Discussion Paper No. 06-037

Detecting Behavioural Additionality

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

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Non-technical summary

In today's modern economies governments play a crucial role within the innovation system by setting regulations, establishing institutions, shaping capabilities and through direct support. In Germany as well as in other European countries the way in which public support has been granted to innovative projects by the firms has undergone a major change within the last two decades. While formerly mostly individual firms were publicly supported, from the 1980s onwards, governments began to fund projects conducted by networks rather than individual firms. Germany has been no exception in this.

Today, the vast majority of publicly funded R&D projects are conducted via collaboration. 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.

Detecting Behavioural Additionality

An Empirical Study on the Impact of Public R&D Funding on Firms' Cooperative Behaviour in Germany [1]

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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 linking 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: H25, L24, O38

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1 Introduction

In today's modern economies governments play a crucial role within the innovation system by setting regulations, establishing institutions, shaping capabilities and through direct support. In Germany as well as in other European countries the way in which public support has been granted to innovative projects by the firms has undergone a major change within the last two decades. While formerly mostly individual firms were publicly supported, from the 1980s onwards, governments began to fund projects conducted by networks rather than individual firms. Germany has been no exception in this. Thus, governments are following the overall trend, by which R&D co-operations[2] have generally become important as a form of R&D organization. Today, the vast majority of publicly funded R&D projects are conducted via collaboration. Despite this development, there are only few empirical studies that analyse the link between public funding and collaboration. This is surprising, especially against the background of the growing evaluation literature on public R&D policies. 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'. However, most of the existing empirical literature on additionality focuses on changes in firms' innovative input or output due to public funding, while a relatively new stream in the additionality concept focuses on changes in the firms' behaviour.

In the context of this new behavioural additionality concept, this study looks at the impact of public funding on the cooperative behaviour of firms. We therefore 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 collaborations that were newly initiated within a publicly funded R&D project, i.e. cases where a company collaborated with the partner for the first time, are as 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. In order to answer the questions we apply non-parametric and parametric estimation approaches, respectively.

The structure of the remainder of the paper is as follows: in section 2, first the theory underlying the motives for collaborative R&D and public funding and the related empirical literature are presented. Then the two hypotheses dealing with the impact of public support on the firms' cooperative behaviour are outlined. The third section depicts the German Federal Government's funding policy during the 1980s and 1990s. In the empirical section (section 4) we describe the data and the econometrics applied. This is followed by a presentation of the results in section 5. Finally, section six concludes.

[2] The terms "collaboration", "co-operation" and "partnership" are used interchangeably.

2 Collaborative R&D and Public Funding

In this chapter the rationales for collaborative R&D and its funding are explained and related empirical literature is presented. Moreover, the two research questions dealing with the impact of public support on the firms' cooperative behaviour are outlined. At the end of this chapter the analysis is embedded in the behavioural additionality concept.

Motives for R&D collaboration

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). Several motives can be found in the literature for firms engaging in collaborative agreements both with other firms such as suppliers, customers or competitors and with universities and research institutes (an extensive overview can be found in Hagedoorn 1993 or Caloghirou et al. 2003).

One motive is related to the nature 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 generates 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 and lead to information flows, called spillover. Firms try to achieve both a high level of knowledge flow into a firm and sufficiently protect internal knowledge from leaking out. The empirical study by Cassiman/Veugelers (2002) was the first which proved that "firms with higher incoming spillovers and better appropriation have a higher probability of cooperating in R&D" (Cassimen/Veugelers 2002: 1179).

Besides the motives related to knowledge spillover, other factors influencing a firm's decision to cooperate exist. One group of motives for co-operations is based on the objective to overcome resource constraints a firm faces. Most firms do not have all the necessary knowledge, capabilities, and financial means for realizing an innovation project. This hampers firms from undertaking this type of projects on their own. Thus, research partnerships are used in order to exploit unique capabilities, to combine competencies and to access complementary knowledge (see e.g. Hagedoorn 1993). Therefore, co-operations also might lead to a reduction of the time from product development to market introduction. Furthermore collaborative agreement might be established in order to share the involved cost and risk (see e.g. Sakakibara 1997).

Furthermore, determinants related to firm characteristics are found to have an impact, e.g. structure of the firm and industry in which it operates, e.g. many empirical studies show that the probability of co-operation increases with firm size (see e.g. Röller et al. 2001).

Rationales for public R&D funding

The externalities of R&D lead to the problem that leaking knowledge increases social returns but reduces private returns. In the case that R&D generates higher social than private returns, the level of R&D activities in the economy in question is below the socially desirable level and market failure occurs (cf. Levin et al. 1987, Adams/Jaffe 1996). Since R&D is of great importance for the innovative potential and competitiveness of an economy, the government is keen to overcome the market failures related to the R&D investments of firms. Therefore, governments 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. The German government is among those taking such action (see e.g. Branscomb/Florida 1997, Martin/Scott 2000).

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 wanted to phase out former policies which relied on project-specific funding of single awardees and advance a collaboration-oriented policy scheme. In particular, R&D co-operation between industry and science should receive special emphasis. The argumentation behind funding collaborative R&D projects runs along the lines 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 "heterogeneous R&D collaborations e.g. between industry and science" (BTDrs 2005).

Related empirical literature and results

Several empirical studies dealing with motives to engage in R&D co-operations exist. But there are only a few studies which analyse the type of co-operation partner and control for the potential impact of public support. Belderbos et al. (2004) investigated the determinants of co-operations with competitors, suppliers, customers, and research institutes in the Netherlands. The subsidy dummy has a significantly positive effect on co-operations with supplier, customer and research institutions. But these effects become insignificant when only newly initiated co-operations are considered. Similar studies which used subsidy dummies are conducted by Dachs et al. (2004) and by Abramovsky et al. (2005). Dachs et al. investigated the co-operation pattern of Austrian and Finnish firms. In Finland national public support significantly increases the likelihood of cooperating with suppliers, competitors and research institutes. In Austria this effect is only found for co-operations with research institutes. Subsidies from the EU only have significantly positive effects on collaborative agreements with suppliers in Finland and customers and competitors in Austria. The study carried out by Abramovsky et al. focused on the choice of co-operation partners – vertical, horizontal, and research institutes - for firms in France, Germany, Spain and the UK. Including a public support dummy in their regressions, they found a significantly positive effect on all co-operation partners in all four countries, except for cooperative agreements with competitors in the UK[3], while the largest marginal effects are on the probability of cooperating with research institutes.[4]

[3] When four other explanatory variables are instrumented in the regression (Incoming spillovers, appropriability, R&D intensity and constraints), public support also becomes insignificant for cooperative agreements with competitors in Spain.

[4] Variables have a significant impact at least on the 5-%-level.

But most of these studies do not correct for the selection bias regarding the participants and non-participants in public funding schemes. The only study we are aware of in which the endogeneity of public support due to the selection bias regarding the participants is taken into account is the one by Busom and Fernández-Ribas (2004). They focused in the analysis on the effect of government support on the decision to cooperate and chosen co-operation partner for Catalan manufacturing firms. In order to correct for a potential endogeneity of program participation, they applied a matching approach. Distinguishing between co-operations with customers or suppliers, research institutes or universities and other organizations they found a significantly positive effect of subsidies on co-operations with all three types of partners. But the largest increase is found for the probability of co-operating with public labs or universities. Public R&D program participation increases this type of partnership by 28%.

Research Question I

Based on the German government's goal, 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 in 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 co-operations between firms and research institutions. For this purpose we compare the type of co-operation partners of subsidized and non-subsidized firms.

Persistence of R&D collaboration

A common theoretical basis underlying co-operation analyses is the transaction cost approach (Williamson 1975, 1985, Hennart 1988, Kogut 1988). Within the transaction cost theory each transaction is treated as discrete, i.e. independently from other transactions. Thus, most of the empirical studies dealing with co-operations treat a cooperative agreement between two partners as a singularity. As a consequence, there are few empirical works dealing with the continuation of R&D co-operations. However, the omission of the phenomenon of multiple co-operations with the same partner may neglect important impacts on the transaction costs associated with these further alliances (Gulati 1995). Most of these described possible impacts associated with the continuation of collaboration with a certain partner stem from the sociological literature.

From a sociological point of view, the main motive which drives two individuals/institutions to collaborate in R&D is trust (Granovetter 2001). Trust can be defined as "an expression of confidence between the parties in an exchange of some kind – confidence that they will not be harmed or put at risk by actions of the other party" (Jones, George 1998: 531). A review of the literature shows that trust can lead not only to the creation of new collaborative agreements (McAllister 1995) but also serve as an explanation why collaborative agreements between partners get renewed or extended. The argumentation is as follows: If a firm enters a collaboration with other firms or other institutions more than once, the common experience from the first collaboration may have generated trust among the participating institutions and the trust created may limit transaction costs associated with further collaborations between the partners (Gulati 1995, Marsden 1981). For instance, the reduction of transaction costs thereby may occur in that sense that a more flexible and/or money saving governance structure can be found (Gulati 1995).

Research Question II

In order to fill the gap in the existing empirical literature, 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 (*second hypothesis*). The government's expectation is that firms change their 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. Following our argumentation, trust may also play an important role in the continuation of collaboration by lowering the involved transaction costs. 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-operations which were newly initiated and continued after funding had 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 at least the same probability of being continued after funding ends compared to co-operations which already existed before funding.

Embedding the analysis in the concept of behaviour additionality

This 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, both immediately and in the short or medium term. We thus link co-operation into the concept of *behavioural additionality* which was first introduced by Buisseret et al. (1995). They broadened the traditional additionality approach/view, consisting of input and output additionality.[5] This new 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: 590). 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 and whether to continue the collaboration. The collaboration strategy is potentially influenced 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. Most of the empirical evaluation studies to date focus on input and output additionalities and neglect

[5] *Input additionality* looks at a firm's inputs, e.g. private R&D investments and analyses whether public R&D grants (partly) substitute or complement private R&D investment. The concept of *output additionality* focuses on changes in the 'output' of the firm's innovation process, like new products or patents, after carrying out publicly and privately co-financed R&D. For an overview of conducted studies see Aerts et al. (2007).

behavioural changes in general and also with respect to collaborative aspects due to public funding.[6]

3 Public R&D project funding in Germany

Direct R&D project funding has become a popular instrument in technology policies in Germany, from the 1980s on. 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.

While in the 1980s, about 1,600 projects per year were funded within this funding scheme, the number steadily increased to over 4,000 projects in 2004.7 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 decreased compared to 1980 by almost 10 percent to about 363 millions euros in 2004. Nevertheless, given the amounts distributed with means of this programme, it is still one most important tool for subsidies for the business sector. Furthermore, the government announced in their High-Tech-Strategy an increase of the budget in the next years again (BMBF 2006).

At the end of the 1980s, the BMBF began to emphasise the funding of projects conducted by networks rather than individual companies. 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 the beginning of 2000, with a proportion of 81 per cent of projects conducted on a collaborative basis. In 2004, 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. These joint research activities where business companies are involved are carried out by an average of three partners, such as other business firms or scientific institutions.

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 directly subsidized R&D 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.8

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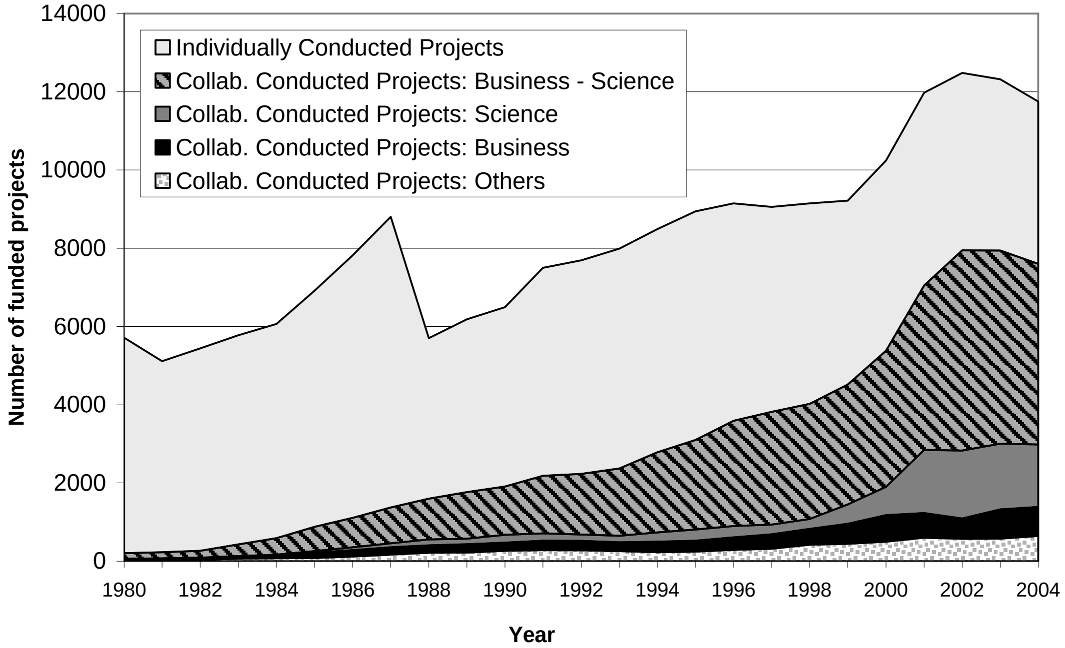
[6] Falk (2004) also used an econometric approach in order to investigate behavioural additionality aspects but her focus is on the impact of subsidies on the innovation capabilities and competence measured by R&D personnel. Other studies dealing with the measurement of behavioural additionality can be found in OECD (2006).

[7] Contract research and projects which receive 100 per cent funding are not included in these numbers.

[8] 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.

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)[9]

Looking at all directly funded projects the clear trend towards collaborative projects remains. 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 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 Empirical model, data and descriptive statistics

4.1 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.

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9 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.

(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. Policymakers aim to induce changes in collaborative behaviour through public funding. Explicitly, public funding is expected to provide a stimulus, increasing the probability of R&D co-operation in new and more heterogeneous 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 we must questioned whether a significant change 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 schemes differ from non-participants in important characteristics, we apply a non-parametric matching procedure (cf. Heckman et al. 1999).[10] 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, for 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

[10] Other studies applying the non-parametric matching approach are e.g. Duguet (2004), Czarnitzki/Fier (2002) or Winterhager et al. (2006).

intuitively attractive idea of balancing the sample of program participants with comparable non-participants. Remaining differences in the outcome variables, namely 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 requires 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. In attempting to answer this, 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[11], 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).

4.2 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 on the manufacturing sector 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. 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 survey 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

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

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. We limited our sample to companies with less than 5,000 employees.[12] 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 process. The telephone interview was structured in four different thematic fields related to the dimensions of behavioural additionality.[13] 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 its 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.

4.3 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.

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[12] 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.

[13] (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.

The descriptive statistics for the firms show that the majority (57%) of these companies participate in diversified co-operations, i.e. 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 using 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.

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		2.947	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 include several characteristics of R&D collaborating firms 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.[14] RDNO serves as base category. Further variables are used to control for intellectual property rights and firms' experiences in 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)[15] 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. The telephone survey makes additional information 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. 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 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

[14] 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.

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

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 subsidies received for the project (GRANT, in millions of euros), may have an impact on these decisions. We capture impacts specific to a particular funding area by including five technology dummies (TEC1-TEC5).[16] 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 to indicate that the location of the firm is in eastern Germany.

5 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.[17] 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 eastern Germany have a higher probability of receiving funds than those located in the western part.

[16] 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.

[17] 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).

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.

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.

Looking at the t-Test conducted prior to the matching procedure, the distribution of several variables differs 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, moving 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.

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

Variable [a)]	Sample	Mean publicly funded	Mean not publicly funded	p-value of two sided t-test [b)]
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.

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., they involve science partners as new members in their R&D collaborations. In the vast majority of cases, heterogeneous R&D networks, i.e. co-operations with both other businesses and science, are established. This result is similar to the finding of Busom/Fernández-Ribas (2004) who showed that participation in a subsidy program has the largest positive effects on the probability of co-operating with universities or public labs.[18]

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:[19] 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

[18] Since they consider in their study both cooperating and non-cooperating firms and they only show the difference between subsidized and non-subsidized firms for the likelihood to cooperate with a certain type of partner, a more detailed comparison is not possible.

[19] More detailed information on the calculation of the ATU can be found in Fier et al. (2005).

other businesses only would decrease markedly and instead, diversified co-operations would be favoured (cf. Table 8 in appendix).

One potential shortcoming of this analysis might be that we are not able to control for co-operations that existed prior to the point of time when the firms applied for public funds. This is due to data restrictions. However, Feldman/Kelley (2001) found in their study that ATP award-winning companies are already better linked to other business at the time of applying for an award than those not awarded. But no significant difference was found for links with research institutions between the two groups. There is no comparable study or result for Germany. Therefore, we cannot rule out the possibility that the results might be overestimated.

(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.

The results show that 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 to 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.

Table 4: Bivariate probit estimation results on continued collaborations

Variables	Collaboration with science continued (SCOPC) coeff. (std. err.)		marg. eff. (std. err.)		Collaboration with industry continued (BCOPC) 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.

As seen in the descriptive statistics, a proportion of the newly initiated co-operations are continued after funding has ended. In order to evaluate the significance of these continued co-operations 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 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 newly initiated co-operations have a highly significantly negative effect on the continuation of co-operations with science, their effect on the continuation of co-operation with business (BCOPI) is weakly significant and the corresponding change in probability is much smaller. The probability of continuation with industry decreases by 6 percentage points if the co-operation is newly initiated.[20] For the continuation of a co-operation with other businesses 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 funding has a longer term effect in this respect.

A shortcoming in this analysis might be that we do not have information on whether the co-operations receive further subsidies, because receiving funds and the continuation of co-operation might be correlated. In the database comprising all projects funded under the direct R&D project funding scheme, we checked whether the co-operation partner received further funding within this scheme. A rather low share of co-operations received further funding. 10 co-operations with other firms and 15 with research institutes received subsidies for projects beginning in the year when the examined project ended or in the subsequent year. We also tried to distinguish in the estimation between co-operations which received further funding and those which did not, but we did not find any significant results. This might be due to the low number of observations. Therefore, this omission might not be severe.

6 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 directly 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

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

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 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 tend to 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 line with 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 a firm's 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, for example the size of the co-operation. We know the types of co-operation partners but not, for instance, the numbers of partners involved. 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 behavioural changes in other areas, 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.