knowledge suitable for publication in peer-reviewed journals, private firms tend to be primarily interested in the commercialization of R&D results. Since R&D projects between different types of partners tend to be multidimensional constructs (Dyer et al., 2006), there often is no single best indicator for evaluating the success of cooperative R&D projects. It would, therefore, be desirable to evaluate R&D success on the basis of multiple indicators. The possibilities of applying such indicators are, however, in most cases severely restricted by the available information. In our analysis, the innovation output of each R&D project is measured by the number of patent applications and the number of publications in order to account for different objectives of partners involved in an R&D cooperation project.

In the following, Section 2 provides a characterization of the main features of the policy program '*Saxonian Support Scheme for R&D Cooperation*', by which the projects in our sample were funded. Section 3 discusses the relationship between the characteristics of R&D cooperation projects and project innovation output and derives the hypotheses to be tested. Section 4 describes the data base and explains the measurement of the dependent and the explanatory variables. Regression results are presented in Section 5. We discuss the results and the implications of our analysis in Section 6. Finally, Section 7 concludes.

2. The Saxonian support scheme for R&D cooperation

The '*Saxonian Support Scheme for R&D Cooperation*' is an important element of the technology- and innovation policy in the German Federal State of Saxony. Based on financial means provided by the European Community, the State Ministry for Economic Affairs and Labor of Saxony (SMWA) introduced this support program in the year 1992. The program is specifically designed to stimulate innovation and R&D cooperation between private firms (primarily SMEs, but also some large firms) as well as between private firms and academic research institutions located in the Federal State of Saxony, thus bringing together science and industry. Pure academic cooperation agreements are not covered by this support scheme (see Niedergassel and Leker (2011) for a recent study of R&D cooperation between academic scientists). Academic institutions include universities, technical colleges and applied (non-university) research institutes, such as the institutes of the Leibniz Association and the Fraunhofer Society.

The program aims at the reduction of the financial risks of R&D projects by providing non-repayable grants up to a certain share of the total expenses of the projects. With the establishment of this support scheme, Saxony has adopted an approach that Bozeman (2000, p. 632) terms "the cooperative technology policy paradigm", where the government acts as an intermediary for initiating projects that affect industrial technology development and innovation. During the 2000–2006 period, 417 R&D cooperation projects received funding within the framework of the support program (Fig. 1). More than three quarters of subsidized R&D projects involved at least one academic institution. Most of these academic–industry R&D cooperation projects included either a university or an extra-mural research institution; 31 of the projects involved both types of academic institutions.

To obtain financial support in the framework of the program, project consortia had to fulfill certain criteria. In particular, project partners had to demonstrate in their proposal that the R&D project under consideration is innovative or technology-oriented, or that it aims at the development or the improvement of products and services that are novel in the sense that they are not already economically exploited within the European Union (EU). The program is explicitly directed towards nine industries or technology fields, which are assumed to be highly relevant in the future (Free State of Saxony, 2000): Materials science, physical and chemical technologies, biological research and technology, microsystems technology, information technology, production technology, environmental technology, medical technology and energy technology. Most of these fields can be regarded as science-based technologies (Meyer-Krahmer and Schmoch, 1998) which are characterized by a relatively

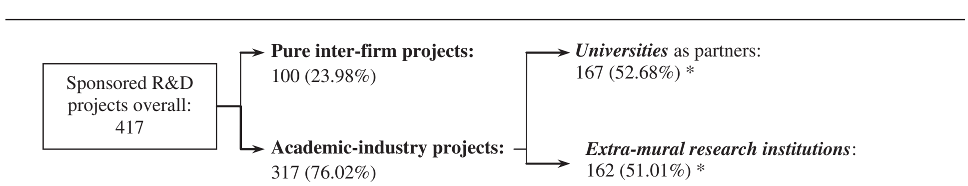

Fig. 1. Composition of cooperation projects subsidized by the '*Saxonian Support Scheme for R&D Cooperation*'. *Note*: *R&D cooperation projects with *at least one* university/extra-mural research institution as partner of the consortia.
Source: Authors illustration.

high need for university–industry cooperation (e.g., Belderbos et al., 2006). This list of industries or technology fields is, however, not very restrictive since nearly every research topic that is commercially relevant can be subsumed under one of these categories.

Proposals could be submitted by private firms that have a location in Saxony as well as by Saxonian universities and other public research institutes engaged in R&D cooperation projects with private firms. Further requirements for being eligible for funding included an appropriate financial contribution of the project partners (not otherwise subsidized) and an assessment of prospects for commercial application of the project outcomes (commercialization strategy). The maximum financial support granted by the SMWA depends on the scale and the specific research content of a particular cooperation project.

3. Hypotheses

3.1. Type and composition of partners in cooperation projects

The composition of the partners in R&D cooperation and the organization of the division of innovative labor are critical elements for the success of cooperative arrangements (Harrigan, 1988). The technological performance of research consortia, for instance, is greatly dependent on their characteristics, particularly the characteristics of co-operating partners (Branstetter and Sakakibara, 2002). Basically, cooperation partners may be classified as customers, suppliers, competitors, specific service providers, universities, private or public research institutes, or government institutions which are located in the same region or in other regions (e.g., Arranz and de Arroyabe, 2008; Aschhoff and Schmidt, 2008; Belderbos et al., 2006; De Faria et al., 2010; Fritsch and Lukas, 2001; Miotti and Sachwald, 2003; Okamuro, 2007; Sakakibara, 1997; Zeng et al., 2010). SMEs and young firms in particular are reliant on external relationships with a variety of partners to obtain access to resources such as skills, equipment, specialized knowledge, capital, business networks and intellectual property rights. Many studies on R&D partnerships concentrate on collaborative R&D between competitors (Hamel, 1991; Hamel et al., 1989; Von Hippel, 1987). In our analysis, we distinguish between cooperation projects that consist entirely of private firms and cooperation projects in which private firms and academic institutions participate. With respect to academic–industry cooperation projects we further differentiate between projects that include universities and those which included extramural research institutes with a strong focus on applied research. Furthermore, we identify R&D cooperation agreements with a dominant (large) private firm, independent of being a pure within-industry or an academic–industry cooperation.

Cooperation with academic institutions, including universities, technical colleges and other public research institutions can be a major source of innovation, firm growth, and competitive advantage. Particularly in novel or emerging technological fields characterized by rapid technological change as well as high uncertainty, cooperation with such public research institutes may in fact be essential (Hall et al., 2003). There is clear empirical evidence of the positive effects of university R&D and academic knowledge on regional innovative output variables and on private-sector R&D (see e.g., Fritsch and Slavtchev, 2007, for an overview). Links to academic institutions can help firms to acquire the most recent scientific knowledge and expertise in specific technological fields or, as Arza and López (2011) recently demonstrated, can provide them access to specific equipment and infrastructure not available internally, e.g., for cost reasons (for an overview of university-based technology transfer, see, for instance, Bozeman (2000), Markman et al. (2005) and Rothaermel et al. (2007)). As Miotti and Sachwald (2003) demonstrated using French CIS-data, firms co-operate with universities primarily in order to get access to complementary resources. Cassiman et al. (2010) show that firms prefer formal co-operative agreements with academic institutions in basic, strategically less important issues. When they pursue projects that generate new and strategically important knowledge, firms prefer contract research with universities. A number of studies have identified positive effects of R&D cooperation between private firms and universities with regard to different measures of innovation performance and technological success (e.g., Aschhoff and Schmidt, 2008; Belderbos et al., 2006; Lööf and Broström, 2008; Miotti and Sachwald, 2003; Okamuro, 2007). Hence, we hypothesize:

H1a. *There is a positive relationship between university involvement in an R&D cooperation project with private-sector firm(s) and the innovation output of the respective project.*

There is also considerable evidence that it is important for private firms to engage in cooperative R&D in the field of applied research. Brockhoff et al. (1991), for instance, find for inter-firm cooperative R&D arrangements, that applied R&D is far more likely to be the objective of such cooperation than purely basic research. In an analysis of a sample of 237 (inter-firm) research consortia in Japan, Sakakibara (1997) finds that particularly the commercialization of R&D projects' output (product or process) is significantly related to application-oriented projects; however, the combined patenting activity of participating partners in a consortium is higher for those that conduct more basic research (Branstetter and Sakakibara, 2002). Kim and Park (2008) tested the impact of several types of cooperation partners on the innovative performance of Korean firms and find that co-operation with research institutes significantly increases the probability of process innovations. We therefore expect:

H1b. *There is a positive relationship between the involvement of applied research institutes in R&D cooperation projects and the innovation output of the respective cooperation projects.*

The size of a private firm engaged in research cooperation may have an important effect on the resource base of the respective project. Accordingly, the involvement of large firms should be more likely to increase R&D projects' innovative success than the participation of small firms only. Cooperative R&D can benefit from the resources large private firms allocate to the project. Large firms normally have greater internal R&D capacities and equipment and a broader as well as deeper knowledge base than smaller firms, so they should contribute to the project output through resource sharing (Okamuro, 2007). For instance, should a knowledge-intensive, small biotech-firm cooperate with a large pharmaceutical firm, the larger firm could facilitate and speed up the commercialization, diffusion and acceptance of innovation and thus greatly contribute to chances of success for the project (Belderbos et al., 2006). Large firms possess valuable resources, such as financial resources, R&D laboratories, specific equipment, skills and technological knowledge of employees. Even though, unbalanced partnerships might be associated with a significant degree of dependency of the small firms on their larger cooperation partners (Brockhoff et al., 1991) or with relatively few complementarities between cooperation partners (Branstetter and Sakakibara, 2002; Harrigan, 1988; Häusler et al., 1994; Veugelers, 1998), small-sized partners do considerably benefit from cooperative R&D with larger firms (Sakakibara, 1997). For this reason we hypothesize:

H1c. *There is a positive relationship between large-firm involvement in R&D cooperation projects and the innovation output of the respective projects.*

3.2. Geographic proximity of partners

Many authors argue that geographical proximity between cooperation partners is conducive to collective innovative endeavors (Asheim and Gertler, 2005; Audretsch and Feldman, 1996; Boschma, 2005; Jaffe et al., 1993). The main reason for this assertion is that spatial proximity may act as a catalyst for the exchange of experiences and the transfer of information and knowledge, particularly if this knowledge is non-codified and tacit in nature. Transfer of this kind of knowledge can require frequent personal interactions (face-to-face contact) between partners, which can be difficult to realize over greater geographic distances (Malmberg and Maskell, 1997). If knowledge spillovers are geographically bounded (e.g., Anselin et al., 1997; Jaffe et al., 1993; Zucker et al., 1998), locating in close vicinity to the sources of spillovers is of crucial importance for their exploitation (Audretsch and Feldman, 1996). The spatial proximity of the partners is, however, neither a necessary nor a sufficient condition for social and cognitive proximity, which is required for a well-working cooperative relationship (Boschma, 2005). It is nevertheless plausible to assume that spatial proximity may be conducive to the emergence of the social relations and mutual understanding.

Following the seminal contribution by Allen (1970), who studied inter-personal communication networks within R&D laboratories, few attempts have been undertaken to assess the impact of geographic distance between the partners of an R&D cooperation on project performance (Hoegl and Proserpio, 2004; Keller, 1986; Mora-Valentin et al., 2004). Hoegl and Proserpio (2004) provide empirical evidence for a positive impact of spatial proximity between the members of an innovation team and the quality of their joint output. Based on data for 145 German cooperative software development teams (within organizational boundaries) they find that geographic proximity is positively related to communication, coordination processes and mutual support within the team. According to the authors (p. 1160), communication between partners is eased "(…) as the high number of spontaneous and/or informal moments of contacts ensure a higher level of richness of the information transferred." In general, close proximity between team members reduces cooperation effort, particularly time and money for traveling and communication. For these reasons we expect that spatial proximity between cooperation partners contributes to the innovation output of the project, because of a more efficient and effective cooperation.

H2. *There is a positive relationship between the geographical proximity of the partners of R&D cooperation projects and the innovation output of the projects.*

3.3. Duration of cooperation project

The duration of cooperative R&D projects might influence their success in several ways. First, implementing the knowledge provided by cooperation partners is not always straightforward. In this respect, time can be a critical factor in developing fertile grounds for acquiring and understanding knowledge that disseminates within the project network. This holds particularly true for the transfer of tacit knowledge that requires frequent personal interaction (see Section 3.2). Such forms of interaction tend to be essentially based on trust and reciprocity, and may, therefore, require a longer-term relationship with dense social interactions. It is plausible to expect that in a long-term relationship each partner contributes in roughly equal terms to the project objectives, thereby securing reciprocity, which is considered to make networking a mutually fruitful channel for the transfer of information, knowledge and technology (Dahl and Pedersen, 2004; Niedergassel and Leker, 2011; Von Hippel, 1987). In contrast to this, a short project duration may prevent reciprocal exchange from certain partners, and thus weakens the cooperative relationship reducing the probability of success. Social connectedness accompanied by reciprocity can be a driving force for trust-based relationships (including loyalty, reliability and honesty), which bear the potential to neutralize opportunistic behavior and free-riding (Häusler et al., 1994; Kale et al., 2000; Uzzi, 1997).

The development of trust is, however, a process that takes time and requires continuous effort from all the cooperation partners. Cooperative partnerships need a long-term horizon to become stable (Veugelers, 1998). Trust-based relationships between cooperating partners develop and tend to be strengthened as the duration of the cooperation advances (Cooke and Morgan, 1998). Based on an initial degree of trust because of contract agreements, the partners get to know each other better, they pursue common objectives and trust further develops as a by-product of the project. Mora-Valentin et al. (2004) establish a link between trust and academic–industry cooperation. They find empirically that global satisfaction as well as the evolution of the cooperative relationship is significantly associated with trust amongst participants. Because project duration is associated with the establishment of reciprocal trust-based relationships within a consortium, we assume a positive impact on innovation output of R&D projects.

H3. *There is a positive relationship between the duration of R&D cooperation projects and the innovation output of those cooperation projects.*

3.4. Scale of cooperation project

The size of cooperation teams as a measure of the scale of the respective project has been found to be an important structural factor that may considerably shape the success of team processes (Bizan, 2003; Hoegl and Proserpio, 2004). One of the most important motives for engagement in cooperative R&D endeavors is to benefit from external knowledge and resources that are complementary to one's own resource base (Brockhoff et al., 1991; Hagedoorn, 1993; Sakakibara, 1997). The chance for every project partner to receive complementary know-how naturally increases with a broader project knowledge base, i.e., with increasing size of the project team. Larger-scaled R&D projects enable the project partners to further extend their technological know-how beyond their own organizational boundaries. If unforeseen problems occur that might require novel solutions, large-scaled projects that include a high number of cooperation partners should provide a relatively high probability that one team member develops an appropriate problem-solving strategy, maybe simply because that partner has encountered comparable or even the same problems in the past. Such specialized know-how bears immense potential to save time and costs, and thus to make projects successful. However, larger projects do not only provide access to larger amounts of knowledge and resources but also have higher costs of coordination and administration. Accordingly, team size has been found as negatively impacting team cooperation, communication and projects' innovative output (Hoegl and Proserpio, 2004; Dyer et al., 2006). Moreover, larger project teams bear greater potential for free-riding behavior (Kandel and Lazear, 1992). Therefore, we assume that research productivity is decreasing with increasing project scale, which leads us to formulate the following hypotheses:

H4. *There is an inverse U-shaped relationship between the scale of R&D cooperation projects and their innovation output.*

3.5. Internationality

Since international markets comprise more suppliers with different types of comparative advantage than domestic markets

R&D projects focusing on international markets face higher competitive pressure than R&D primarily aimed at the domestic market. In particular, it is plausible to assume that in order to successfully compete on international markets firms need to be close to the 'technological frontier' (Acemoglu et al., 2006). Hence, these firms should be rather knowledge intensive and perform relatively high-level R&D projects that have a correspondingly high propensity of generating results that can be patented or be subject of a scientific publication. Accordingly, empirical research indicates that the success of inter-firm cooperative R&D is positively affected if participating firms are affiliates of foreign multinational groups (Belderbos et al., 2006; Lhuillery and Pfister, 2009). There is also evidence that internationality in terms of presence on international markets (e.g. share of exports) has a positive impact on innovation at the firm level (e.g. Bhattacharya and Bloch, 2004; Felder et al., 1996; Schneider et al., 2010). It is therefore reasonable to assume that the intended commercialization (or exploitation) range of R&D cooperation affects innovation incentives (Negassi, 2004) and, therefore, the innovation output of R&D cooperation projects.

H5. *There is a positive relationship between the intended international commercialization range of the results of R&D and the innovation output of R&D cooperation projects.*

3.6. Experiences from prior cooperation

Experience from previous cooperation projects can be expected to improve the innovative output of an ongoing R&D cooperation project (Petruzzelli, 2011). For instance, Dyer and Singh (1998) and Barajas and Huergo (2010) argue that cooperation experience results in the development of relational capital and of efficiently working cooperation routines. These routines can help to facilitate the transfer of knowledge and to decrease transaction and coordination costs within an R&D consortium (Dyer et al., 2006). Experiences of cooperation partners may, therefore, also reduce the probability of conflicts between projects' team members. Particularly, a history of repeated interaction with the same cooperation partner(s) might be most conducive to the establishment of cooperation routines and trust-based relationships (Petruzzelli, 2011). While some authors could not confirm positive effects from prior cooperation experience (Hoang and Rothaermel, 2005; Dyer et al., 2006), most of the available empirical evidence suggests a positive relationship between cooperation experience and the success of subsequent cooperation projects (e.g., Anand and Khanna, 2000; Kale et al., 2002; Petruzzelli, 2011; Sampson, 2005). Hence, we expect:

H6. *There is a positive relationship between the experience of R&D cooperation partners from prior subsidized cooperative projects and the innovation output of an R&D cooperation project.*

4. Data and measurement

4.1. Data base

Our data on R&D cooperation projects were provided by the Development Bank of Saxony (SAB) which serves as an intermediary, allocating and distributing the funds available in the program. The SAB provided complete datasets for each of the subsidized cooperative R&D projects within the funding period 2000–2006. Overall, 417 cooperative R&D projects that were subsidized within the program have been identified in this data. Besides basic information, such as the project title, the starting date of the R&D project and the amount of funding, the data set includes information on the partners involved in each R&D project, such as geographical location. With respect to the individual outcomes of each subsidized R&D cooperation project, project leaders had to provide information whether the cooperation resulted in the application of patents or in publications (see Section 4.2.1).

4.2. Measurement of key variables

4.2.1. Innovation output of subsidized R&D cooperation projects

The innovation output of subsidized R&D cooperation projects is measured as the number of patent applications and as the number of publications that *directly emerged from an R&D project*. Patent applications include all applications at the German Patent and Trade Mark Office (DPMA) as well as applications at the European Patent Organisation (EPO). Patent applications are used instead of patents granted in order to avoid underestimation of project innovation output due to the sometimes-long time-spans between patent application and the final granting of patents (Okamuro, 2007). There are well-known methodological problems associated with patent applications as an indicator for innovation performance (Griliches, 1990; Schmoch, 1999). For instance, patenting behavior differs across industries and not all inventions are patented. There are several reasons why inventors may prefer other mechanisms to appropriate rents from R&D activities, most frequently secrecy (Cohen et al., 2000; Mansfield et al., 1981). Reasons for not patenting might include application costs, the high efforts to demonstrate the novelty of the invention or the perceived ease of inventing around patents (see Cohen et al., 2000). Notwithstanding these concerns, patents show a strong relationship to R&D expenditures and, therefore, are a suitable indicator of both inventive input and output (Griliches, 1990).

The second measure of the innovation output of subsidized R&D cooperation projects is the number of scientific publications by project members (Acs and Audretsch, 1993; Coombs et al., 1996). Besides the publication of articles in international, refereed academic journals, we also include publications in professional technical journals that specialize in publishing information on new products and processes in particular industries. The term 'publication' here refers to both types.

Data on patent applications and publications as innovation output of particular cooperation projects were extracted from the project database of the SAB (see Section 4.1 for more details). This approach enables us to establish direct linkages between the characteristics of a project and its innovation output.

While the initial data creation took place in 2008, the SAB provided an update with respect to the number of patent applications and publications in early 2010. We can therefore allow for a maximum four-year time lag between termination of a project and the application for patents and the publication of project results. Without a long time lag we would systematically under-estimate the innovation output of those R&D projects that started close to the end of the observation period. Overall, in 2010, the SAB records 539 patent applications and 1219 publications for the 417 R&D projects that are included in our analysis. The average number of patent applications per project is 1.29. Few R&D projects record more than two patent applications (13.7 percent); about 57 percent of the projects did not generate a patent at all. Seven percent of R&D projects record at least ten publications, while for 60 percent of R&D projects, there is a maximum of one publication; about 53 percent have no scientific publication based on the project. 31.2 percent of subsidized R&D cooperation projects had neither a patent application nor a publication.

To take account of the differences regarding the importance of project characteristics between the two measures of innovation output, two dependent variables are specified. While PATENTS reflects the total number of patent applications per R&D project,

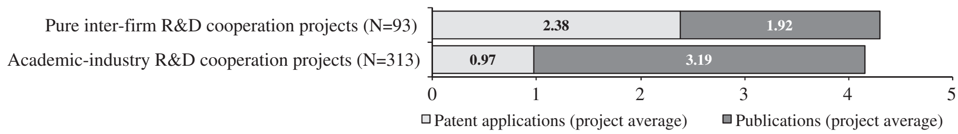

Fig. 2. Average number of patent applications and publications per R&D cooperation project by type of cooperation partners.

PUBLICATIONS measures the total number of publications recorded for each R&D project as innovation output.

We are particularly interested in comparing the differences between academic–industry R&D projects and pure inter-firm R&D projects. Fig. 2 shows that the total innovation output of these two types of R&D projects is in approximately the same range. Academic–industry projects record on average 4.15 patent applications or publications while pure inter-firm projects have an average of 4.30 patent applications or publications. However, there is a difference with regard to the proportion of patent applications and publications between the two types of projects. While the innovation output of academic–industry projects is characterized by a relatively high share of publications, pure inter-firm projects contribute almost in equal parts to the two measures of innovation output. This finding underscores the importance of distinguishing between these two types of R&D projects in the regression analyses. We applied the non-parametric Mann–Whitney-U-Test (MW-U-Test) for indentifying differences between the subgroups. For patent applications as measure of innovation output, the MW-U-Test implies systematic differences between academic–industry projects and pure inter-firm projects (statistically significant at the 5 percent-level). For publications as measure of innovation output, the difference is not statistically significant at the 5 percent-level ($p=0.125$).

4.2.2. *Explanatory variables and descriptive statistics*

A total of 564 different partners (firms, universities, research institutes, etc.) were involved in the R&D projects covered in our database. Whereas the majority of actors participated in one ($N=353$) or two ($N=110$) cooperation projects, there are nine participants that were involved in at least ten projects during the period 2000–2006. The maximum number of participants in a cooperative R&D project is 29. Similar patterns are reported for government-sponsored research consortia in Japan (Branstetter and Sakakibara, 2002) and for cooperative R&D agreements between firms and research organizations in Spain (Mora-Valentin et al., 2004).

We introduce a dummy variable UNIVERSITY, which takes the value of one (zero otherwise) if an R&D project involves a (department of a) university or technical college. A further dummy variable APPLICATION indicates an applied research institute (such as an institute of the 'Fraunhofer Society') as part of the project consortium (1=yes, 0=no). Note that the constructs are neither mutually exclusive nor do they specify how many universities (or academic institutions respectively) are involved. LARGE indicates if there is at least one large private firm within a project consortium (1=yes, 0=no). With respect to employment figures, private firms are considered to be large by the European Commission, if they have at least 250 employees. We adopt this threshold value for our analysis.

For our empirical analysis, we apply a measurement of proximity as geographic distance (see also Petruzzelli, 2011), thereby assuming that close spatial proximity interacts with and simultaneously favors the social proximity of the partners involved in the cooperation project. The dataset allows us to construct a variable that measures the mean distance between the respective ZIP-code areas of all project partners (DISTANCE) at the time the project proposal was accepted by the SMWA. More precisely, we calculated the distance between every possible dyad of cooperation partners. These distances were summed up and then divided by the total number of possible dyads. Some related studies use arbitrary measures of proximity (less/more than a particular threshold value, e.g., Mora-Valentin et al., 2004) or specific constructs including several items (Hoegl and Proserpio, 2004; Keller, 1986). The duration of each particular R&D project – as given in the SAB-database – is measured as a metric variable—the total number of days (DURATION). To control for any non-linear effects of project duration, we additionally specify a variable containing the squared duration time (DURATION_SQ).

Project scale can be proxied by different measures. We use two criteria. Following Hoegl and Proserpio (2004), the size of the cooperation team in terms of the absolute number of partners as outlined in the project application is included in the regression (PARTNERS). Within the '*Saxonian Support Scheme for R&D Cooperation*' there were no restrictions with respect to the maximum number of project partners. Most projects consist of two or three partners with only a few projects with more than five cooperation partners. This pattern again corresponds to that detected by other studies (Mora-Valentin et al., 2004). As the second measure of project scale, the amount in funding (in million Euros) enters the regression analysis (FUNDING). For both measures of projects scale, the squared values enter the regression analysis to test our hypothesis of an inverse U-shaped relationship (FUNDING_SQ, PARTNERS_SQ). Based on the proposals submitted to the SMWA, we measure the intended commercialization range of the results of R&D cooperation projects through a dummy variable INTERNATIONALITY. This variable assumes the value one if R&D projects' outcomes focus on international markets, rather than domestic markets (variable has the value zero).

Since we have information about support of R&D cooperation projects within the program under investigation for the 1994–2000 period which has been additionally provided by the SAB, we are able to assess the experience of R&D cooperation partners from prior cooperation in subsidized cooperation projects. The variable EXP_COORD indicates if and how often a project coordinator (in 2000–2006) has been coordinating R&D cooperation projects funded by the program in the previous period (1994–2000) and, therefore, relates to the specific experience of the R&D project coordinator. Nearly one Third of coordinating partners have such experience. The variable EXP_PROJECT specifies the general experience of the whole project consortium with prior projects in the program. We expect both indicators to exert a positive impact on projects' innovation output.

In order to control for possible effects of technology, we introduce six dummy variables for technology fields of R&D cooperation projects the program is directed to (see Section 2): materials science (T_MAT), physical and chemical technologies (T_PCT), biological research and technology (T_BIO), information technology (T_IT), production technology (T_PROD) and OTHERS which includes other technology fields and serves as reference category.We have full information on 406 R&D cooperation projects. Eleven R&D projects are omitted from the regression analyses due to missing data for one or several variables. Table 1 gives a summary of and descriptive statistics for all the variables and Table 2 shows the correlations between the variables.

Table 1
Description and descriptive statistics of dependent and explanatory variables that are included in the regression analysis (*N* (obs)=406).

Variable	Description	Mean	St. D.	Min	Max
Dependent variables of innovative output					
Patents	Total number of patent applications	1.29	2.60	0	19
Publications	Total number of publications	2.90	6.09	0	74
Scale of cooperation project					
Funding	Project funding (in million Euros)	0.78	1.190	0.013	14.78
Funding_SQ	Squared value of project funding (in million Euros)	1979516	11899340	1181	218415720
Partners	Total number of partners	2.67	1.01	2	7
Partners_SQ	Squared number of partners	8.16	7.81	4	49
Project characteristics					
Duration	Duration of the R&D project (in days)	825	274	244	1956
Duration_SQ	Squared value of duration of the R&D project (in days)	757021	497546	59536	3825936
Distance	Mean distance of all partners in R&D projects (in km)	31.31	31.45	0	147
Internationality	International commercialization range of results (1/0)	0.34	0.47	0	1
Exp_coord	Projects coordinator experience (frequency)	0.38	0.95	0	4
Exp_project	Total experience of all partners in R&D project	4.72	5.26	0	36
Cooperation partners					
University	Involvement of university/technical college (1/0)	0.41	0.49	0	1
Application	Involvement of applied research institute (1/0)	0.06	0.24	0	1
Large	Involvement of at least one large firm (1/0)	0.19	0.39	0	1
Technology fields					
T_BIO	Technology field: biological research and technology (1/0)	0.05	0.22	0	1
T_PROD	Technology field: production technology (1/0)	0.20	0.40	0	1
T_IT	Technology field: information technology (1/0)	0.21	0.41	0	1
T_MAT	Technology field: materials Science (1/0)	0.13	0.34	0	1
T_PCT	Technology field: physical and chemical technologies (1/0)	0.30	0.46	0	1
T_OTHERS	Technology field: others (Including environmental and medical technology, energy technology, microsystems) (1/0)	0.10	0.30	0	1

According to the correlation matrix, multicollinearity problems may only be expected between DURATION/DURATION_SQ, PARTNERS/PARTNERS_SQ and FUNDING/FUNDING_SQ (Hair et al., 1998).

Since the numbers of patent applications and of publications, as our dependent variables, are whole numbers, these variables can assume any non-negative integer value. Fig. 3 shows the distribution of the number of patent applications and the number of publications per project in our dataset. The sample mean of PATENTS is 1.29, and the variance is 6.76; for PUBLICATIONS the mean is 2.9 with a variance of 37.1. Since Pearson dispersion statistics (Hilbe, 2007) indicate significant overdispersion of these variables we apply negative binomial regression as the estimation technique (Cameron and Trivedi, 2005; Hilbe, 2007). Given the considerable share of projects that did not generate a patent or a publication at all, a zero-inflated version of the negative binomial regression might deem appropriate. In such an approach, only a selection of the cases with zero values of the dependent variable is included in the regression whereby a logit-model is used to predict these 'true' zero values. The results of the regressions may, however, be shaped by the variables used for this selection procedure. Various versions of such an approach have been tested that did not lead to any significant deviations from the results of the models that included all cases in the regression procedure. For reasons of methological simplicity, we only report the results of the models that included all available cases. Stata/SE 11.1 was used to perform the statistical analyses.

5. Regression results

For each of the two dependent variables we first estimate a model including all 406 usable observations in our sample. To control for possible differences in the effects of explanatory variables between academic-industry projects and pure inter-firm projects, separate models are estimated for these two cooperation types (Table 3). We also tested several models where we excluded particularly those variables that may lead to multicollinearity in the model. However, the results proved to be very robust. Our regression results support the assumption that university involvement (UNIVERSITY) is an important predictor for PUBLICATIONS as innovation output of R&D cooperation projects (models 4 and 5). With respect to PATENTS, we do not find a statistically significant positive impact for university involvement. Regarding the participation of an applied research institute, the results do not support H1b with respect to a positive impact on patent applications and/or publications as innovation output of R&D cooperation projects. APPLICATION is insignificant for all specifications. We also controlled for possible joint effects of a combination of universities and an applied research institute by including an interaction term (UNIVERSITY $\times$ APPLICATION). However, no statistically significant results were obtained for this variable. Large-firm involvement in R&D cooperation projects (LARGE) is generally positively associated with PATENTS (model 1). This effect is particularly strong in purely inter-firm projects (model 3). A statistically significant negative effect for large-firm involvement is found for PUBLICATIONS as output variable for inter-firm projects (model 6). No such effect is found for models 4 and 5.

Our estimations indicate no statistically significant influence of spatial proximity between cooperation partners and a project's innovation output. Alternative specifications as categorical variables comparable to Mora-Valentin et al. (2004) were tested. All such alternative indicators produced similar results that are, therefore, not reported here. Hence, hypothesis H2 has to be rejected. Neither prior coordinating experience (EXP_COORD) nor prior experience of the whole project consortium (EXP_PROJECT) significantly influences the innovation output of R&D projects. We additionally tested each of the two measures for prior experience separately as well as by including an interaction term combining these two measures. There were only minor changes in our estimations. Hence, hypothesis H6 also has to be rejected.

Table 2
Bivariate correlations of dependent and explanatory variables that are included in the regression analysis (*N* (obs)=406).

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
(1)	Patents	1																			
(2)	PublicationS	*0.21*	1																		
(3)	Funding	*0.55*	*0.26*	1																	
(4)	Funding_SQ	*0.47*	*0.19*	*0.85*	1																
(5)	Partners	*0.18*	*0.10*	*0.22*	0.06	1															
(6)	Partners_SQ	*0.18*	0.09	*0.20*	0.05	*0.98*	1														
(7)	Duration	0.05	*0.31*	*0.15*	−0.01	*0.17*	*0.18*	1													
(8)	Duration_SQ	0.07	*0.32*	*0.18*	0.01	*0.18*	*0.20*	*0.98*	1												
(9)	Distance	*−0.11*	*−0.11*	*−0.15*	*−0.11*	*0.12*	*0.11*	−0.01	−0.02	1											
(10)	Internationality	0.03	*0.26*	0.02	−0.01	−0.02	−0.01	*0.31*	*0.28*	−0.05	1										
(11)	Exp_coord	−0.07	−0.03	−0.03	−0.04	0.02	0.01	−0.03	−0.04	−0.07	*0.12*	1									
(12)	Exp_project	0.04	0.08	0.08	0.04	*0.38*	*0.38*	0.08	0.10	0.06	*−0.10*	−0.02	1								
(13)	University	*−0.12*	*0.19*	*−0.10*	−0.08	0.07	0.07	0.09	0.08	−0.02	−0.01	*−0.16*	0.02	1							
(14)	Application	−0.04	−0.01	−0.09	−0.04	0.05	0.04	−0.05	−0.05	*0.11*	−0.07	0.02	0.07	*−0.17*	1						
(15)	Large	*0.33*	0.09	*0.34*	*0.22*	*0.28*	*0.28*	0.13	*0.14*	−0.01	0.01	*−0.11*	*0.11*	−0.09	−0.07	1					
(16)	T_BIO	−0.03	0.01	−0.02	−0.02	−0.06	−0.06	0.04	0.03	0.05	−0.08	−0.06	0.08	0.07	0.08	*−0.12*	1				
(17)	T_PROD	*0.11*	*−0.18*	0.03	−0.03	*0.19*	*0.18*	0.07	0.06	0.04	−0.04	*−0.14*	0.00	−0.07	−0.07	0.07	*−0.12*	1			
(18)	T_IT	*−0.16*	0.00	*−0.13*	−0.05	−0.09	−0.08	−0.03	−0.05	−0.06	−0.02	−0.07	−0.04	0.07	0.02	0.05	*−0.13*	*−0.26*	1		
(19)	T_MAT	−0.04	0.00	−0.08	−0.04	*−0.10*	−0.09	−0.04	−0.02	−0.04	−0.06	−0.05	0.01	0.01	0.09	−0.03	−0.09	*−0.19*	*−0.21*	1	
(20)	T_PCT	0.10	*0.10*	*0.18*	*0.13*	−0.01	−0.02	−0.05	−0.04	−0.08	*0.12*	*0.33*	−0.03	*−0.11*	−0.07	−0.02	*−0.16*	*−0.33*	*−0.34*	*−0.26*	1
(21)	T_OTHERS	−0.02	−0.01	−0.03	−0.04	0.06	0.06	0.04	0.05	*0.16*	0.02	*−0.12*	0.03	*0.10*	0.20	−0.02	−0.08	*−0.17*	*−0.18*	*−0.13*	*−0.22*

Numbers in italics indicate significant correlations on the 5 percent level.

There is no clear evidence in our estimates that the duration of cooperative R&D projects is positively associated with their innovation output. With respect to PATENTS, we find a significant U-shaped relationship for pure inter-firm R&D projects (model 3). For PUBLICATIONS, DURATION is statistically significant in two models, but the squared value DURATION_SQ only for model 5. This might be seen as weak evidence for an inverted U-shaped relationship. Pure inter-firm projects seem not to be affected by duration (model 6).

A positive impact of international commercialization strategies of R&D cooperation projects on innovation output (Hypothesis H5) can only be found for the number of publications (models 3 and 4, but not in model 5). For patent applications the intended commercialization range is insignificant.

There are no significant effects for the number of partners in an R&D cooperation project (PARTNERS and PARTNERS_SQ) across all six model specifications. However, the volume of project funding exerts statistically significant positive effects on the innovation output of R&D projects across all but two of the models (FUNDING). Additionally, an inverted U-shaped relationship between projects' funding and innovation output can be confirmed for three models. FUNDING_SQ has a significantly negative influence on projects innovation output in models 1, 2 and 6. Thus, hypothesis H4 can only partially be confirmed.

6. Discussion and policy implications

Our analysis focused on the relationships between project characteristics and the innovation output of R&D cooperation projects. A summary of our results is presented in Table 4.

In accordance with previous studies of the success of cooperative agreements (Branstetter and Sakakibara, 2002; Harrigan, 1988; Okamuro, 2007) our findings suggest that the design of a R&D consortium can be an important predictor of the consortiums' innovation output. We find that projects that involve large private firms tend to be considerably more successful with regard to the number of patents generated than projects without any larger partners. This relationship seems particularly relevant for purely inter-firm cooperation, which implies that this type of cooperative R&D particularly benefits from the resources and the experiences large firms can devote to the project. We could not find such relationships for R&D cooperation projects involving academic partners. The inclusion of large industry partners seems, however, unimportant if the number of publications is taken as a measure for a project's innovation output. Interestingly, for inter-firm cooperation this relationship shows a weak, but significantly, negative sign. The number of resulting publications is particularly affected if universities participate in an R&D project. This may be not surprising since university researchers have a primary interest in publications documenting their research productivity.

Our results provide evidence for a positive effect of the amount of resources that are devoted to a cooperative R&D project. We particularly find a highly significant positive relationship between the extent of funding of R&D projects and the number of patents as indicator of innovation output. Regarding the number of publications the evidence is weaker. Here, we only find a significantly positive effect for inter-firm projects. These results may be regarded as an indication that more resources are required for generating patent applications than for publications. This underscores our findings concerning the impact of large industry partners in R&D projects (see above). Overall, our findings for projects' funding are in contrast to Bizan (2003) who reports insignificant results for technical success (but significantly negative results for duration to commercialization) using total budget spending by all project partners as indicator

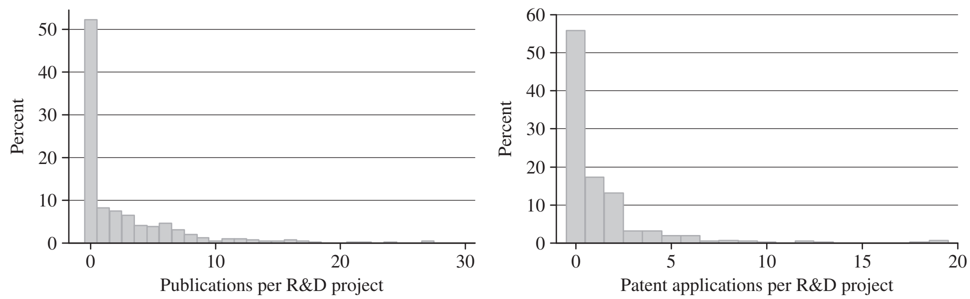

Fig. 3. Distribution (histograms) of publications and patent applications. *Notes*: Histogram for publications is restricted to R&D projects with a maximum of 30 publications.

Table 3
Results of negative binomial regression for the determinants of innovative output of R&D cooperation projects (standard errors in parentheses).

	Dependent variable: (number of) patents			Dependent variable: (number of) PUBLICATIONS		
	Model 1 Full sample	ModeL 2 Academic – industry	Model 3 Inter – firm	MODEL 4 Full sample	MODEL 5 Academic – industry	MODEL 6 Inter – firm
Project scale						
Funding	*0.511 (0.135)*[a]	*1.040 (0.309)*[a]	*0.346 (0.199)*[c]	0.251 (0.160)	0.472 (0.369)	*0.794 (0.248)*[a]
Funding_SQ	*– 0.000 (0.000)*[b]	*– 0.000 (0.000)*[b]	– 0.000 (0.000)	– 0.000 (0.000)	– 0.000 (0.000)	*– 0.000 (0.000)*[b]
Partners	0.292 (0.416)	0.449 (0.445)	0.287 (0.996)	0.667 (0.453)	0.646 (0.492)	1.242 (1.282)
Partners_SQ	– 0.031 (0.056)	– 0.052 (0.058)	– 0.014 (0.137)	– 0.078 (0.061)	– 0.078 (0.066)	– 0.146 (0.181)
Project characteristics						
Duration	– 0.002 (0.001)	0.001 (0.002)	*– 0.008 (0.003)*[a]	*0.003 (0.002)*[b]	*0.005 (0.002)*[a]	– 0.002 (0.003)
Duration_SQ	0.000 (0.000)	– 0.000 (0.000)	*0.000 (0.000)* [a]	– 0.000 (0.000)	*– 0.000 (0.000)*[c]	0.000 (0.000)
Distance	– 0.002 (0.003)	– 0.003 (0.003)	– 0.003 (0.005)	– 0.001 (0.003)	– 0.003 (0.003)	0.005 (0.005)
Internationality	0.019 (0.183)	0.035 (0.220)	– 0.287 (0.340)	*0.856 (0.182)* [a]	*0.888 (0.211)* [a]	0.415 (0.352)
Exp_coord	– 0.120 (0.093)	– 0.131 (0.096)	– 0.138 (0.496)	– 0.129 (0.102)	– 0.170 (0.105)	0.191 (0.536)
Exp_project	– 0.003 (0.016)	– 0.019 (0.019)	0.007 (0.028)	– 0.001 (0.019)	– 0.007 (0.022)	0.005 (0.041)
Cooperation partners						
University	– 0.180 (0.182)	– 0.133 (0.207)	– –	*0.580 (0.189)* [a]	*0.460 (0.213)*[b]	– –
Application	0.238 (0.366)	0.432 (0.377)	– –	0.292 (0.381)	0.326 (0.398)	– –
Large	*0.753 (0.209)* [a]	*0.508 (0.256)*[b]	*1.035 (0.362)*[a]	– 0.107 (0.261)	0.257 (0.304)	*– 1.263 (0.562)*[b]
Technology fields						
T_BIO	– 0.102 (0.420)	– 0.090 (0.464)	– 0.331 (1.017)	– 0.068 (0.454)	0.137 (0.516)	– 0.826 (1.020)
T_PROD	– 0.056 (0.308)	– 0.218 (0.348)	0.316 (0.603)	– 0.489 (0.335)	– 0.273 (0.397)	– 0.770 (0.666)
T_IT	*– 1.017 (0.330)*[a]	*– 1.270 (0.389)*[a]	– 0.439 (0.613)	0.179 (0.330)	0.011 (0.378)	0.770 (0.619)
T_MAT	– 0.277 (0.335)	– 0.256 (0.359)	0.081 (0.819)	0.288 (0.367)	0.389 (0.408)	– 0.811 (1.074)
T_PCT	– 0.133 (0.299)	– 0.275 (0.327)	0.234 (0.639)	0.360 (0.317)	0.451 (0.355)	0.079 (0.649)
Constant	0.026 (0.873)	*– 1.687 (1.014)*[c]	2.389 (1.876)	*– 3.210 (1.016)*[a]	*– 4.098 (1.222)*[a]	– 2.120 (2.320)
Number of Observations	406	313	93	406	313	93
Pseudo R^2 (Prob > χ^2)	*0.087 (0.000)*[a]	*0.064 (0.000)* [a]	*0.155 (0.000)* [a]	*0.065 (0.000)* [a]	*0.066 (0.000)* [a]	*0.123 (0.001)* [a]
Log Likelihood	– 556.210	– 392.638	– 150.489	– 757.103	– 604.676	– 140.675

Coefficients/standard errors in italics indicate statistical significance.

[a] Significant at the 1 percent-level.
[b] Significant at the 5 percent-level.
[c] Significant at the 10 percent-level.

for project scale. However, there is also considerable evidence in our results for decreasing returns if projects become too large in terms of funding.

We could not identify any effect of spatial proximity between cooperation partners and projects' innovation output. This result is in line with most of the previous empirical research, where Petruzzelli (2011) even finds that larger geographical distance between partners in university–industry collaborations may lead to an increase of innovative project outcomes. An explanation for the insignificance of geographical proximity between cooperation partners in our study might be that in cases where complementarity of project partners is very important, the appropriate partners may be located in larger geographical distances (other countries). This suggests that the role of spatial proximity for cooperative innovation processes may be overestimated in large parts of the respective literature. However, this paper and Petruzzelli (2011) is not the first that provides empirical evidence that geographic proximity has no significant effect on innovation output; see, for example Beise and Stahl (1999) and Vedovello (1997) for similar results. We may hypothesize that, although partner are located proximate to each other, they mostly tend to fail to establish social dimensions of proximity which can be regarded important for innovation and learning (Boschma, 2005). However, we could not account for such social dynamics within cooperative R&D projects that are possibly shaping R&D project outcomes (for instance decision-making processes) due to missing information on these issues. Such interactions naturally take place on an inter-individual level rather than between organizations.

The insignificance of prior cooperation experience that we found is in line with Dyer et al. (2006), but contrasts findings by Petruzzelli (2011), suggesting that cooperation routines could not yet be developed. Although we were able to account for prior coordinating and subsidization experiences, we cannot exclude that more detailed information about earlier relationships of

Table 4
Summary of the empirical results concerning the status of the hypothesis.

Hypothesis: There is a(*n*)…	Supported	Partially supported	Not supported
…positive relationship between *university involvement* in an R&D cooperation project with private-sector firm(s) and the innovation output of the respective project.		X	
…positive relationship between the *involvement of applied research institutes* in R&D cooperation projects and the innovation output of the respective cooperation projects.			X
…positive relationship between *large-firm involvement* in R&D cooperation projects and the innovation output of the respective projects.		X	
…positive relationship between the *geographical proximity of the partners* of R&D cooperation projects and the innovation output of the projects.			X
…positive relationship between the *duration of R&D cooperation projects* and the innovation output of those cooperation projects.		X	
…inverse U-shaped relationship between *the scale of R&D cooperation projects* and their innovation output.		X	
…positive relationship between the intended *international commercialization range of the results* of R&D and the innovation output of R&D cooperation projects.		X	
…positive relationship between the *experience of R&D cooperation partners from prior subsidized cooperative projects* and the innovation output of a R&D cooperation project.			X

particular cooperation partners would reveal such an effect of prior experience.

Important relationships were identified that may be taken into account by policy-makers when designing support programs. A first thing that may be learned from our analysis is that project scale in terms of funding matters for the innovation output of a project. This relationship particularly holds if patents are sought by the project consortium, i.e., commercialization of R&D results is the objective. At first glance, this sounds simplistic, but it is not at all self-evident that higher budgets lead to better results. Evidence for this argument is given in our analysis when considering publication in peer-reviewed journals, where the extent of funding has a much weaker impact on the innovation output of a project. The message for policy makers at this point is that R&D projects should not be too small but have a critical mass. In times of shrinking public budgets this finding may lead to the conclusion that instead of reducing the average funding per project it might be more efficient to reduce the number of public funded R&D projects. Second, the positive effects deriving from the involvement of large firms should be an interesting message for innovation policy. While most R&D programs primarily aim at SMEs, policy makers should realize that in case of R&D cooperation projects, larger firms have a lead function, and program guidelines in terms of project eligibility should account for this effect. Third, the empirical findings point to positive effects of an involvement of universities (including technical colleges) into R&D projects. This confirms current practice and should encourage policy makers to continue or to enforce stimulation of science-industry projects.

7. Concluding remarks

The present paper contributes to the understanding of cooperation in R&D through providing novel insights on the relationship between the innovation output of R&D cooperation projects and project characteristics. We used project-level data for 406 publicly funded R&D cooperation projects. The innovation output of R&D cooperation projects was measured as the number of patent applications and the number of publications of project members as outcomes of an R&D project. Prior empirical work mainly focused on factors that lead to the establishment of R&D cooperation and on the impacts of R&D cooperation on the performance of the partners involved. Only few attempts have been made so far to explore the relationship between project characteristics and its innovation output.

Our study is subject to some limitations that might suggest avenues for further research. Most importantly, we cannot account for a possible selection bias. R&D projects that apply for public funding are screened according to a number of criteria (e.g., degree of novelty, technology-orientation—see Section 2) by the administration to assess their success chances. Project consortia with a considerable risk of being not successful in reaching their project objectives might be systematically excluded. Unfortunately, there exists no information about the actual approval decisions. This means that we do not have insight regarding the number and the attributes of project proposals that have been rejected. Such selection processes suggest a matching approach that compares subsidized R&D projects with an appropriate control group of comparable cooperative R&D projects that have not received public financial support. As demonstrated by Czarnitzky et al. (2007) for R&D cooperation in Germany and Finland, innovation output of collaborating but non-subsidized firms could benefit significantly if these firms would additionally participate in publicly subsidized R&D programs. This suggests the existence of unexploited innovation potentials (Czarnitzky et al., 2007). Identifying an appropriate control group to perform such analyses is, however, complicated because necessary information is hardly available.

A further limitation of our analysis results from our two measures of innovation output, patent applications and publications. First, since not all projects that did not apply for a patent or have a publication in an academic journal can be deemed failures we may have underestimated the success of such projects. Second, in the present study, we could not control whether the inventions developed during R&D cooperation projects are commercially successful. We used the patent applications as proxy for project innovation output and not the actual grant, because the time span between the application for and granting of patents may be considerable. It would be rather interesting and important to analyze the post-project performance of participants, thereby linking projects output to performance measures. Such an analysis could, for example, show, to what extent the partners of a subsidized R&D cooperation project tend to collaborate after public funding has ended, i.e. if subsidies have an effect beyond the duration of the project. Initiation of long-lasting R&D cooperation would be a benefit of respective programs that we, unfortunately, could not account for in our analysis.

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Michael Schwartz is a Research Associate at the Halle Institute for Economic Research (IWH), Department of Urban Economics. He received his Ph.D. in Economics from the Friedrich-Schiller-University of Jena. His research interests are in the fields of technological change, local innovation systems, entrepreneurship, technology transfer and especially incubators and science parks.

Francois Peglow is Ph.D. student and a Research Associate at the Max Planck Institute for Demographic Research in Rostock. He studied economics at the University of Halle–Wittenberg. He also holds a master degree in empirical economics and scientific policy advice.

Michael Fritsch is a Professor of Economics at the Friedrich–Schiller–University Jena, Germany, and Chair of Business Dynamics, Innovation and Economic Change. His current research is focuses on the effects of market dynamics and innovation activity on economic development. His main interest is in entrepreneurship, particularly starting new businesses, their success and failure, as well as their impact on the evolution of the respective industry and region.

Jutta Günther is a Senior Economics at the Halle Institute for Economic Research (IWH), Department of Structural Economics (Head of Department), and the coordinator of the Research Group Knowledge and Innovation. Her research focuses on Innovation Systems in Post-Transition Economies, Technology transfer between science and industry and research- and innovation policy.