Discussion Paper No. 06-037

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An Empirical Study on the Impact of Public R&D Funding on Firms' Cooperative Behaviour in Germany

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Abstract

Subsidising research networks has become a popular instrument in technology policies, driven mainly by expected positive spillovers. In particular, the stimulation of R&D co-operation between scientific institutions and industry is considered as most promising. In the context of policy evaluation we analyse if public R&D funding is suitable for influencing firms' collaborative behaviour in the intended way and where applicable, if a lasting change results. The empirical analysis is based on German CIS data and a supplemental telephone survey. Using a nearest-neighbour matching approach we find that R&D funding is indeed a particularly valuable tool for the linking of science into industry R&D partnerships. However, we also show in a bivariate probit analysis that newly initiated R&D co-operations with science are less likely to be continued after funding has ended compared to already existing co-operations. Therefore, the behavioural change induced by public funding is not necessarily long-lived.

Keywords: Public Funding, Firm Behaviour, Policy Evaluation, R&D Co-operation

JEL-Codes: O32, O38, H32, L22, C20

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Non-technical summary

Public funding of research and development (R&D) activities is an integral function of innovation policies implemented by the governments of most OECD countries. Its primary objective is to increase the innovative potential and competitiveness of the respective economy. In Germany, direct R&D project funding is an important funding tool used by the government. Since the end of the 1980s a clear trend towards the funding of projects conducted in networks rather than individual companies can be observed. In 2004 two-thirds of all directly funded projects were part of a collaborative network.

In the face of shrinking government budgets and intensified international competition in the field of technology, increasing the efficiency of innovation policies has become crucial. Hence, evaluations have shifted into focus for politicians and economists.

Within the framework of evaluation approaches, the present study aims to investigate behavioural additionality effects with the focus on collaboration, i.e. changes in firms' behaviour in terms of co-operation arising from publicly funded R&D projects. We ask whether public R&D funding is adequate for influencing firms' collaborative behaviour. The data used in the empirical analysis is based on the Mannheim Innovation Survey database, the German Federal Government's R&D funding database, the German Patent Office database and telephone interview survey data. We examine 659 German firms involved in R&D collaboration and investigate (i) whether public R&D funding stimulates firms to collaborate with a different set of partners (business firms, scientific institutions or both) compared to where public funding has not been received and by means of 142 observations (ii) whether newly initiated collaborations within a publicly funded R&D project are likely to last compared to already existing collaborations, after public funding has ended.

Our first research question is: can public R&D funding be used as a trigger for involving new types of partners in a co-operation? To examine this effect, we characterise R&D partnerships as business-only, science-only and as involving the combination of both business and science partners. Within a nearest-neighbour matching approach, we compare the resulting sets of R&D collaborations between publicly-funded and non-publicly-funded firms. In a second step using a bivariate probit analysis we investigate if a potential change lasts and ask: are newly initiated co-operations more likely, or at least as likely, to be continued compared to already existing co-operations?

We find that public R&D funding is, in particular, a means of stimulating the inclusion of science as a new partner in industry R&D partnerships. In this respect, i.e. stimulating new and more diversified types of partnerships, public funding achieves its aim. However, we also show that newly initiated industry-science R&D co-operations are less likely to be continued after funding has ended compared to already existing co-operations. Overall, public funding tends to integrate science into business R&D partnerships, but these newly-established networks are not necessarily continued after funding has ended.

1 Introduction

Public funding of research and development (R&D) activities is an integral function of innovation policies implemented by the governments of most OECD countries. Its primary objective is to increase the innovative potential and competitiveness of the respective economy. In the face of shrinking government budgets and intensified international competition in the field of technology, increasing the efficiency of innovation policies has become crucial (OECD 2004a). Hence, there is growing demand for rigorous evaluation of R&D policies to form the basis of national learning processes and sound decision-making by policy makers and participants. Evaluations of R&D incentive schemes are of particular importance in judging the impact and effects of such governmental interventions. The impetus behind the popularity of evaluation approaches is linked to growing expectations of achieving additional sustainable returns on public investments, denoted by the term ‘additionality’.

Evaluations are broadly defined as systematic and objective assessments of on-going or completed projects, programmes or policies with respect to design, implementation and results. Their primary concern is to shed light on the key criteria of efficiency, effectiveness, impact and sustainability, as policy makers and, in the end, taxpayers inquire about the additionality effects which may result from a policy measure (OECD 2001). Concepts of measuring additionality deal with the question of how policies have affected the current situation or performance of participating agents or sometimes even of the entire economy. Assessing the effects of public funding, empirical studies have focused almost exclusively on additionalities regarding firms’ input, e.g. supplementary R&D investments, and companies’ output, e.g. increasing patent applications (cf. David et al. 2000, Czarnitzki et al. 2004). But changes of firm’s behaviour throughout the R&D process, e.g. regarding the organization or strategy of R&D, might also be induced by public funding. These changes are called ‘behavioural additionality’ effects.

This study looks at national R&D funding of private businesses in Germany and investigates behavioural additionality effects, thereby focussing on changes regarding collaborative behaviour. We ask whether public R&D project funding is adequate for influencing firms’ co-operation practices in Germany. In particular, we investigate different types of collaborative research due to public R&D funding. The question on which we intend to shed light is whether public R&D funding stimulates firms to participate in new kinds of R&D co-operation, especially in co-operations with scientific institutions (science), which results in more diversified co-operation. Moreover, we examine if within a publicly funded R&D project newly initiated collaborations, i.e. cases where a company collaborated with the partner for the first time, are as likely or even more likely to last compared to already existing co-operations, after public funding has ended. If newly initiated co-operations are continued after the funded project has ended, a sustainable change in firms’ collaborative behaviour is achieved through public funding.

The structure of the remainder of the paper is as follows: First, we give a brief overview of economic theory and the rationale for public funding of business R&D. In the third section we analyse the change witnessed in the German Federal Government’s funding policy during the 1980s and 1990s. Section four presents the evaluation concept and research questions. In the empirical section we describe the data and the econometrics applied, followed by a presentation of the results. Finally, section seven concludes.

2 Rationales for collaborative R&D funding

For a better understanding of the rationales for collaborative R&D funding, we describe first shortly the distinctive features of R&D and secondly we outline the impact of these unique characteristics of R&D on the firms' decision to engage in R&D co-operations.

Characteristics of R&D

Starting with Arrow's (1962) work, economists have realised that investment in R&D differs substantially from other types of investment, e.g., in physical assets. R&D consists of knowledge, which has characteristics typical of a public good (Coase 1974). Unlike investment in physical assets, returns on the creation of knowledge cannot be fully appropriated by the inventor. In the business sector such knowledge leaks out of the firm, e.g., by employees leaving the company. Thus, competitors benefit from the inventor and original investor's efforts. The evidence of significant spillovers of private investments in the field of R&D and innovation is shown by a host of empirical analyses (cf. OECD 2004b, Klette et al. 2000, Jones 1998). Due to these externalities, economists recognise the two sides of R&D as a rather general problem: Leaking knowledge increases social returns but reduces private returns and prevents R&D activity in the long run. In the case that R&D could possibly generate high social returns without covering the private cost, market failure occurs and the level of R&D activities in the economy in question is thus below the socially desirable level (cf. Levin et al. 1987, Adams/Jaffe 1996, Mathews 1996).

Furthermore, the inherent risk of failure associated with each R&D project leads to the fact that potential investors are reluctant to finance such investments, since they have less information about the expected returns than the firm. Additionally, the financing of R&D is more difficult than other types of investment due to its intangible character. Often, it does not offer any collateral in credit negotiations. Thus, the level of R&D in the economy decreases even further.

Explanations of R&D collaborations

Since R&D is of great importance for firms, they have to find a way to overcome or at least to mitigate the inherent obstacles to R&D. One answer for firms is to engage in R&D collaborations. The number of R&D partnerships has increased considerably since the beginning of the 1980s and nowadays co-operation is a widely used form of organizing R&D (Hagedoorn 2002). In R&D co-operations the level of voluntary knowledge flow can be determined by the R&D partners since they can decide on how much knowledge they exchange. The result is that via R&D co-operations, firms achieve both a high level of knowledge flow into a firm and sufficiently protect internal knowledge from leaking out.

Besides the motives related to knowledge spillover, other factors influencing a firm's decision to cooperate can be identified. They can be mainly categorized into two groups: (1) overcoming resource constraints a firm faces, e.g. constraints in terms of knowledge, competencies and financial means which hamper firms from undertaking innovation projects on their own and (2) determinants related to firm characteristics, e.g. structure of the firm and industry in which it operates, e.g. many studies show that the probability of co-operation increases with firm size.[2]

The motives, mechanisms and benefits of research consortia emerge from different theories and empirical studies. The theoretical explanations are mainly based on three perspectives: (a) transaction cost theory, (b) strategic management theory and (c) industrial organisation theory.[3] In transaction cost theory, R&D co-operations are explained as a hybrid form of organisation between a market and a hierarchy, to facilitate an activity specifically related to the production and dissemination of technological knowledge. Due to the lacking appropriability of R&D, positive external effects are generated. In order to internalise such effects, companies prefer to engage in research collaborations with possible third party users of their research results. In strategic management theory, research partnerships are explained by competitive reasoning (jointly defending market positions against competitors), by strategic networks (economies of scale and scope), by a resource based view of the firm (to exploit unique capabilities), by dynamic capabilities (to combine competencies) and by strategic options on new technologies (to determine resources for superior future performance). In the theory of industrial organisation, research collaborations are explained by the existence of market failures due to the perceived nature of knowledge as a public good. The majority of theoretical studies deal with imperfectly appropriable R&D and an increase of market power (e.g. Katz 1986, d'Aspremont/Jacquemin 1988, Freeman 1991, Kamien et al. 1992, Katsoulacos/Ulph 1998, Robertson/Gatignon 1998, Kamien/Zang 2000). Empirical studies dealing with incentives to engage in R&D co-operations are e.g. Cassiman/Veugelers 2002 and Belderbos et al. 2004a.

Public funding and R&D collaborations

To overcome market failures related to the R&D investments of firms, governments also take action and use a variety of policies, so that technology gaps can be avoided and, in the end, national and European competitiveness is strengthened (Fahrenkrog et al. 2002, Branscomb/Florida 1997, Martin/Scott 2000). In OECD countries four main policy instruments are used for this purpose: (1) establishment of public research infrastructure, e.g. public laboratories, (2) government funding of R&D performed by businesses, e.g. public subsidies for specific R&D projects, (3) fiscal incentives like tax deductions for R&D expenditure and (4) property rights, e.g. governments compensate for market failure by using property rights to protect knowledge which has been exclusively paid for and generated by a firm. Today, many countries have implemented a mix of these policy tools to foster domestic innovation performance (Capron/van Pottelsberghe de la Potterie 1997).

In Germany, a complex system of public R&D funding was established in the 1970s. Public funding schemes are employed in all areas of industry and technology. Today, the German research system is generally financed through targeted, short- to medium-term funding of R&D projects and through medium- or long-term basic funding of institutional

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[2] Further theoretical arguments concerning questions related to research partnerships can be found in, e.g.Vonortas (1997) or de la Mothe/Link (2002); for a survey see Caloghirou et al. (2003).

[3] See Hagedoorn et al. (2000) for a detailed overview.

research. In international comparison, the German R&D policy stands out mainly by its lack of supportive fiscal measures. In Germany subsidies for R&D projects have become a popular instrument in technology policies, from the 1980s on. At the federal level, direct R&D project funding for industry is almost exclusively provided by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Economics and Labour (BMWA).

In line with theory, the German Federal Government justifies its public R&D funding with the existence of external effects, i.e., that third parties can use research results and thus gain an economic advantage without paying the technology developer a fee. “In such cases the incentives may be too weak for innovative companies to develop private R&D activities in these areas to the desirable extent if economic profitability considerations were included” (BMBF 1993). The purpose of such funding is to achieve high international standards of performance in selected areas of research and development in order to stay competitive in the end (BMBF 2002).

At the end of the 1980s when R&D co-operation was seen as a useful form of R&D organization, the German government decided to reconfigure the incentive structure towards R&D collaborations. They want to phase out such former policies which relied on project-specific funding of single awardees and advance a collaboration-oriented policy scheme with the goal of allowing spillovers. This has been addressed, in particular, at small and medium sized enterprises (SMEs) and scientific research. The main objective associated with this policy change is to increase public funding efficiency. The further argumentation in funding collaborative R&D projects runs along the line of spillovers and the desired know-how transfer: “Collaborative R&D intends to involve as many companies and scientific organisations as possible within a publicly funded project, to bundle individual resources and capabilities, to stimulate the technology transfer between industry and science, and to achieve synergies while funding should get less selective but more diffusive” (BMBF 1988, BTDrs 2005). The aim is to achieve a widespread efficiency of public R&D funds by stimulating “multidisciplinary R&D collaborations e.g. between social-, natural- and engineering scientists” (BMBF 2004) and “heterogeneous R&D collaborations e.g. between industry and science” (BTDrs 2005).

3 Facts and figures on public R&D project funding in Germany

In Germany, direct R&D project funding is an important funding tool for the government. It is characterised by the funding of a concrete field of technology on a cost-sharing basis. In principle, such business R&D project funding is available to all domestic firms. However, each public R&D programme has specific characteristics, such as different application procedures, different requirements and different agencies which are responsible for funding proceedings. These agencies assist the federal ministries in funding concepts, advise potential applicants seeking support for research and offer consulting with respect to the exploitation of patents and licences (BMBF 2004).

The importance of direct R&D funding to the business sector is revealed by the number of funded companies and projects and the total amount of these grants. In the 1980s, an average of 1,623 projects per year were funded with an average amount of 394 million euro (cf. Table 1).[4] The indicators show different changes in the following decades. The number of publicly funded projects steadily increased up to 4,080 projects in 2004. The number of funded companies more than tripled from 1980 to 2004.

The Federal Government's total R&D budget available for spending on firms did not grow proportionally with the increase in awarded projects. Rather, the total R&D budget and therefore the average award size have been decreasing at the same time. The average total awarded to private firms in the 1980s stood at 394 millions euros; in 2004 the amount was about 363 millions euros (-8 %). This means that more than twice as many projects and three times as many firms were funded with less money. Consequently, the average award size for R&D projects has decreased from 242,000 euros in the 1980s to its present low of 89,000 euros in 2004. Furthermore, a shift took place regarding how the money was divided among the different technology areas. While the relative amount granted for projects in the areas of the environment, energy and transportation decreased in that time period, it was primarily the ICT sector which became more important. About 46 per cent of the funding budgets are allocated to projects of the ICT sector in 2004.

Table 1: Statistics on direct R&D project funding for the business sector by the BMBF (1980-2004)

	1980-89[a)]	1990-99 [a)]	2000	2001	2002	2003	2004[b)]
Total number of funded projects	1,623	2,264	3,469	3,876	4,072	4,086	4,080
Number of individually conducted projects	1,171	586	644	628	538	520	527
Number of collaboratively conducted projects	452	1,679	2,825	3,248	3,534	3,566	3,553
Per cent of indiv. conducted projects	72.2	25.9	18.6	16.2	13.2	12.7	12.9
Per cent of collab. conducted projects	27.8	74.1	81.4	83.8	86.8	87.3	87.1
Avg. number of participants in collaborations	3.3	3.2	3.3	3.3	3.2	3.1	3.0
Total R&D budget committed (mio. €)	393.7	318.1	395.6	414.9	397.8	380.9	362.9
Budget committed to indiv. conducted projects (mio. €)	267.2	104.4	114.2	114.2	98.7	94.5	79.4
Budget committed to collab. conducted projects (mio. €)	126.5	213.7	281.4	300.7	299.0	286.4	283.6
Avg. grant size for indiv. conducted projects (mio. €)	0.225	0.185	0.177	0.182	0.183	0.182	0.151
Avg. grant size for collab. conducted projects (mio. €)[c)]	0.334	0.136	0.100	0.093	0.085	0.080	0.080

Legend: a) Figures represent the average on a yearly basis; b) preliminary numbers; c) Basis: single collaborative project

Source: BMBF PROFI database (2005), calculations by ZEW; 1980 to 1989: West-Germany; without contract research and R&D projects funded at 100 per cent; Deflated time series amounts (1995=100).

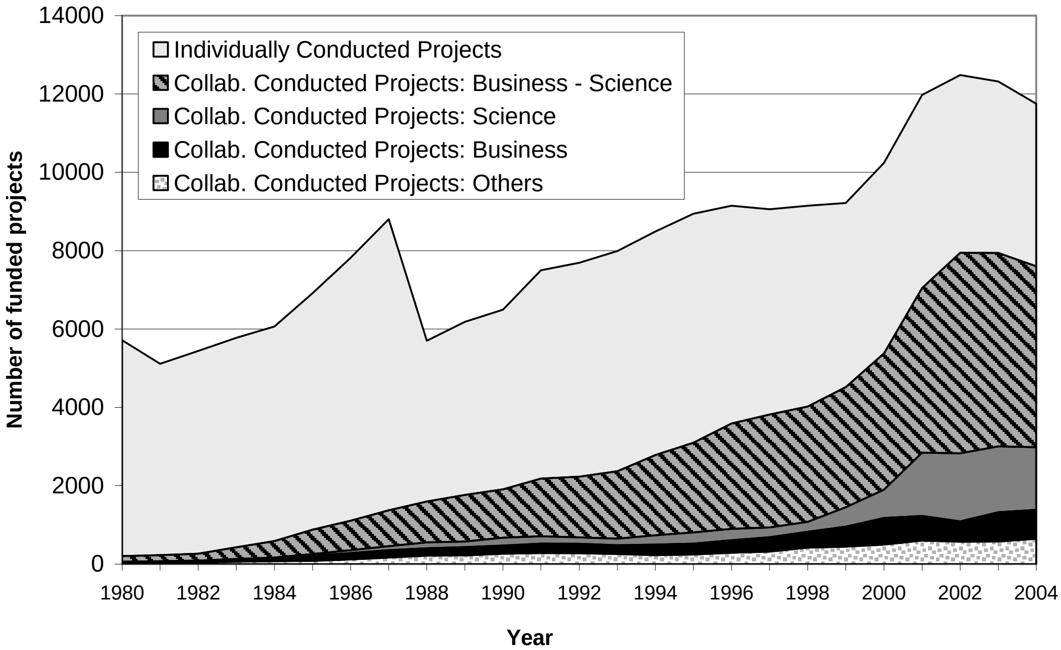
At the end of the 1980s, the BMBF began to emphasise the funding of projects conducted by networks rather than individual companies which can be confirmed by the distribution of the number of funded projects and funding amounts. While in the 1980s about 72 per cent of all funded projects in the business sector were individual R&D projects, the opposite was true by beginning of 2000, with a proportion of 81 per cent of projects conducted on a collaborative basis (cf. Table 1). Currently, about 87 per cent of all publicly funded projects of the business sector are collaborative R&D projects and these receive 78 per cent of the funding budget. Looking at the respective project size, it appears that presently a

[4] Contract research and projects which are funded by 100 per cent are not taken into account.

typical individually conducted project is smaller by a quarter than the total amount of joint R&D projects, taking the sum of all the projects belonging to one network. But a single project of one co-operation partner is only about half the size of an overall individually conducted project. This is because these joint research activities where business companies are involved are carried out by an average of three partners, such as other firms or scientific institutions. In 2004, the largest of these networks was composed of 34 partners.

The BMBF did not only intend to emphasize collaborative R&D in general, but they wanted to fund more diversified co-operations with respect to the type of participating partners. Figure 1 graphs all publicly funded projects, not restricted to the business sector, according to whether they are part of a network and, if so, which kinds of partners are involved.[5]

Figure 1: Direct R&D project funding by BMBF in Germany (1980 – 2004)



Source: Calculation by ZEW based on the German Federal Government's database PROFI (2005)[6]

Looking at all directly funded projects the clear trend towards collaborative projects remains. While in 1980 almost all of the funded projects were conducted by individual companies, the proportion of projects conducted in collaboration with two or more companies rose steadily. In 2004 two-thirds of the projects were part of a network. The increase thereby applies to all types of collaborations, i.e., any combination of business networks and research institutes/universities, but it is by far the largest for networks of business companies and

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[5] Firms are differentiated between business sector, science sector, like universities or research institutions, and other institutions ("others"), e.g. federal state ministries, municipal authorities, or chambers of commerce.

[6] Numbers are not restricted to the business sector. The eye-catching peak in the number of individually conducted projects between 1985 and 1987 is due to the funding program for improving vocational training for disadvantaged young persons.

scientific institutions. Most of the collaborative projects in which business companies take part also involve scientific institutions. Hence, the government implemented its plan to shift funding towards diversified co-operations.

4 Investigating 'additionalities'

In line with the trend towards controlling and planning strategies in R&D policy, the demand for evaluations of the implemented technology policies has grown. Evaluation processes help to assess the efficiency and effectiveness of political intervention by offering new insights into the impact of policies.

It is evident that in terms of measuring the success of a policy measure, different indicators may be applied depending on different perspectives. Policy makers may see high numbers of participants as a success indicator, firms may primarily view profits as an indicator of success and consumers may judge success according to novelty and the prices of the available products. Nevertheless, these measures all illustrate that an additional effect, called 'additionality', is usually expected. The additionality concept has been more recently used in evaluations specifically to analyse public R&D grants on the firm level. Empirical examinations of additional effects are based on quantitative database information.

The measurement of additionality can be systematised into three concepts: (i) input additionality, (ii) output additionality and (iii) behavioural additionality. *Input additionality* looks at firm's inputs, e.g. private R&D investments, and may be characterised by the question: Do public R&D funds foster 'inputs' related to business R&D resources? This input-related concept analyses whether public R&D grants (partly) substitute or complement private R&D investment.[7] This question has been studied in several OECD countries, using matching grants to qualify government-industry co-financing of R&D projects in the business sector. The concept of *output additionality* does not focus on changes in a firm's R&D spending, but instead analyses the 'output' of the firm's innovation process, like new products or patents, after carrying out publicly and privately co-financed R&D. It analyses whether public R&D grants contribute to the outcome of firms' R&D processes (see e.g. Branstetter/Sakakibara 2002 and Czarnitzki et al. 2004)

The concept of *behavioural additionality* is the newest one of the three and was first introduced by Buisseret et al. (1995), who broadened the traditional additionality concept by claiming that "companies and institutions undertaking publicly sponsored projects are rarely left unchanged by the experience". This concept can be defined as "the change in a company's way of undertaking R&D which can be attributed to policy actions" (Buisseret et al. 1995). Public funding might induce changes of firm's behaviour regarding the organization or strategy of R&D, e.g. companies redesign their long-term research strategies or their R&D management due to the publicly funded R&D project. It provides more detailed insight into operational modes, know-how diffusion and appropriability, sustainability of R&D projects and financial issues (Georghiou/Roessner 2000).

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[7] David et al. (2000) survey microeconomic and macroeconomic studies on this topic. More recent studies are, for example, Wallsten (2000), Lach (2002) and Almus/Czarnitzki (2003).

One specific aspect of firms' R&D behaviour is the firms' collaborative R&D activities. A firm decides whether to cooperate in R&D at all, and if so, with which type of partner. The collaboration strategy is influenced potentially by public funding. Firms might be encouraged by public funding to extend their already existing co-operations or to enter co-operations with new (types of) partners.[8]

Most of the empirical evaluation studies to date focus on input and output additionalities and thus neglect behavioural changes in general and also with respect to collaborative aspects due to public funding. Sakakibara (2001) analysed Japanese government-sponsored R&D consortia over 13 years and found evidence that the diversity of a consortium is associated with greater R&D expenditure by the participating firms. Overall, the results provide support for spillover effects. The magnitude of the effect of participation in an R&D consortium on firm R&D expenditure is found to be nine per cent, on average. Branstetter/Sakakibara (2002) examine the impact of government-sponsored research consortia on the research productivity in Japan by measuring their patenting activities over time. They find evidence that participants in research consortia tend to increase their patenting after entering a consortium, which is interpreted as evidence for spillovers. The marginal increase of participants' patenting in targeted technologies, relatively to the control firms, is large and statistically significant. Hall et al. (2003) seek a better understanding of the performance of university-industry partnerships by surveying a sample of pre-commercial research projects which were funded by the U.S. government's Advanced Technology Program.

Feldman/Kelley (2001) find in a multivariate regression analysis that award-winning companies are already better linked to other business at the time of applying for an award than those not awarded and are more likely to have an important new R&D partner on the project. Other empirical studies have been based on case studies, or on the account of a few highly publicized co-operative R&D projects which are not representative (David et al. (2000), Wallsten (2000), Busom (2000), Lach (2002)) .

The study presented here focuses on firms' *behaviour* regarding co-operations in publicly funded R&D projects, thereby adding to the discourse on the restructuring of public R&D funding in Germany. We ask whether its most important tool, public R&D project funding, is adequate for influencing firms' collaborative behaviour. We thus link co-operation into the concept of behavioural additionality:

- Our first hypothesis is that public R&D funding stimulates firms to seek new types of R&D partners, i.e., public funding is suitable for fostering a change of firms' cooperative behaviour towards a more diversified set of partners. For example, let's say a company already cooperates in R&D with its suppliers and customers. We investigate if public funding supports these already existing instances of co-operation or if collaborative R&D funding gives incentives for firms to get involved in new types of partnerships, in particular multidisciplinary R&D collaborations. For this purpose we compare the type of co-operation partners of funded and non-funded firms. As regards this matter, the

[8] Regarding the empirical literature dealing with co-operation, the main focus is on the decision to cooperate in general, or with specific types of partners, and the impact of co-operation on firms' performance, e.g., Kleinknecht/Reijnen 1992, Cassiman/Veugelers 2002, Tether 2002, Cincera et al. 2003, Belderbos et al. 2004b.

government's rationale in subsidising R&D co-operation between industry and science is to improve the transfer and application of technologies and scientific knowledge, e.g., via the exchange of expertise among performers, and to stimulate and support innovations and patent activities.

- In the second hypothesis we examine firms' characteristics in terms of the continuation of joint R&D once public funding has ended, that is, we test whether business or science collaborations newly initiated within a publicly funded R&D project are lasting. The government's expectation is that firms change attitudes and behaviour by discovering valuable assets in R&D co-operation. Hence, companies overcome their prior reservations to partnering in their strategic field of R&D and maintain collaborative activities. On the other hand, newly initiated co-operations might bear a higher risk of failure due to differing expectations regarding the project outcome or of the - previously unknown - project partner. In order to evaluate the proportion of co-operation which were newly initiated and continued after funding has ended, we compare these with the continuation of already existing co-operations. If the funding has a longer term effect, the newly initiated co-operations should have a higher or at least the same probability of being continued after funding ends compared to co-operations which already existed before funding.

5 Empirical model, data and descriptive statistics

5.1 Methodology

In this section, microeconometric analyses of firms' collaborative behaviour are conducted in order to investigate (a) whether public R&D funding is suitable for fostering a change of firms' usual R&D partnerships and (b) whether newly initiated collaborations within a publicly funded R&D project are continued even if public funding has ended.

(a) Changes of firms' R&D partnerships due to public funding

To examine the first effect, i.e. the involvement of new types of partners in cooperative activities due to public funding, we will compare two groups of firms that collaborate in R&D. We distinguish firms without public funding from those which receive funds and investigate their R&D partnerships. In accordance with a distinction in the German public funding procedures we analyse firms by R&D collaborations with (i) other businesses only, (ii) with scientific institutions ("science") only and (iii) by their involvement of a combination of both business and science. Policy makers aim to induce changes in collaborative behaviour through public funding. Explicitly, public funding is expected to provide a stimulus for increasing the probability of R&D co-operation in new and more heterogenous R&D combinations: companies which have previously cooperated solely in R&D with other firms, e.g., clients and/or suppliers, should gain incentives for involvement in more heterogeneous partnerships, i.e. co-operations with both other businesses and science. Germany's public funding schemes favour collaborative research projects in general but do not predetermine the type of partner. Since public R&D funding is a cost-sharing approach it reduces firms' R&D costs. But it has to be questioned whether a significant changes in the collaborative behaviour towards more heterogeneous kinds of partnerships is induced.

In order to correct for a possible selection bias, which occurs when participants in public measures differ from non-participants in important characteristics, we apply a non-parametric matching procedure (cf. Heckman et al. 1999). With this approach we directly address the question, "With which set of partners would a funded firm with a given set of characteristics have cooperated, if it hadn't had a funded project?" The participation in a publicly funded R&D project is also called treatment. We investigate the potential change of collaborative behaviour that may arise from public funding. Our sample exclusively contains R&D collaborating firms, of which we are able to distinguish whether they are subsidised or not subsidised. The matching estimator balances the sample individually for each observation with respect to the variables included in the matching procedure. The fundamental evaluation question can be illustrated by an equation describing the *average treatment effect of treatment on the treated* (ATT):

$$ATT = E\left(Y^T \mid S=1\right) - E\left(Y^C \mid S=1\right),$$

where Y^T is the outcome variable, that indicates with which partner(s) the firm cooperates, namely, only with other businesses, only with science or with both types. The status S refers to the group: S=1 is the treatment group (subsidised firms) and S=0 the non-treated firms (non-subsidised firms). Y^C is the potential outcome which would have been realised if the treatment group (S=1) had not been treated. The problem is obvious: While the outcome of the treated firms in case of treatment, $E(Y^T|S=1)$, is directly observable, this is not the case for the second term on the right side of the equation. With whom would these firms have collaborated if they had not received the treatment, i.e. the public funding? $E(Y^C|S=1)$ is a counterfactual situation which is not observable and, therefore, has to be estimated. In the case of matching, this potential outcome is constructed from a control group of non-participants (collaborating and not publicly funded firms). The matching relies on the intuitively attractive idea of balancing the sample of program participants with comparable non-participants. Remaining differences in the outcome variables, the sets of co-operation partners, between both groups are then attributed to the treatment, i.e. the public direct R&D project funding (Heckman et al. 1997).

In order that the ATT can be identified two assumptions have to hold: the Conditional Independence Assumption (CIA) and common support. The CIA implies that all the characteristics which influence both treatment and outcome have to be observed. Common support ensures that for each treated observation a similar control can be found.

(b) Continuation of firms' new R&D partnerships even if public funding ends

What happens with an R&D partnership when public funding ends? The predominant question is whether the partners continue to collaborate or if the established network dissolves. Thereby, we pay special attention to newly initiated collaborations in order to evaluate if public funding has a longer term effect on the co-operation behaviour. Does co-operation that was established for the funded project last after public funding has ended? Collaboration need not be restricted to the funded project period; instead, companies could continue joint activity, e.g., in the same or another project. They might especially decide to do so in cases where the companies considered the funding and co-operation as valuable (Hypothesis 1).

A proportion of the funded projects are continued after funding has ended. In order to evaluate this proportion we compare the newly initiated co-operations, which represent a behavioural change due to the funding, with those that already existed. Due to potential heterogeneity among firms, technologies or funds, we apply a multivariate approach, namely a bivariate probit model[9], to test the hypothesis. This enables us to control for effects of several variables in our analysis. Accordingly, we simultaneously estimate the likelihood of the continuation of co-operation with science and co-operation with business. On the basis of the estimation results we check whether the variable for the newly initiated co-operation has a significant impact on the continuation of the R&D partnerships (Hypothesis 2).

5.2 Data and telephone survey

The company data used in the following empirical analysis is based on the Mannheim Innovation Panel (MIP), the German Federal Government's direct R&D funding database (PROFI), the German Patent Office database (DPMA) and Computer Aided Telephone Interview (CATI) data.

In an initial step we use data from the Mannheim Innovation Panel (MIP), an annual innovation survey conducted by the Centre for European Economic Research (ZEW) on behalf of the BMBF since 1993. The 2001 survey represents the German part of the third Community Innovation Survey. The data cover the manufacturing sector and selected service sectors. We use the 2001 and 2004 waves of the MIP as they are the only ones to contain data on R&D co-operations and funding. This means the surveyed information corresponds to the years 2000 and 2003 or to the period 1998-2000 and 2001-2003, depending on the specific variable. Because the analysis deals with behavioural changes concerning R&D co-operation, we only use firms which maintain R&D co-operation. The question on co-operation relates to the preceding three year period. On top of that, the firms have to name the type of their co-operation partners. Since only the innovative firms were asked the questions on co-operation our sample is restricted to firms with innovative activities. In order to achieve valid results, we decided to limit our sample to manufacturing firms and, moreover, to companies with less than 5,000 employees.[10] In a second step, we merge this firm level data with the Federal Government's R&D funding database (PROFI). This database contains all federal civilian direct R&D funding activities carried out in Germany by the BMBF or its former ministries since the 1970s. In a third step, we extract information on patents from the German Patent Office (DPMA) database which covers patenting activities in Germany since 1980. As both the DPMA and the PROFI databases are census data, our sample is determined by the MIP. In the end, we have 659 German firms to be used for the estimations.

In addition, data from the telephone survey on behavioural patterns were used. For the survey cases from the PROFI database where the publicly funded R&D projects expired between 2002 and 2004 were selected. This time period guarantees a higher probability of contacting the responsible R&D managers involved in the R&D funding and implementation

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[9] For a description of bivariate probit models see, e.g., Greene (2003).

[10] As the matching relies on the idea of comparing similar observations, we decided to restrict the sample to companies with less than 5,000 employees because it is not very meaningful to look for similar firms when they are larger than this threshold.

process. The telephone interview was structured in four different thematic fields related to the dimensions of behavioural additionality.[11] For the behavioural assessment of the impact of publicly funded R&D projects on collaborations, the interviewees were asked about their status of co-operation with respect to public funding. The telephone survey was conducted with the CATI system because of its high flexibility in reporting interviews and higher response rates compared to mail surveys. Finally, we collected a pool of 1,891 unique companies, of which 524 were selected randomly to be surveyed. Every selected company was called on average 2.6 times for different reasons, such as the responsible R&D project manager being unavailable. In summary, 39 per cent of the R&D managers contacted participated in the survey and a full set of data is available for 142 firms.

5.3 Variables and descriptive statistics

On the basis of the MIP data, 659 collaborative R&D performers are identified. We differentiate between three kinds of R&D partnerships on the basis of the type of co-operation, to examine our first hypothesis:

(i) Business-Business co-operation (BCOP): a firm collaborates only with other businesses,

(ii) Business-Science co-operation (SCOP): a firm collaborates only with scientific institutions,

(iii) Business-Science & Business co-operation (SBCOP): a firm collaborates with other businesses and scientific institutions.

The descriptive statistics of the firms show that the majority (57%) of these companies participate in multidisciplinary co-operations, the business-science & business (SBCOP) co-operation (Table 2). About 24 per cent of all firms only cooperate with science (SCOP) and about 19 per cent have partnerships only with business (BCOP). Furthermore, we distinguish the collaborating firms into recipients of public R&D funds (during the preceding three year period) and companies who cooperate in R&D without public funding. Collaborating recipients of public R&D funding are labelled by a dummy variable (FUND). In our sample most companies have been publicly funded by the Federal State within programmes or initiatives (63 %). If we just focus on these publicly funded R&D collaborating firms, we observe a slightly higher tendency in the heterogeneous SBCOP: 65 per cent of these firms have R&D co-operations with science and industry, 27 per cent cooperate only with science and eight per cent of all firms only have business R&D partnerships.

[11] (I) Significance and contribution of the respective publicly funded R&D project; (II) Impact of the publicly funded R&D project on collaborations; (III) General strategies underlying the acquisition and conduct of firms' R&D projects, and (IV) General questions about R&D activities in the considered firm. See Fier et al. (2005) for further details on the questionnaire.

Table 2: Descriptive Statistics of the German Survey (659 observations)

Variables			Mean	Std. Dev.	Min	Max
FUND	Recipients of public R&D funding	FUND=1	0.625	0.484	0	1
BCOP	R&D collaboration only with other business	BCOP=1	0.188	0.391	0	1
SCOP	R&D collaboration only with science	SBCOP=1	0.238	0.426	0	1
SBCOP	R&D collaboration with science and other business	SBCOP=1	0.573	0.495	0	1
ln(TURN)	Log of turnover		2.945	1.967	-2.973	7.616
ln(AGE)	Log of firm's age		2.945	1.043	0	5.425
EXINT	Export intensity		0.334	0.262	0	1
RDNO	No R&D activities	RDNO=1	0.049	0.215	0	1
RDOC	Occasional R&D activities	RDOC=1	0.158	0.365	0	1
RDRE	Regular R&D activities	RDRE=1	0.793	0.405	0	1
PATDL	Patent dummy (lagged variable)	PATDL=1	0.200	0.401	0	1
EAST	Eastern Germany	EAST=1	0.319	0.466	0	1
YR	Year 2003 (base year: 2000)	YR=1	0.581	0.494	0	1
IND1	NACE Codes: 10, 11, 12, 13, 14, 26, 40, 41, 45	IND1=1	0.085	0.280	0	1
IND2	NACE Codes: 15, 61, 17 ,18, 19	IND2=1	0.039	0.195	0	1
IND3	NACE Codes: 20, 21, 22, 36, 37	IND3=1	0.044	0.205	0	1
IND4	NACE Codes: 23, 24, 25	IND4=1	0.159	0.365	0	1
IND5	NACE Codes: 27, 28, 29, 34, 35	IND5=1	0.382	0.486	0	1
IND6	NACE Codes: 30, 31, 32	IND6=1	0.112	0.316	0	1
IND7	NACE Codes: 33	IND7=1	0.179	0.384	0	1
*SCOPC**	R&D collaboration with science continued	SCOPC=1	0.718	0.451	0	1
*BCOPC**	R&D collaboration with business continued	BCOPC=1	0.746	0.437	0	1
*SCOPI**	R&D collaboration with science new initiated	SCOPI=1	0.430	0.497	0	1
*BCOPI**	R&D collaboration with business new initiated	BCOPI=1	0.634	0.483	0	1
*BEGIN**	Accelerated beginning of project	BEGIN=1	0.542	0.500	0	1
*EXT**	Extended project scope	EXT=1	0.556	0.499	0	1
*ln(GRANT)**	Log of funding amount		11.990	0.930	9.358	14.803
*ln(TURN)**	Log of turnover		1.558	2.048	-2.017	7.093
*EAST**	Eastern Germany	EAST=1	0.394	0.490	0	1
*SERVICE**	Service sector	SERVICE=1	0.338	0.475	0	1
*TEC1**	Environment; Energy; Transportation	TEC1=1	0.268	0.444	0	1
*TEC2**	Materials	TEC2=1	0.155	0.363	0	1
*TEC3**	Life Science	TEC3=1	0.077	0.268	0	1
*TEC4**	ICT	TEC4=1	0.338	0.475	0	1
*TEC5**	Cross-Sectoral Activities; Education/Science	TEC5=1	0.162	0.370	0	1

Note: *N=142 collaborating & publicly funded firms involved in the CATI survey
Source: ZEW Databases (2005)

In the analysis we take several characteristics of R&D collaborating firms into account as exogenous variables. Since larger companies have a higher probability of co-operating in general and therefore tend to have more experience of co-operation, it is probable that they already maintain or have previously maintained co-operations with their possible partners (Fritsch/Lukas 2001). For this reason, we control for firm size in terms of the log of turnover, whereby turnover is measured in millions of euros (TURN). Firm's experiences on markets and with competitors are controlled by their age (AGE, in logarithm). Companies differing in the regularity of their R&D activities might be heterogeneous with respect to their R&D organisation and thus might select a different set of partners. In order to capture this, we use three dummy variables: measuring whether firms exhibit no (RDNO), occasional (RDOC) or regular R&D (RDRE) activities. Regular R&D activities of firms might have a different influence on their choice of the co-operation partner.[12] RDNO serves as base category. Further variables are used to control for intellectual property rights and firms' experiences in

[12] Cassiman/Veugelers (2002) found a positive effect of permanent R&D on co-operation with suppliers and customers, and a negative one on co-operations with research institutions, although both effects are not significant.

foreign markets. A lagged patent dummy (PATDL) is used to capture a firm's appropriability capabilities and the export intensity (EXINT) indicates the degree of foreign sales. The lagged patent dummy variable represents the firm's ability to appropriate the gains from conducted R&D, insufficient protection mechanisms for their own R&D results might prevent the firms from performing joint research with other businesses, in particular with competitors (Katz/Ordover 1990). We include the export intensity results due to the fact that firms who face international competition are more likely to conduct R&D and thus participate in specific R&D partnerships. All regressions include a dummy which denotes eastern German firms, as they may face different conditions due to the ongoing transformation process of the eastern German economy (EAST). We also include a dummy variable indicating the year of observation (YR2003; base year: 2000) and industry variables (IND1-IND7)[13] to take into account distinctive features in different industries.

Within the CATI survey, 142 publicly funded R&D collaborating firms reported on internal R&D activities, explained the effects of the participation in public R&D programmes and gave more information about their collaborations. Through the telephone survey, additional information becomes available to complement the MIP survey data. This information is used to test the second hypothesis, whether newly initiated business or science collaborations within a publicly funded R&D project are continued after the funding ends. Thereby, the continuation of collaboration need not be restricted to the funded project. The companies could also continue joint activity in another project. We distinguish two kinds of partnerships which have been continued after funding ended:

(i) Business-Business co-operation continued (BCOPC): a firm's R&D collaboration with other businesses continues after the funding period has ended,

(ii) Business-Science co-operation continued (SCOPC): a firm's R&D collaboration with science continues after the funding period has ended.

Overall, almost 75 per cent of the co-operations are continued after the funding has ended. For firms which initiate new co-operation with business or science in the publicly funded R&D project, the dummy variables BCOPI and SCOPI are generated. Looking at the newly initiated co-operations with other businesses, 72 per cent of these were continued after funding had ended. In comparison, this percentage equals 79 if the collaborations that already existed are considered. This difference increases for co-operations with scientific institutions. Only 54 per cent of newly initiated collaborations are continued, compared to 85 per cent of those already established. If the funding has a longer term effect on collaboration, the newly initiated co-operations should have a higher or at least the same probability of being continued after funding ends compared to co-operations which already existed before funding, while controlling for other factors. Furthermore, we include two dummy variables in order to measure the effect of the funding which might be also linked to co-operation in general. The dummy variable BEGIN indicates whether the funding of an R&D project accelerated the beginning of the project. An extended project scope due to funding is captured by the dummy variable EXT. Both are expected to have a positive impact on the decision to continue co-operation. The scope of the funded collaboration project, measured by the total amount of the received subsidies in the funded project (GRANT, in millions of euros), may have an impact

[13] The overview of the aggregated industries is shown in the appendix, Table 5.

on these decisions. We capture impacts specific to a particular funding area by including five technology dummies (TEC1-TEC5).[14] The reference category consists of projects belonging to cross-sectoral activities or education/science (TEC5). Moreover, firm-specific characteristics are included. We control for the size of the firm with the logarithm of turnover (TURN). Firms which are active in the service sector are labelled by the dummy variable SERVICE. The base category is the manufacturing sector. We include the dummy EAST indicating that the location of the firm is in eastern Germany.

6 Empirical results

(a) Changes of firms' R&D partnerships due to public funding

We perform a matching estimation to correct for a possible selection bias comparing publicly funded R&D collaborating companies and those not publicly funded. We investigate whether non-publicly funded firms collaborate in R&D with a different set of partners (firms from business, science or both) compared to the counterfactual situation, i.e., to the situation if these firms had been publicly funded.

Given the broad range of variables in our dataset we are confident that we have enough information on the firms to sufficiently approximate the decision-making process regarding the funding (treatment) and co-operation partner (outcome) so that the CIA holds.

Before proceeding the actual matching, a probit model on the probability of receiving funding (FUND) was estimated.[15] The results show that the size of the firm has an inverted U-shaped impact. The probability of a firm being publicly funded is higher if R&D activities are carried out regularly or occasionally. Firms which already had patents in the previous year have a higher probability of participation. Regarding the export behaviour no effect is found. A selectivity of funding towards younger firms is detected. Firms based in East-Germany have a higher probability of receiving funds than those located in the western part.

The propensity score of this estimation is labelled PSCORE. In order to find a control observation for each treated firm, the nearest neighbour approach with replacement based on the mahalanobis distance is applied. Besides PSCORE the Mahalanobis metric restriction is defined by size (TURN), the lagged patent application dummy (PATDL), the regularity of R&D activities (RDNO, RDOC, RDRE), the age (ln(AGE)), industry group dummies (IND1-IND7), and the region (EAST).

To ensure that common support for the treated firms is fulfilled in the matching, 13 treated observations had to be dropped, representing three per cent of all funded firms. But by means of a t-Test it can be shown that this drop does not lead to any significant change in the means of the considered variables. Therefore, the loss of the 13 observations can be neglected.

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[14] The funding areas are aggregated as follows: environment/energy, materials; life science, cross-sectoral activities/education/science. The detailed aggregation can be seen in the appendix, Table 6.

[15] The results of the probit estimation can be found in the appendix, Table 7. The matching procedure is described in detail, e.g., by Czarnitzki /Fier (2002).

In order to evaluate the quality of the matching we re-estimate the propensity score by using only the matched sample and taking account of replacement in the control group by weighting. As stated by Sianesi (2004) the pseudo-R2 after matching should be quite low because there should be no more systematic differences in the regressors between treated and control companies. In our setting, the Pseudo-R2 after the re-estimation is fairly low and equals 0.0173. Furthermore, a likelihood ratio suggests that there is no joint significance of all covariates of the probit model after matching.

Table 3 illustrates the differences between the two groups, R&D collaborating and publicly funded firms as the treatment group and R&D collaborating but not publicly funded firms as the control group, showing the considered characteristics and the outcome variables before and after matching.

Table 3: Matching results on R&D collaborating firms (399 matched pairs)

Variable [a]	**Sample**	**Mean**		**p-value of two sided t-test** [b]
		publicly funded	**not publicly funded**	
FUND	Before matching	1	0	
	After matching	1	0	
PSCORE	Before matching	0.703	0.498	0.000
	After matching	0.694	0.662	0.220
ln(TURN)	Before matching	2.641	3.451	0.000
	After matching	2.753	2.770	0.947
ln(AGE)	Before matching	2.753	3.272	0.000
	After matching	2.777	2.955	0.185
EXINT	Before matching	0.331	0.340	0.688
	After matching	0.335	0.337	0.940
RDNO	Before matching	0.019	0.097	0.000
	After matching	0.020	0.020	1.000
RDOC	Before matching	0.124	0.215	0.002
	After matching	0.129	0.129	1.000
RDRE	Before matching	0.857	0.688	0.000
	After matching	0.852	0.852	1.000
PATDL	Before matching	0.206	0.190	0.619
	After matching	0.211	0.180	0.593
EAST	Before matching	0.422	0.146	0.000
	After matching	0.404	0.323	0.240
BCOP	Before matching	0.083	0.364	0.000
	After matching	0.080	0.356	0.000
SCOP	Before matching	0.267	0.190	0.025
	After matching	0.263	0.148	0.030
SBCOP	Before matching	0.650	0.445	0.000
	After matching	0.657	0.496	0.026

a) Eight industry dummies and a dummy variable indicating the year of the survey are not reported. But after matching the respective means are not significantly different.
b) After matching, standard errors of t-statistics for two sided t-test on mean equality are based on the approximation by Lechner (2001) which accounts for sampling with replacement in the selected control group.
Note: 13 treated observations had to be dropped due to common support.

Looking at the t-Test conducted prior to the matching procedure, several variables differ in their distribution between the funded firms and the matched control group. However, the matching estimator is successful in balancing out these differences. After matching, these differences vanish. Hence, it is possible to estimate the causal effect of public funding on the recipients.

On the question of how publicly funded firms on average would have behaved if they had not been publicly funded, we find that R&D funding is, in particular, a tool that stimulates the inclusion of science in R&D partnerships. The proportion of companies which cooperate in R&D solely with industry, such as clients and/or suppliers (BCOP), is fairly low for funded firms. As a result of public funding, firms change their R&D strategy away from only business-to-business co-operation: Only 8 per cent of the funded firms cooperate in purely business-to-business relationships, while 36 per cent of firms would have chosen this partnership if they did not receive public funds.

Firms which exclusively cooperate in R&D with science show a significant increase in their co-operation behaviour due to public funding (SCOP): 26 per cent of publicly funded firms cooperate solely with science and this share would have been lowered to 15 per cent if public funding had not taken place. But the highest rise is observed for the formation of more heterogeneous co-operations. The results show that 50 per cent of the publicly funded firms would have cooperated in R&D with science and industry if public funding had not taken place. This share increased up to 66 per cent due to funding.

Overall, we find evidence that public funding has a significant influence on the selection of collaboration partners. Instead of business-to-business R&D partnerships, collaborating firms decide in favour of science-business and science only partnerships due to public funding, i.e., involving science partners as new members in their R&D collaborations. In the vast majority of cases, multidisciplinary R&D networks, i.e. co-operations with both other businesses and science, are established.

Since in our study the treatment group is larger than the control group, we also estimate the average treatment effect on the untreated (ATU) in order to validate the results: the effect of public funding in terms of the co-operation partner for the non-funded firms. The estimates of ATU are in line with the ATT and suggest that the share of co-operations with other businesses only would decrease markedly and instead, multidisciplinary co-operations would be favoured (cf. Table 8 in appendix).

(b) Continuation of firms' new R&D partnerships after public funding has ended

We investigate collaboration behaviour when public funding has ended. This analysis is based on the group of publicly funded and R&D collaborating companies which participated in the CATI survey. In order to test which determinants influence the probability of continuing collaborations when the public R&D project funding has ended, we distinguish between co-operations with science and business. In the bivariate probit model the endogenous variables are dummy variables indicating whether the collaboration with science (SCOPC) and the collaboration with business (BCOPC) were continued. Table 4 shows the results of the regression model.

Table 4: Bivariate probit estimation results on continued collaborations

	Collaboration with science continued (SCOPC)		Collaboration with industry continued (BCOPC)	
Variables	**coeff. (std. err.)**	**marg. eff. (std. err.)**	**coeff. (std. err.)**	**marg. eff. (std. err.)**
ln(GRANT)	0.309 ** (0.146)	0.092 ** (0.043)	0.082 (0.136)	0.014 (0.023)
SCOPI	-1.107 *** (0.225)	-0.338 *** (0.071)	-	-
BCOPI	-	-	-0.417 (0.265)	-0.065 * (0.038)
BEGIN	0.294 (0.251)	0.088 (0.076)	0.900 *** (0.266)	0.161 *** (0.049)
EXT	0.817 *** (0.253)	0.247 *** (0.078)	0.081 (0.269)	0.014 (0.045)
ln(TURN)	0.086 (0.079)	0.025 (0.023)	0.114 (0.080)	0.019 (0.013)
EAST	0.650 ** (0.305)	0.181 ** (0.080)	0.237 (0.310)	0.038 (0.049)
SERVICE	0.239 (0.325)	0.069 (0.090)	0.373 (0.341)	0.058 (0.048)
TEC1	0.114 (0.469)	0.033 (0.133)	-0.966 ** (0.490)	-0.213 (0.133)
TEC2	-0.300 (0.485)	-0.095 (0.164)	-1.236 ** (0.500)	-1.326 * (0.171)
TEC3	-0.114 (0.580)	-0.035 (0.184)	6.681 *** (0.555)	0.211 *** (0.040)
TEC4	0.244 (0.448)	0.070 (0.125)	-1.052 ** (0483)	-0.219 * (0120)
RHO	0.593 ***	(0.132)		
Number of obs.	142			

Note: Significant at the 1%-level (***), 5%-level (**), 10%-level (*)
Heteroskedasticity robust standard errors are presented.
Marginal effect (at the sample means) for the probability of continuing the collaborations with science, unconditional on the continuance of collaboration with industry; and vice versa. For dummy variables, the marginal effect represents the discrete change from 0 to 1.

The results show the likelihood of continuing the corresponding collaboration is higher if the companies gain specific experiences through the funding. Some firms broadened their initial research spectrum due to public funding (EXT). This extension of the R&D project volume has a positive influence on the continuation of collaborations with science. A positive effect of the extension of the project volume does not apply for co-operation with business. Due to the funding, about half of the firms were able to expedite the beginning of the project since potential financial gaps and negotiations were reduced. With regard to business-business co-operations, a faster initial project start (BEGIN) increases the likelihood of continuing the collaboration with business partners. This observation could be explained by the fact that firms were able to realise a comparative advantage over competitors because of the earlier project start. In order to maintain this advantage, the business-business partnership is more likely to be continued.

We find that the total amount of R&D funds awarded (ln(GRANT)) has a significantly positive effect on the probability of continuing collaboration with scientific institutions. Large-scale R&D project grants tend to be more complex, which has two effects. Firstly, it is sometimes not possible to keep to the scheduled end-date and the collaborative project has to be continued. Secondly, additional research topics emerge due to the complexity, as argued above. The funding volume does not have an influence on continuing business-business collaboration after the funding has ended.

A firm's location in eastern Germany has a positive effect on the continuation of collaboration with science. Other firm characteristics like size (ln(TURN)) or belonging to the service sector (SERVICE) do not affect the probability of continuation of any type of co-operation. Overall, it seems that firm characteristics do not play a crucial role for the continuation of collaboration, only for the decision to cooperate at all and with whom.

As seen in the descriptive statistics, a proportion of the newly initiated co-operations are continued after funding has ended. In order to evaluate its significance we compare these with the already existing co-operations and check if a newly initiated co-operation is at least as likely to be continued as a funded co-operation which already existed before funding, while controlling for other factors which might influence the decision whether to continue a collaboration. Regarding hypothesis two, we find that co-operations with scientific institutions which were newly initiated for the funded project are less likely to be continued after funding has ended than co-operations which already existed prior to the funded project (SCOPI). The probability of the continuation with science decreases by approximately 34 percentage points if the co-operation is newly initiated. Long-term partnerships might mean co-operation on a more trustful basis, not involving such high risks as co-operation with new partners. This, in turn, may make continuation more plausible. A newly initiated co-operation may not be able to achieve or outweigh this effect. Overall, public funding tends to integrate science into business R&D partnerships, but the newly established networks are not necessarily lasting after funding has ended.

While the effect of newly initiated co-operations is highly significantly negative regarding the continuation of co-operations with science, it is weakly significant regarding the continuation of co-operation with business (BCOPI) and the change in probability is much smaller. The probability of the continuation with industry decreases by 6 percentage points if the co-operation is newly initiated.[16] For the continuation of a co-operation it does not matter significantly whether it was newly initiated for the project or whether it already existed before funding began. If the government achieves its aim of assuring that a new co-operation with another business is established for the funded project, the probability of continuing this co-operation is almost as high as it is for already existing ones. Therefore, the achieved funding has a longer term effect in this respect.

[16] The marginal effect of SCOPI is significant on the 10% level. Looking at the coefficient of SCOPI, the significance vanishes.

7 Conclusions

Public funding of R&D activities has become an integral function of innovation policies in many OECD countries. From a scientist's as well as a policy maker's point of view, understanding the mechanisms and impacts associated with these public interventions is of particular importance. Its increasing relevance can be ascribed to decreasing government budgets and the necessity to design policy measures more efficiently. In Germany, direct R&D project funding is an important funding tool used by the government. Since the end of the 1980s a clear trend towards the funding of projects conducted in networks rather than individual companies has emerged. In 2004 two-thirds of all direct funded projects were part of a collaborative network.

This research study focuses on firms' behaviour regarding co-operations in publicly funded R&D projects. We ask whether public R&D funding is adequate for influencing firms' collaborative behaviour. More precisely, we investigate (i) whether public R&D funding stimulates firms to participate in new kinds of R&D co-operation (with business firms only, with science only or both) and (ii) whether newly initiated collaborations within a publicly funded R&D project are at least as likely to last as already existing co-operations, after public funding has ended. Our research is based on different databases and a telephone survey. For the first research question the sample consists of observations for 659 collaborating German firms, for the second question we have 142 observations.

Overall, the results of our analyses vary depending on the type of the co-operation partner. Public funding is successful in integrating scientific institutions as a new type of partner in co-operations. Funded companies have more diversified co-operation networks. Publicly funded collaborative R&D is suitable for changing co-operative behaviour: Firms which had exclusively cooperated with other business companies involve science as a new partner in their R&D activities due to the funding. Hence, public funding achieves its aim of broadening R&D networks, in the government's expectation of strengthening spillovers and innovativeness.

Regarding the longer term, a proportion of the funded projects last after funding has ended. In order to evaluate this proportion we compare the newly initiated co-operations with those that already existed. The newly initiated co-operations with science have a higher probability of being broken up again after funding has ended compared to co-operations with science which already existed before funding was introduced. Hence, this change in firms' co-operation behaviour is more short-lived. On the other hand, the newly initiated co-operations with business, which might not be seen as a behavioural change in the co-operation strategy since it is not a new type of partner, have a longer term effect. This is demonstrated by the fact that they have at least the same probability of being continued as already existing business co-operations.

A proportion of co-operations which were newly initiated with science are continued but the question is if this proportion is high enough to satisfy the government. If we compare the proportion with already existing co-operations the probability of continuation for newly initiated co-operations with science is lower, for new co-operations with other businesses it is almost as high as for already existing ones.

This study is a first attempt to evaluate behavioural changes in a quantitative analysis. In doing so, it focuses on the collaborative aspect, which is only one form of the behavioural additionality concept. Unfortunately, our number of observations is rather small, so it would be helpful to verify the results using a larger dataset. But if the results were confirmed, the question would arise as to whether the government is satisfied with the long term effect on co-operation behaviour. However, this is only one goal of R&D policy. Other objectives are achieved as shown in other studies, like input additionality, i.e. firms increase their innovation expenditures due to public direct R&D funding. In order to obtain a long term effect on co-operation behaviour another tool might prove more successful.

Furthermore, for the first research question, it would be helpful to have more detailed information on the specific co-operations like the size of the co-operation. We know the types of co-operation partners but not, for instance, the numbers of involved partners. In the second analysis, other measures could be discussed in order to evaluate the success of the funding with respect to the achievement of a longer-term behavioural change.

Public funding might also induce changes in other behavioural terms, like the management of R&D. It would be interesting to extend the evaluation to other behavioural aspects.

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Appendix

Table 5: Industries used and regression aggregates

Industry	NACE Rev. 1	Description
IND1	10	Mining of coal and lignite; extraction of peat
	11	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying
	12	Mining of uranium and thorium ores
	13	Mining of metal ores
	14	Other mining and quarrying
	26	Manufacture of other non-metallic mineral products
	40	Electricity, gas, steam and hot water supply
	41	Collection, purification and distribution of water
	45	Construction
IND2	15	Manufacture of food products and beverages
	16	Manufacture of tobacco products
	17	Manufacture of textiles
	18	Manufacture of wearing apparel; dressing and dyeing of fur
	19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
IND3	20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	21	Manufacture of pulp, paper and paper products
	22	Publishing, printing and reproduction of recorded media
	36	Manufacture of furniture; manufacturing n.e.c.
	37	Recycling
IND4	23	Manufacture of coke, refined petroleum products and nuclear fuel
	24	Manufacture of chemicals and chemical products
	25	Manufacture of rubber and plastic products
IND5	27	Manufacture of basic metals
	28	Manufacture of fabricated metal products, except machinery and equipment
	29	Manufacture of machinery and equipment n.e.c.
	34	Manufacture of motor vehicles, trailers and semi-trailers
	35	Manufacture of other transport equipment
IND6	30	Manufacture of office machinery and computers
	31	Manufacture of electrical machinery and apparatus n.e.c.
	32	Manufacture of radio, television and communication equipment and apparatus
IND7	33	Manufacture of medical, precision and optical instruments, watches and clocks

Table 6: Aggregates of funding areas

Aggregated funding area		Funding area	
TEC1	Environment/energy/ transportation	C1	Marine and polar search
		C2	Marine technology
		D1	National funding of space research and space technology
		E4	Decommissioning of nuclear facilities; risk sharing
		F1	Socio-ecological research; regional sustainability
		F2	Sustainable production; cleaner environmental technology
		F7	Global change (including peace-building research)
		N0	Research and technology for mobility and transport (including traffic safety)
		O1	Geosciences (especially deep drillings)
		O2	Raw material supplies

TEC2	Materials	L1	Materials research; materials for emerging technologies
		L2	Physical and chemical technologies
		P2	Buildings; R&D for preserving the architectural heritage; road building R&D
TEC3	Life science	G0	R&D in the health sector
		H0	R&D to improve working conditions
		K0	Biotechnology
TEC4	ICT	I1	Computer science
		I2	Basic information technologies
		I3	Application of microsystems (incl. application of microelectronics; microperipherals)
		I4	Production engineering
		I5	Multimedia
TEC5	Cross-sectoral activities/ education/science	B0	Large-scale equipment for basic research
		S1	Vocational training research
		S2	Other educational research
		V0	Humanities; economics and social sciences
		W1	Structural/innovative (generic) measures
		W2	Other generic activities
		Y2	Not R&D-relevant expenditures for vocational training – no science
		Y3	Remaining not R&D-relevant expenditures for vocational training – no science

Table 7: Probit estimation on being publicly funded (659 observations)

Variables	**Coeff.**		**Std. Err.**
ln(TURN)	-0.254	***	0.086
ln(TURN)2	0.026	**	0.013
Ln(AGE)	-0.120	**	0.059
EXINT	0.204		0.233
RDOC	0.669	**	0.287
RDRE	1.200	***	0.265
PATDL	0.274	*	0.147
EAST	0.807	***	0.143
YR	0.209	*	0.116
IND2	-0.001		0.336
IND3	-1.170	***	0.331
IND4	-0.484	**	0.238
IND5	-0.033		0.216
IND6	-0.220		0.253
IND7	-0.132		0.244
CONSTANT	-0.204		0.375
Log-Likelihood	-361.799		
Pseudo R-squared	0.170		

Note: Significant at the 1%-level (***), 5%-level (**), 10%-level (*)

Table 8: Estimated average treatment effect on the untreated R&D collaborating firms (245 matched pairs)

Variable [a)]	Sample	Mean: not publicly funded	Mean: publicly funded	p-value of two sided t-test [b)]
FUND	Before matching	0	1	
	After matching	0	1	
PSCORE	Before matching	0.502	0.297	0.000
	After matching	0.498	0.485	0.604
Ln(TURN)	Before matching	3.451	2.641	0.000
	After matching	3.450	3.305	0.506
Ln(AGE)	Before matching	3.272	2.753	0.000
	After matching	3.266	3.339	0.576
EXINT	Before matching	0.340	0.331	0.688
	After matching	0.340	0.363	0.463
RDNO	Before matching	0.097	0.019	0.000
	After matching	0.090	0.069	0.542
RDOC	Before matching	0.215	0.124	0.002
	After matching	0.216	0.212	0.938
RDRE	Before matching	0.688	0.857	0.000
	After matching	0.694	0.718	0.672
PATDL	Before matching	0.190	0.206	0.619
	After matching	0.192	0.180	0.804
EAST	Before matching	0.146	0.422	0.000
	After matching	0.147	0.143	0.927
BCOP	Before matching	0.364	0.083	0.000
	After matching	0.359	0.135	0.000
SCOP	Before matching	0.190	0.267	0.025
	After matching	0.192	0.196	0.936
SBCOP	Before matching	0.445	0.650	0.000
	After matching	0.449	0.669	0.000

a) Eight industry dummies and a dummy variable indicating the year of the survey are not reported. But after matching the respective means are not significantly different.
b) Standard errors of t-statistics for two sided t-test on mean equality are based on the approximation by Lechner (2001) which accounts for sampling with replacement in the selected control group.
Note: 2 treated observations had to be dropped due to common support.