Discussion Paper No. 18-002

Estimating the Benefits of R&D Subsidies for Germany

Mila Koehler

ZEW

Zentrum für Europäische Wirtschaftsforschung GmbH

Centre for European Economic Research

Discussion Paper No. 18-002

Estimating the Benefits of R&D Subsidies for Germany

Mila Koehler

Estimating the benefits of R&D subsidies for Germany[1]

Mila Koehler[a,b]

a) Centre for European Economic Research (ZEW), Dep. of Economics of Innovation and Industrial Dynamics, Mannheim, Germany
b) KU Leuven, Dep. of Managerial Economics, Strategy and Innovation, Leuven, Belgium

January 2018

Abstract
In Germany, R&D subsidies are an important tool to support innovation in the private sector. This paper studies the welfare effects of R&D subsidies distributed through the German federal government's thematic R&D programs between 1994 and 2011. The analysis is based on a structural model of the R&D subsidy process which allows to estimate the benefits of R&D subsides to the German economy. The model takes into account heterogeneous application costs of firms and identifies the effect of the subsidy on the federal government's utility as well as on firm profits.

Assuming a welfare-maximizing federal government, the estimated average social rate of return is 34% for Germany in the period 1994 to 2011. Thereby effects on firm profits are similar to effects on spillovers to the rest of the German economy. Besides results show that the subsidy rate decision in Germany remained remarkably stable over time, and that application costs as well as the marginal profitability of subsidized R&D projects are lower after the year 2000 compared to the years before.

JEL-Classification: D61, H25, L59, O31, O38

Keywords: R&D, Innovation, R&D Subsidies, Innovation Policy, Welfare Economics

Contact details
Mila Koehler
Centre for European Economic Research (ZEW), Department of Economics of Innovation and Industrial Dynamics, L7, 1, 68161 Mannheim, Germany
Phone: +49-621-1235-283, email: mila.koehler@zew.de

[1] I owe special thanks to Otto Toivanen for his helpful comments and discussions throughout this work. Great thanks goes also to Dirk Czarnitzki, Reinhilde Veugelers, Pierre Mohnen, Georg Licht and the SIMPATIC network and audience (FP7/2007-2013 - grant agreement no. 290597) for helpful discussions, as well as to the Flemish Science Foundation who financially supported this research project with its PhD scholarship. The views expressed in this publication are the sole responsibility of the author.

1. Introduction

Given the well-known market failures associated with R&D (Arrow 1962), governments seek to increase firms' incentives to invest in R&D. First, companies cannot appropriate all returns from their initial R&D investments as knowledge generated in R&D activities will spill over to rivals. Second, firms may suffer from financial constraints for R&D projects due to asymmetric information between the company and external investors such as banks. There is high uncertainty about the expected returns of R&D activities and unlike investment in physical capital, R&D expenses are immediately sunk as the largest fraction of R&D is wages for R&D employees. Therefore, industrialized countries typically grant intellectual property rights and subsidize R&D in the business sector in order to alleviate market failure associated with R&D. Despite numerous studies (see Zúñiga-Vicente et al. 2014) it is still not well understood how R&D subsidies perform and whether the social gains exceed social costs when providing state aid to an industrial R&D project.

This paper contributes to the existing literature on the evaluation of the effect of R&D subsidies by estimating the benefits of R&D subsidies for Germany. The analysis is based on a structural model of the R&D subsidy process designed by Takalo, Tanayama and Toivanen (2013a). Germany is an especially interesting case to study because it is Europe's biggest and one of its most innovative economies (OECD 2011, BMBF 2012, EC 2013)[2] and Europe's biggest spender of public R&D[3]. In addition, R&D subsidies are an important policy tool to support industrial R&D in Germany (BMBF 2012). There are no R&D tax credits in place like in some other European countries as e.g. the Netherlands, Spain or the UK. This study also profits from the rich data available for Germany, which allows studying the benefits of thematic R&D subsidies between 1994 and 2011.

Assuming that the German federal government behaves as a benevolent social planner, results show that one euro of R&D subsidies from thematic R&D programs yields on average a social return of 1.34 euros to the German economy. Thereby R&D subsidies affect estimated firm profits and spillovers[4] to the rest of the German economy to the same extent. When studying changes over time, the analysis reveals that the subsidy rate decision remained very constant over time. In contrast, firms' application costs as well as the marginal profitability of subsidized projects were higher in the years 1994 to 2000 than in the years 2001 to 2011.

The paper is structured as follows. Section 2 reviews the previous literature on R&D subsidies for Germany. The theoretical model of the R&D subsidy process is described in section 3 and complemented with an overview about the innovation policy in Germany in section 4. Section 5 presents the data and descriptive statistics while section 6 discusses the econometric implementation of the theory model. Estimation results are presented in section 7, effects of the subsidy on welfare in Germany in section 8. Section 9 concludes.

---

[2] Germany has received the highest score on the average quality of patents filed a the European Patent Office between 2000 and 2010 (OECD 2011, p.6) and filed in the years 2000 till 2009 much more patents per millions of inhabitants which are relevant for the world market, i.e. filed at the World Intellectual Property Organization (WIPO), when compared to the US, Japan and EU-27 (BMBF 2012, p.394ff). According to the Innovation Union Scoreboard, Germany belongs to Europe's innovation leaders amongst other countries such as Sweden, Finland and Denmark (EC 2013).

[3] See the government intramural expenditure on R&D (GOVERD) of the OECD main science and technology indicators database on http://www.oecd.org/sti/msti.htm, accessed on December 22, 2017.

[4] Note that the term "spillovers" contains not only knowledge or technology spillovers to other firms but also how consumer surplus is affected. In other words *spillovers* are *all the good and bad things* from an innovation project *that flow to the German economy* and are *not reflected in the profits of the firm* that conducts the innovation project.

2. Previous literature

Existing research that evaluates the effect of R&D subsidies usually analyses input and output additionalities of R&D subsidies (compare the overview of R&D subsidies studies of Zúñiga-Vicente et al. 2014). As Czarnitzki et al. (2015) demonstrate in their cross-country study comparing the R&D subsidy systems of Germany, Finland, Spain, The Netherlands, and Belgium, the process of granting R&D subsidies differs considerably between countries. Therefore the following review focuses on results of R&D evaluation studies for Germany.

Input additionality studies for Germany find that firms that receive R&D subsidies invest more into R&D when compared to the situation of not receiving R&D subsidies (Czarnitzki and Fier 2002, Almus and Czarnitzki 2003, Czarnitzki and Licht 2006, Aerts and Schmidt 2006, Hussinger 2008, Aschhoff 2009, Czarnitzki and Lopes-Bento 2014, Hud and Hussinger 2015, Czarnitzki and Hussinger 2017).[5] Hence, public support of industrial R&D projects in Germany does not fully crowd out private R&D investments. Output additionality studies for Germany find that publicly and privately induced R&D have a similar output productivity in terms of the probability to file a patent, the number of patents filed, and the sales share with new products (Czarnitzki and Licht 2006, Aschhoff 2009, Czarnitzki and Lopes-Bento 2014, Czarnitzki and Hussinger 2017). While these studies demonstrate that R&D subsidies increase the innovative activity and innovation outcomes in Germany, the overall costs and benefits of distributing R&D subsidies to the private sector are unknown.

This study contributes to the existing literature on the evaluation of the effects of R&D subsidies by estimating the benefits of R&D subsidies based on a structural model of the R&D subsidies developed by Takalo, Tanayama and Toivanen (2013a). The model of the R&D subsidy process allows estimating the increase in firms' profits due to the subsidy, the effect of the subsidy on the Finnish funding agency's utility, as well as firms' application costs. This enables calculating the social rate of return of the R&D subsidy. The model was originally estimated for a sample of Finnish firms in the period 2000 to 2002. Assuming that the Finnish funding agency behaves welfare maximizing, the authors find a positive social rate of return of R&D subsidies of 1.51 euro per euro of R&D subsidy for Finland and that R&D subsidies in Finland affect firm profits to a larger extend than they increase spillovers to the rest of the Finnish economy.

3. The model of the R&D subsidy process

This section provides a brief overview of the structural model of the R&D subsidy process of Takalo et al. (2013a).[6] The model, of course, abstracts the real world features of the funding process, but captures its most important ones. The model of the R&D subsidy process consists of three stages. The first stage is the decision of the firm to apply for a subsidy with project i. The second stage is the decision of the funding agency on how much to support a project, which is measured by the subsidy rate s_i. The third stage is the decision of the firm on how much to invest into an R&D project (RD_i) given the subsidy rate the project receives.

The model assumes that there are no fixed costs of R&D and that firms are not financially constrained when making their R&D decision. Firms do not misuse the subsidy amount $s_i RD_i$ and conduct only one project at a time. Hence, the subscript i denotes project and firm interchangeably. There is incomplete information between the firms and the funding agency

[5] Studies from Hussinger (2008), Aschoff (2009), Hud and Hussinger (2015) and Czarnitzki and Hussinger (2017) are also based on evaluating data from R&D subsidies of thematic R&D programs in Germany.

[6] For further details on the model and statistical assumptions the interested reader is referred to Takalo et al. (2013a).

due to η_i, a random shock to the spillover rate of project i, which is known by the agency but unknown by the firm. So the firm does not know how the agency will evaluate the R&D project and therefore does not know if and to which extent the agency will subsidize the R&D project. Due to incomplete information a firm may decide to invest into submitting a costly application, but is denied a subsidy. There is also random shocks to the profitability and application costs of project i. All random shocks are drawn from common knowledge distributions. The model is solved by backward induction.

Stage 3 - the R&D investment decision. Let us first consider the third stage, i.e. the R&D investment decision. Firms are profit maximizers. Their profit function for project i is specified as

(1) $$\Pi(RD_i, s_i, X_i, \varepsilon_i) = exp(X_i\beta + \varepsilon_i) lnRD_i - (1 - s_i)RD_i,$$

where X_i is a vector of observable firm characteristics, β a vector of parameters to be estimated, and ε_i the random shock to the marginal profitability of project i. As equation (1) shows, R&D investments have decreasing returns to scale, because the relationship between R&D and profits is logarithmic. Firms maximize their profits by setting the optimal R&D investment RD_i. The first order condition yields

(2) $$RD_i = \frac{exp(X_i\beta+\varepsilon_i)}{1-s_i}.$$

From equation (2) it follows that the optimal R&D investment for project i increases with the subsidy rate.

Stage 2 - the subsidy decision. If the firm applies for a subsidy, the second stage is the funding decision. In Germany the funding decision is incumbent on the Federal Ministries. The federal government is assumed to maximize the social welfare of the economy, i.e. consumer and producer surplus. Its expected utility from project i is given by

(3) $$U = V(RD_i(s_i), Y_i, \eta_i) + \Pi(RD_i(s_i), s_i, X_i, \varepsilon_i) - gs_iRD_i(s_i) - F_i.$$

The federal government's utility of project i increases with increasing expected spillovers V_i and expected firm profits Π_i from project i. It decreases in the opportunity costs of funding (g) like costs of taxation, and the fix costs F_i. F_i consists out of the firm's application costs and the federal government's costs of screening project i. Spillovers V_i depend on the level of R&D investment $RD_i(s_i)$, Y_i a vector of observable firm characteristics affecting the spillover rate of a project, and η_i the shock to the spillover rate of project i. Note that in the context of this model the term spillovers captures all externalities of project i to the economy that are not captured by the firm's profits from project i. In other words, the spillovers of project i are all the good and bad things that flow to a nation's economy, which are not appropriated by the R&D conducting firm itself but affect consumer or producer surplus. V_i can also include idiosyncratic benefits of the federal government that may for example have the incentive to give maximum subsidy rates in order to administer fewer projects at the same time or reflect personal benefits of the federal government from bribing.

The federal government maximizes its utility from project i by setting the optimal subsidy rate s_i. The spillovers of an R&D project are defined as

(4) $$V_i = (Y_i\delta + \eta_i)RD_i.$$

Hence, the spillover rate per euro of R&D is

(5) $$\frac{\partial V_i}{\partial RD_i} = Y_i\delta + \eta_i.$$

The spillover rate per euro of R&D depends on a vector of observable firm characteristics Y_i,[7] δ a vector of parameters to be estimated, and η_i a random shock to the spillover rate from project i. η_i is unobserved by the firm when applying, but known by the federal government. This implies that the applicant firm does not know exactly how the federal government will rate the spillovers of project i to the economy or how the project affects the benefits of the federal government. Maximizing the federal government's utility from project i taking account of equations (2) and (5) and using the envelope theorem yields

(6) $$s_i = 1 - g + Y_i\delta + \eta_i .$$

The optimal subsidy rate depends negatively on the opportunity costs of funding g, and positively on the spillover rate per euro of R&D and the shock to the spillover rate η_i. The subsidy rate has an upper and a lower bound. It may be zero in case a project is rejected and capped at a maximum subsidy rate ($\bar{s}_i$). EU guidelines foresee that public funding of private R&D activities should not cover more than 50% of project costs (EC 1986, EC 1996, EC 2006). There are exemptions for SMEs, R&D collaborations, and firms located in economically disadvantaged regions like eastern Germany. Therefore the maximum subsidy varies depending on firm and project characteristics. The minimum constraint $s_i = 0$ binds for $\eta_i \leq \underline{\eta} \equiv g - 1 - Y_i\delta$, while the maximum constraint $s_i = \bar{s}_i$ binds for $\eta_i \geq \bar{\eta} \equiv \bar{s}_i + g - 1 - Y_i\delta$.

Stage 1 – the application decision. The first stage depicts the firm's decision whether or not to apply for a subsidy. A firm will apply for a subsidy, if its expected profits from applying minus its application costs K_i exceed the expected profits from not applying. The expected profits from applying depend on the firm's belief of how the federal government will rate its project. $\phi(\eta_i)$ denotes firm i's beliefs about η_i and $\Phi(\eta_i)$ the corresponding cumulative distribution function. Dropping the subscript i, the application decision rule can be written as

(7) $$d = 1\left\{\begin{matrix}\Phi\left(\underline{\eta}\right)\Pi(RD(0),0) + \int_{\underline{\eta}}^{\bar{\eta}}\Pi\left(RD\big(s(\eta)\big),s(\eta)\right)\phi(\eta)d\eta + \\ [1-\Phi(\bar{\eta})]\Pi(RD(\bar{s}),\bar{s}) - K \geq \Pi(RD(0),0)\end{matrix}\right\},$$

where d takes value one if a firm applies for a subsidy and zero otherwise. The expected profit from applying in equation (7) consists of three parts. The first part in the curly brackets denotes the belief of the firm how likely it will receive no funding for project i, $\Phi(\underline{\eta})$ times the profit given no subsidy, i.e. $s_i = 0$ and $\Pi_i(RD(0),0)$. The second term in the curly brackets denotes a firm's belief of receiving a subsidy rate for project i that is not censored at zero or the maximum subsidy rate times the profits from receiving that specific subsidy rate. This can be calculated by integrating the expected profits over the random spillover shock for project i under the area $\underline{\eta} < \eta_i < \bar{\eta}$, which corresponds to $0 < s_i < \bar{s}_i$. The third term in the curly brackets is the probability that project i receives the maximum subsidy rate, which is $(1 - \Phi(\bar{\eta}_i))$, times the profits from receiving $\bar{s}$.

The expected profits from applying for the subsidy are reduced by the application costs. The application costs are specified as

(8) $$K_i = exp(Y_i\theta + \nu_i).$$

The application costs for project i depend on a vector of observed firm characteristics Y_i, a vector of parameters to be estimated θ, and a random cost shock ν_i which is observed by the firm and the federal government but not by the econometrician.

[7] Note that Y_i is a vector of observable firm characteristics affecting the spillover rate per euro of R&D of project i, while X_i is a vector of observable firm characteristics affecting the profitability and application cost of R&D of project i.

4. Innovation policy in Germany

R&D subsidies. In Germany R&D subsidies for project funding are an important policy tool to support industrial R&D (BMBF 2012). In contrast to most other OECD countries, there are no R&D tax credits in place. R&D subsidies to firms are granted either via thematic or generic R&D programs (BMBF 2012). With the thematic R&D programs the federal government aims at increasing Germany's competitiveness by targeting R&D subsidies to R&D projects in technological areas that the federal government views as particularly important for the future technological competitiveness of Germany (BMBF 2012).[8] The generic R&D programs are not directed to specific technological areas and allow supporting e.g. R&D infrastructure investments, technology transfer, and innovation networks (BMBF 2012). They are targeted to support especially SMEs and firms in eastern Germany. Bank loans, equity investments, and guarantees also exist but play a minor role in Germany.

The federal ministries – mainly the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for Economics and Technology (BMWi) – design the R&D programs, i.e. they decide program content, duration of the support, subsidy requirements, and the maximum subsidy amounts distributed to an R&D project. Firms, universities, and research institutions can apply to receive government funding under a specific R&D program. Usually, the federal ministries pass on the administrative and scientific-technical work to the Program Management Agencies that have the scientific and technical expertise to administer and guide the R&D program. In Germany there are currently 14 Program Management Agencies (BMBF 2013). The Program Management Agencies "are commissioned to advise applicants, prepare funding decisions, process the projects and monitor their success" (BMBF 2010, p.24). The final subsidy decision is however incumbent on the Federal Ministries.

Application and granting procedure. There are one- and two-step application and granting procedures for R&D subsidies in Germany. In the one-step procedure the applicants hand in their final project application, which the federal ministry will then accept or reject. In the two-step procedure firms only hand in a short concept paper of their R&D project in the first step. If the concept paper gets accepted, a full application is handed in in a second step. The two-step procedure is used to reduce the administrative burden for applicants as well as the agencies and speed up the application process. The two-step procedure is especially used for R&D programs directed at SMEs. While the two-step procedure reduces the administrative burden for those firms rejected at the first stage, it remains the same for enterprises that have to file a full application (Aschhoff et al. 2012).

For the purpose of the theory model it is assumed for simplicity that there is only a one-step application procedure in place as modelled by Takalo et al. (2013a) for Finland. Three reasons justify this simplification. First, the two-step procedure is only in place for some but not all R&D programs. Second, full application costs for the two-step procedure do not differ from those of the one-step procedure. Third, application costs are found to be of only minor importance for Finnish firms by Takalo et al. (2013a).

The exact selection criteria vary from program to program. General selection criteria are: The project fits into the thematic outline of the R&D program; the relevance of the research goal and the quality of the R&D project; the know-how and expertise of the applicant (and its

---

[8] Technological areas, in which the German federal government intends to achieve or maintain high international standards of R&D, comprise among others: basic research, marine and polar research, space research, energy research, ecological and sustainable development research, health and medicine, biotechnology, material, physical and chemical research, aerospace research, R&D in agriculture, forestry and farming. Thereby these technological fields are covered by different programs in a given year. This is also reflected in the institutional structure, as there are 14 Program Management Agencies which are specialized in different technological fields.

partners); the economic and technical potential and risk; the possible economic utilization of the innovation; and if the project is a cooperation or not (Fier 2002, Aschhoff et al. 2012). Besides, the financial solvency of the firm is very important, as the federal government wants to avoid writing off R&D projects because grant receivers are unable to meet financial obligations (Aschhoff et al. 2012). Therefore firms have to prove their ability to pay their share of the project costs. The credit screening will be done with special care for firms that apply for the first time.[9]

Subsidy rate. Germany applies the Community Framework for State Aid for R&D (EC 1986, EC 1996, EC 2006). Hence, industrial research usually gets a maximum subsidy rate of 50% i.e. the share of public funding may cover at maximum half of the total project costs. There are a few possibilities though to receive a bonus on top of the maximum subsidy rate of 50%. Some bonuses have also been changing over time between the Community Frameworks for State Aid for R&D from 1986, 1996 and 2006. A bonus may be paid in the following cases:

- SMEs may receive an additional rate of 10%, as it is assumed that they face greater financial constraints and are thus more eligible to receive state aid. From 2007 on small enterprises can even receive a bonus of 20%.
- Economically disadvantaged regions like eastern Germany can get a bonus of 10%.
- Collaborative projects could receive a bonus of 10% from 1997 on and a bonus of 15% from 2007, as it is assumed that collaboration induces higher spillovers.

There is, however, also an absolute maximum subsidy rate. According to the Community framework from 1996 (EC 1996) a subsidy to the private sector should not exceed 75% and according to the Community framework from 2006 (EC 2006) not exceed 80%. In the Community framework from 1986 it is only mentioned that the subsidy rate should not be so high that it diminishes the commitment of the firm to the project (EC 1986).

5. Data and descriptive statistics

5.1 Data

The granting behaviour for R&D subsidies of the federal government in Germany is analysed using the PROFI database from the Federal Ministry of Education and Research. The PROFI database contains project-level information on R&D subsidies from thematic R&D programs since 1969. The data does not contain information about generic R&D subsidy programs.[10] Besides, the PROFI database contains only successful applications, but no rejected applications, a fact accounted for in the empirical analysis. In case a firm got granted more than one application per year, only the first application filed is used in the subsequent analysis (see also Takalo et al. 2013a).

The sample of firms that could potentially apply for a thematic R&D program stems from the Mannheim Innovation Panel (MIP) of the Centre of European Economic Research (ZEW).[11] The MIP is conducted annually since 1993. The data is representative for German firms with at

[9] Note that Takalo et al. (2013a) estimate the structural model for Finland, where the funding agency rates projects on a scale of 1 to 5 on two dimensions: economic and technological risk. In contrast to Finland, a systematic grading system of R&D projects is not used in Germany.

[10] Hence, the analysis in this paper does not reflect effects of generic R&D programs which are mainly targeted to SMEs and firms located in eastern Germany.

[11] General information on the MIP can be found under http://www.zew.de/en/forschung/mannheim-innovation-panel-innovation-activities-of-german-enterprises/?cHash=2f5ad528d970811ef72a75fc0a186a0c.

least 5 employees in the production sector as well as for a number of service sectors (Rammer 2012).[12] Most firm characteristics such as the number of employees, sales per employee, if a firm is an SME, exporter or part of a company group, regional and industry dummies come from the MIP data. Firm age and regional dummies are used from the Creditreform database. The Creditreform database is the biggest database on German companies. It contains the information of firms' credit reports (Creditreform 2013).

As I analyse the effect of R&D subsidies from thematic R&D programs that are targeted to support R&D in specific technological fields, industries where firms generally do not apply for thematic R&D subsidies are excluded from the sample. These are manufacturing of tobacco products, sale, wholesale and retail trade, real estate activities, and renting (see Table 9 in the Appendix for a list of the industries contained in the sample). When the project-level subsidy data (PROFI) is combined with the firm-level data (MIP and Creditreform), the firm-level data is lagged by one or two years in order to avoid direct simultaneity. If firm characteristics from the previous period were not observed, the firm characteristics are lagged by two years. The application information from the PROFI dataset in 1994 to 2011 is matched to the MIP data for the years 1992 to 2010. For 2,320 observations that stem from 1,395 firms the R&D subsidy information can be linked to the one- or two-year lagged firm characteristics of the MIP.[13] The final sample of potential applicants comprises 90,999 observations between 1994 and 2011 that stem from 20,976 firms. The random sample of firms between 1994 and 2011 is treated as a pooled cross-section.

The 90,999 firm-year observations are used to estimate the firms' application decision. The 2,320 observed R&D projects in the data are used to estimate the subsidy decision by the German federal government as well as the project-level R&D investment decision of the firm. In case a firm received a subsidy, the amount of the project-level subsidy, the total size of the R&D project and the project's subsidy rate, i.e. the share of public funding on the total project costs, is observed.

5.2 *Variables*

The variable SUBSRATE is defined as the subsidy amount on total project costs granted to successful applicants. The dummy variable ACCEPTED takes value one if a firm got an R&D subsidy for a project application, and zero otherwise. If the firm received a subsidy, the size of the subsidized project level R&D is observed. Project level R&D (RD) is measured in euros and deflated with base year 2000.[14] To avoid results being driven by outliers, the top one percent of the largest R&D projects is dropped from the sample.

The following firm characteristics are employed in the subsidy rate decision, application rate decision and R&D investment decision. The log of firm age (LNAGE) and its square (LNAGE2) account for differences between young and old firms. The log of employment

[12] The survey is representative for the production sector (mining, manufacturing, energy and water supply) as well as for a number of service sectors (wholesale trade, transport/postal services, media services, computer services and telecommunications, financial services, consulting/marketing, technical and R&D services, other firm-related services) (Rammer 2012). Each year about 6,000 firms participate in the written or online survey. Since participation in the survey is voluntary about 4,500 firms are asked via telephone to avoid biased survey results. The MIP is structured as a panel, i.e. questionnaires are sent each year to the same sample of firms. Every second year the sample is extended by a random sample of newly funded firms to replace firms that dropped out of the sample e.g. because they are closed down.

[13] For 2,146 observations the firm information is lagged by one year and only for 174 observations lagged by two years.

[14] RD is deflated with a sector-specific deflator of the gross value added provided by the Federal Statistical Office in Germany (Statistisches Bundesamt, Destatis-Genesis, Bruttowertschöpfung nach Branche, data retrieved 18th December 2012).

(LNEMP) and its square (LNEMP2) account for differences in firm size. Very large firms that indicate to employ more than 50,000 employees are dropped from the sample to avoid outliers determining the results. This accounts for less than 0.1% of firms in the sample. Sales per employee (SALESEMP) and its square (SALESEMP2) are included to account for differences in labour productivity. SALESEMP is measured in million euros and deflated using the year 2000 as the base year. To avoid outliers the top one percent of SALESEMP is dropped from the sample.

EXPORTER is a dummy variable that takes value one if the firm exports and zero else. GROUP is a dummy that takes value one if the firm is part of a group and zero otherwise. It is important to account for past funding experiences since there are learning effects in applying for funding. Aschhoff (2010) finds path dependency of receiving thematic R&D funding in Germany based on a sample of over 6,000 firms from the manufacturing and service industries in the period 1994 to 2005. Information about past project funding contained in the PROFI database allows to create the dummy variable PREVAPPL which takes value one if the company has received any funding within a thematic R&D program in the past and zero else. The variable LNPASTPROJ contains the log of the number of funded projects a firm received in the past.[15] The SME dummy takes value one, if a company is a small and medium enterprise and zero otherwise. The SME status is only contained in the application and subsidy rate decision and serves as exclusion restriction in the R&D investment equation. The SME status affects the maximum subsidy rate and hence the probability of a firm to apply for a subsidy, while it does not affect the profitability of R&D.

In addition, ten different regional dummies (REG1-REG10) control for differences between regions in Germany (see Table 8 in the Appendix). Thereby three regions (REG8, REG9, and REG10) are regions in eastern Germany. Twelve sector dummies account for differences across industries (N1-N12, see Table 9 in the Appendix), and 18 year dummies account for changes in the subsidy rate decision, application decision and R&D investment decision over time (YEAR1994-YEAR2011).

5.3 *Descriptive statistics*

Table 1 shows the descriptive statistics of the total sample differentiated by subsidy status.[16] The group of non-subsidy receivers consists mainly out of non-applicants, but contains also rejected applicants because rejections cannot be identified in the subsidy data available. The average subsidy rate granted to an R&D project of a firm between 1994 and 2011 in the sample is 48%. The minimum subsidy rate in the data is 10%, while the maximum subsidy rate is 80%. The median firm receives a subsidy of 50% which corresponds to the maximum subsidy rate to industrial research according to EU guidelines (see Section 4). Higher subsidy rates may be granted to collaborative R&D projects, SMEs and firms located in eastern Germany. The distribution of the subsidy rate depicted in Figure 1 demonstrates that the subsidy rate is centred around 50% and peaks at the even numbers of 30%, 40%, 50%, 60% and 70%.

The size of a publicly funded thematic R&D project in Germany is 366,000 euros for the median firm and 620,000 euros on average. The share of firms in the sample that received project funding is 2.6%. The share of SMEs is with 60% significantly lower among the subsidy receivers when compared to the non-subsidy receivers of which 80% are SMEs. Accordingly, firms that receive public R&D funding are significantly larger in terms of the number of

[15] As many companies did not receive funding for previous R&D projects, I take the logarithm of the number of funded projects in the past plus one, so that the logarithm of the number of funded projects a firm received in the past (LNPASTPROJ) will be zero, if a firm did not receive funding in the past.

[16] Descriptive statistics of regional, industry and year dummies are displayed in Table 10 in the Appendix.

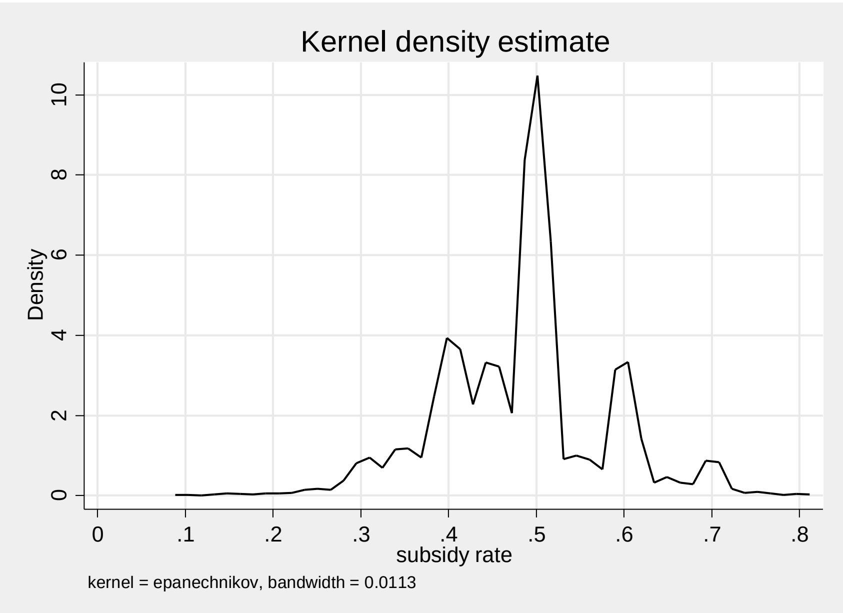
employees (on average 1,295 employees compared to 300 employees). They are also more often part of a group (47% compared to 33%) and export more often.

Table 1: Descriptive statistics

Variables	Subsidy receivers					Non-subsidy receivers					t-test
	med.	mean	s.d.	min.	max.	med.	mean	s.d.	min.	max.	
SUBSRATE	0.50	0.48	0.09	0.10	0.80						
RD[a]	365.7	619.9	749.9	0.7	6,072.0						
SME	1	0.60	0.49	0	1	1	0.80	0.40	0	1	***
AGE	14	29	37	1	359	17	30	37	1	680	
EMP	110	1,295	4,034	1	42,289	45	300	1,519	1	48,000	***
SALESEMP	0.11	0.15	0.15	0.00	2.50	0.10	0.14	0.17	0	2.62	***
GROUP	0	0.47	0.50	0	1	0	0.33	0.47	0	1	***
EXPORTER	1	0.83	0.38	0	1	1	0.60	0.49	0	1	***
PREVAPPL	1	0.63	0.48	0	1	0	0.09	0.28	0	1	***
PASTPROJ	1	4.01	9.81	0	112	0	0.18	1.09	0	79	***
No. of obs.			2,320					88,679			

Note: [a] Values are presented in thousand euros. Columns with heading med. display the median values, s.d. the standard deviation, min. minimum values and max. maximum values. *p<0.10, **p<0.05, ***p<0.01. Descriptive statistics of regional, industry and year dummies are displayed in Table 10 in the Appendix.

Figure 1: Subsidy rate for industrial R&D projects between 1994 and 2011



Note: Kernel density of the distribution of the subsidy rate for those 2,320 firms that received a subsidy. The subsidy rate is the share of public funding on total project cost.

There is a small but significant difference in terms of labour productivity (SALESEMP) which is slightly higher for subsidized firms. The average age of firms is 30 in the sample and similar for subsidy and non-subsidy receivers. The descriptive statistics reveal path dependency in public R&D funding. 63% of subsidy receivers already received thematic R&D funding in the past when compared to only 9% of the non-subsidy receivers. Accordingly, current subsidy receivers have on average received subsidies for 4 projects in the past, while the non-subsidy receivers conducted on average only 0.2 projects in the past.

Regarding sectoral differences it shows that the largest share of subsidy receivers stems from the R&D, architecture and engineers industry (N11) with 16%. This is followed by the machinery and equipment industry (N3) with 14%, the medical, precision and optical instruments industry (N6) with also 14%, and the radio, television, and communication equipment industry (N5) with 7% (see Table 10 in the Appendix).

6. Econometric implementation

This section describes how the theoretical model illustrated in section 3 can be estimated. The econometric implementation of the theory model presented in section 3 follows the structural model of the R&D subsidy process presented by Takalo et al. (2013a). The model of Takalo et al. (2013a) is tailored to the data of the Finnish funding agency Tekes. In contrast, the empirical model presented in the following is tailored to the German subsidy data available through the PROFI database. Recall that in contrast to the Finnish data from Tekes, the PROFI database does not contain information on rejected applications, i.e. the case that the subsidy rate $s_i = 0$ is not observed. Therefore the estimation of the application decision and the subsidy decision in Germany are adjusted to account for not observing rejected applications. In addition, the Finnish data contains the rating of R&D projects regarding their technological and economic risk by the Finnish funding agency Tekes, which is not the case for Germany. The econometric implementation described in the following aims to be as concise as possible.[17]

The theoretical model presented in section 3 yields equations of the federal government's subsidy rate decision and the firms' application and R&D investment decision. The game theoretic model starts with the application decision of firms, followed by the federal government's decision on the optimal subsidy rate, while on the last stage the firm makes the optimal R&D investment decision. In contrast to theoretical model, in the empirical implementation the subsidy rate decision is estimated first, followed by the application decision and the R&D investment decision of the firm. The reason is that a firm's application decision depends upon the firm's belief of how applying will affect its profits, which is estimated using information from the federal government's subsidy rate decision.

The subsidy rate decision. As a first step, the subsidy rate of project i is estimated using a left-truncated and right-censored Tobit model. The data is left-truncated at zero because rejected applicants are not observed, and it is right-censored at the maximum subsidy rate ($\bar{s}_i$). The maximum subsidy rate may vary between 50 and 80% depending on a firm's SME status, location in eastern or western Germany and if the subsidized project involves an R&D collaboration (see Section 4). As equation (6) demonstrates, the optimal subsidy rate s_i^* can be estimated by

(9) $$s_i^* = 1 - g + Y_i\delta + \eta_i.$$

To account for left-truncation in a right-censored regression model, the partial likelihood is conditioned on the fact that an observation is in the sample, i.e. an application is successful conditional on applying ($P_{S/A}$). Assuming a normal distribution $P_{S/A}$ can be described by

[17] For a more extensive description of the econometric implementation, statistical assumptions and implications of the model of the R&D subsidy process the interested reader is referred to Takalo et al. (2013a).

(10) $$P_{S/A} = 1 - \Phi\left(\frac{0-(1-g+Y_i\delta)}{\sigma_\eta}\right) = \Phi\left(\frac{1-g+Y_i\delta}{\sigma_\eta}\right).$$

The left-truncated and right-censored likelihood function assuming a normal distribution is given by equation (11), where z_i is one in case a project receives the maximum subsidy rate, and zero otherwise.

(11) $$\mathrm{L} = \prod\left[\frac{\frac{1}{\sigma_\eta}*\phi\left(\frac{s_i-(1-g+Y_i\delta)}{\sigma_\eta}\right)}{\Phi\left(\frac{(1-g+Y_i\delta)}{\sigma_\eta}\right)}\right]^{1-z_i} * \prod\left[\frac{1-\Phi\left(\frac{\bar{s}-(1-g+Y_i\delta)}{\sigma_\eta}\right)}{\Phi\left(\frac{(1-g+Y_i\delta)}{\sigma_\eta}\right)}\right]^{z_i}$$

The estimation of the subsidy rate allows the identification of the spillover parameters δ as well as the variance of η_i the spillover shock to project i. The parameter vector δ measures how the German federal government values each euro of R&D invested in project i and allows the calculation of the expected increase in the federal government's utility by project i that is not captured by the firm's profits from project i. Multiplying the spillover rate per euro of R&D from equation (5) with the amount of project-level R&D investment RD_i yields a measure of the spillovers of project i

(12) $$V_i = (Y_i\delta + \eta_i)\, RD_i\ ,$$

where Yi is a vector of observable firm characteristics affecting a projects' spillover rate. V_i captures the spillovers of project i to the German economy under the assumption that the German federal government acts as a benevolent planner and maximizes social welfare by setting the optimal subsidy rate for project i. The estimation of the subsidy rate does not allow the identification of the opportunity costs of funding (g) and the federal government's screening costs ($F_i - K_i$, where K_i are firm i's application costs). The estimation of the impact of project i on welfare will be upward biased, in case the screening costs are significant. The subsidy rate decision is estimated based upon 2,320 observations.

Application decision. The available data only contains grant receivers of thematic R&D programs, no rejections. To account for this fact the empirical model used in this paper is adjusted and hence differs from the empirical model presented by Takalo et al. (2013a). Findings on the application behaviour of successful applicants to all potential applicants in Germany can be generalized by the following method.

The probability of firm i to successfully apply for an R&D subsidy ($P_{accepted}$) equals the probability to apply for a subsidy (P_A) times the probability to receive a subsidy conditional on applying ($P_{S/A}$).

(13) $$P_{accepted} = P_A * P_{S/A}$$

The probability of firm i to receive a subsidy conditional on applying ($P_{S/A}$) is estimated based on the results of the subsidy rate equation (see equations (10) and (11)) by

(14) $$\hat{P}_{S/A} = \Phi\left(\frac{1-g+Y_i\hat{\delta}}{\hat{\sigma}_\eta}\right).$$

Y_i denotes the vector of firm characteristics of the subsidy rate equation, $\hat{\delta}$ denotes the estimated coefficients and $\hat{\sigma}_\eta$ the estimated standard error from the left-truncated and right-censored Tobit estimation. Plugging $\hat{P}_{S/A}$ into equation (13) yields a Probit model for $P_{accepted}$ that allows to identify the application probability by accounting for the estimated probability to receive a subsidy conditional on applying.

The application equation given by (7) can be simplified using (1), (2), and (8) receiving the probability of firm i to apply for a subsidy.

(15) $P_A = \{X_i\beta - Y_i\theta + ln[-E(\ln(1-s_i))] > \nu_i - \varepsilon_i\}$

As not all applicants for R&D subsidies are observed in the data, the probability of firm i to receive a subsidy ($P_{accepted}$) is estimated as equation (16) demonstrates.

(16) $P_{accepted}(d_i = 1|X_iY_i) = \{X_i\beta - Y_i\theta + ln[-E(\ln(1-s_i))] > \nu_i - \varepsilon_i\} * \hat{P}_{S/A}$

Thereby d_i is a dummy variable taking on the value one in case firm i received a subsidy, and zero otherwise (ACCEPTED). Accounting for the estimated probability of firm i to be successful conditional on applying ($\hat{P}_{S/A}$) from equation (14) allows to identify the firm's application probability.

The term $ln[-E(\ln(1-s_i))]$ states firm i's belief about how applying will increase its profits. It is estimated for each potential applicant in the sample. The subsidy rate decision allows to calculate a predicted subsidy rate for each firm i that depends on a vector of firm characteristics Y_i. Taking into account the distribution of the shock to the spillover rate η_i enables the estimation of the expected increase in profits from applying for each applicant. For this purpose the probability of firm i to receive a certain subsidy rate is multiplied with the profits of firm i from receiving that specific subsidy rate. The application decision is estimated for all 90,999 observations. The error term of the application decision is assumed to be normally distributed with mean zero and standard deviation of one.[18]

The R&D investment decision. Taking the logs of the optimal R&D investment equation (2) yields

(17) $ln[(1-s_i)RD_i^*(s_i)] = X_i\beta + \varepsilon_i$,

where RD_i^* is the actual project level R&D investment of the subsidized project i.[19] The dependent variable in (17) is the amount of own funds the firm invests into project i, i.e. the R&D investment net of the subsidy amount. It is explained by a vector of firm characteristics X_i and ε_i the shock to the marginal profitability of R&D.

The R&D investment decision is estimated by a Heckman two-step procedure, where the first stage is the decision of a firm to apply with project i and the second stage is the project-level R&D investment decision. The model is identified by two exclusion restrictions: First, the firm's belief of how applying will affect its profits $ln[-E(ln(1-s_i))]$ and second, the SME status. SMEs may receive a 10% mark-up on the maximum subsidy rate, which should affect their application behaviour but should not affect the marginal profitability of R&D. As an effect of firm size in terms of the number of employees is taken into account when estimating the optimal R&D investment, the SME status itself should have no impact on the marginal profitability of R&D. While the application decision is estimated for 90,999 observations, the project level R&D investment decision is estimated for 2,320 observations. The estimation of (17) yields an estimate of the β parameters, which measure the impact of firm characteristics

---

[18] This is in contrast to Takalo et al. (2013a) who estimate the standard deviation of the error term of the application decision. The standard deviation is assumed to be one due to numerical problems encountered when estimating $\sigma_{\upsilon-\varepsilon}$.

[19] Note that for Germany the actual project level R&D investment of the subsidized project is observed, while Takalo et al. (2013a) observe the planned project level R&D investment for Finland. Therefore the latter estimate the amount of planned own funds the firm invests into project i employing the maximum subsidy rate $\bar{s}_i$ which yields $ln[(1-\bar{s}_i)RD_i^*(\bar{s}_i)]$, while I estimate for Germany the amount of actually spend own funds employing s_i yielding $ln[(1-s_i)RD_i^*(s_i)]$.

X_i on the marginal profitability of R&D, and an estimate of the variance of the shock to the marginal profitability ε_i.

Identification of application costs. Recall that the application costs are specified as $K_i = \exp(Y_i\theta + \nu_i)$. The application cost parameters θ are identified through the application decision together with the R&D investment decision.

The coefficients of the application decision in equation (16) take the form $(\beta - \theta)/\sigma_{\nu-\varepsilon}$ for those firm characteristics that appear in X_i and Y_i. Thereby X_i is the vector of firm characteristics in the R&D investment decision, while Y_i is a vector of firm characteristics affecting the application decision. The coefficient for the SME status which only appears in Y_i is given as $-\theta/\sigma_{\nu-\varepsilon}$. Recall that the β parameters are identified through the R&D investment equation and the standard deviation of the application decision $\sigma_{\nu-\varepsilon}$ is assumed to be one, which allows to identify the application cost parameters θ. Note that firms' application costs are solely identified through the theoretical structure of the model. Standard errors of the application cost parameters are estimated by a bootstrap using 400 replications.

The error term of the application cost shock function is given by $\nu = (1 + \rho)\varepsilon + \nu_0$, dropping the subscript i. This shows that the application cost shock and the shock to the marginal profitability of project i can be correlated with each other. The correlation of the marginal profitability shock ε with ν is given by ρ. The uncorrelated part of the application cost shock is captured in ν_0.

Endogeneity. A common worry in the R&D subsidy evaluation literature is potential endogeneity of the subsidy decision. The model assumes that the shock to the spillover rate η_i is uncorrelated with ε_i the shock to the profitability of R&D. In the applied model spillovers of project i affect the optimal R&D investment and thereby the profitability of R&D through the subsidy rate (see equation (17)). On the other hand spillovers $V_i = (Y_i\delta + \eta_i)\, RD_i$ are linear in the amount of R&D investments of project i and therefore endogenous to ε_i, the shock to the marginal profitability of R&D. In contrast, the optimal subsidy rate increases in the amount of spillovers *per euro of R&D* and is therefore uncorrelated with ε_i (see equation (9)).

Firm characteristics Y_i and X_i. All three equations are estimated employing firm observables. The application decision and subsidy decision are estimated using the same set of firm observables Y_i. The R&D investment decision is estimated using a vector of firm characteristics X_i, which contains the same variables as Y_i except for the SME status, because the SME status is used as exclusion restriction in the Heckman selection model. As described in detail in section 5, firm observables comprise firm age, number of employees, sales per employee, if the firm is part of a larger group, if the firm exports or not, having received R&D subsidies previously, the SME status, regional, industry and year dummies.

Changes over time. The dataset at hand covers 18 years of observations from 1994 to 2011. In order to account for changes over time four different model specifications are estimated. The first specification estimates the structural model for all years from 1994 until 2011 as a pooled sample employing year dummies to account for changes over time (model 1). Second, in order to analyse changes over time in the explanatory variables, the model is estimated for three time blocks, each of six years length: 1994/99 (model 2), 2000/05 (model 3), and 2006/11 (model 4).

7. Estimation results

7.1 The subsidy rate equation and spillovers

The estimation of the subsidy rate equation (9) allows us to learn about the granting behaviour of the German federal government. Results for model 1 to 4 of the left-truncated and right-censored Tobit estimation on the subsidy rate (SUBSRATE) are displayed in Table 2. The table displays coefficient estimates controlling for time, regional and sector dummies. The coefficient estimates of time, regional and sector dummies are displayed in Table 11 and Table 12 in the Appendix.

Results demonstrate that SMEs receive on average a subsidy rate that is 3 percentage points above that of non-SMEs, all else equal. This reflects the possibility to grant SMEs a bonus of 10% upon the maximum subsidy rate for industrial research is 50%. The effect on the subsidy rate for SMEs changed over time (see model 2, 3 and 4 in Columns 2, 3 and 4 of Table 2). While SMEs do not receive a significantly higher subsidy rate in the period 1994/99, SMEs receive on average a 2.5 percentage points higher rate in the period 2000/05, which further increases to an average mark-up of 4.6 percentage points in the period 2006/11. This may reflect that the federal government increased its focus on supporting R&D activities of SMEs from the late 1990s on, when the conservative party under chancellor Helmut Kohl was replaced by the social democratic party under chancellor Gerhard Schroeder in 1998. Note that firms that are part of a larger enterprise group receive on average and all else equal a 3 percentage points lower subsidy rate. This may partly reflect that SMEs which are part of a group are not entitled to receive a bonus on the subsidy rate of 50%.

Results demonstrate that over time projects of SMEs are perceived to generate higher spillovers per euro of R&D than projects of large firms. Yet total spillovers of SMEs are smaller than those of large firms, because the average project size of SMEs in the dataset is with 512,000 euros smaller than the average project size of larger firms which is 780,000 euros. In that regard the findings are similar to those of Bloom et al. (2013) who find that smaller firms generate lower technological spillovers to other firms, because smaller firms operate in technology “niches”, where few other firms operate. Note, however, that the measure of spillovers is *more general* compared to Bloom et al. (2013) who only measure *technological* (or knowledge) spillovers that “increase the productivity of other firms that operate in similar technological areas” (p. 1314 Bloom et al. 2013). Spillovers in this study include not only technological spillovers to other firms but also the increase in consumer surplus due to newly created knowledge.

Firm size in general affects the subsidy rate following a u-shape. At the turning point are firms with 8,103 employees, who receive on average and all else equal an 8.1 percentage points lower subsidy rate compared to firms with one employee. Note that the median subsidy receiving firm in the sample has 110 employees, and the average subsidy receiving firm has 1,295 employees (see Table 1 in section 5.3). Merely 4% of subsidy receivers in the sample have more than 8,000 employees which implies that for most firms in the sample subsidies will decrease with increasing firm size. Interestingly, the effect of firm size on the subsidy rate becomes only significant from the year 2000 on, when also the SME effect becomes significant.

Neither firm age (LNAGE) nor labour productivity measured by sales per employee (SALESEMP) affect the subsidy rate decision (see model 1). Looking at changes over time, I find a u-shaped relationship between sales per employee and the subsidy rate for the years 2006 to 2011. The turning point is at sales of half a million euros per employee. Those firms receive a 3 percentage points lower subsidy rate compared to a firm that is making no sales. As in the case of firm size the majority of firms in the sample is located in the declining part of the u-shape relationship. Merely 3% of subsidized firms in the sample have sales per employee exceeding half a million euros per employee. Hence, in the years 2006 to 2011 R&D projects of firms with higher labour productivity are mostly perceived to generate less spillovers to the German society when compared to R&D projects of less productive firms.

Table 2: Subsidy rate equation results

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
SME	0.032***	0.022	0.025**	0.046***
	(0.007)	(0.016)	(0.011)	(0.010)
LNAGE	0.004	-0.033*	0.010	0.015
	(0.007)	(0.019)	(0.011)	(0.010)
LNAGE2	-0.001	0.005	-0.002	-0.003
	(0.001)	(0.003)	(0.002)	(0.002)
LNEMP	-0.018***	-0.006	-0.019***	-0.013**
	(0.004)	(0.015)	(0.007)	(0.005)
LNEMP2	0.001***	0.001	0.001**	0.001
	(0.000)	(0.001)	(0.001)	(0.000)
SALESEMP	-0.023	0.031	0.045	-0.127**
	(0.024)	(0.058)	(0.039)	(0.057)
SALESEMP2	0.008	-0.029	-0.010	0.127*
	(0.016)	(0.028)	(0.025)	(0.074)
PREV_APPLICANT	-0.017***	-0.004	-0.014*	-0.020***
	(0.005)	(0.014)	(0.008)	(0.008)
LNPASTPROJ	0.011***	0.005	0.011**	0.011***
	(0.003)	(0.008)	(0.004)	(0.004)
EXPORTER	0.009*	0.018	0.004	0.008
	(0.005)	(0.015)	(0.008)	(0.008)
GROUP	-0.033***	-0.033***	-0.033***	-0.031***
	(0.004)	(0.011)	(0.007)	(0.007)
Constant	0.512***	0.491***	0.500***	0.492***
	(0.018)	(0.062)	(0.027)	(0.024)
Time dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes
σ_η	0.081***	0.079***	0.075***	0.083***
	(0.001)	(0.003)	(0.002)	(0.002)
Wald-test	781***	107***	417***	404***
Log likelihood	2,313.76	264.64	904.46	1,198.65
No. of obs.	2,320	356	813	1,151

Note: Table displays coefficients of a left-truncated and right-censored Tobit model. Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01. Estimation results for time, industry and region dummies are presented in Table 11 and Table 12 in the Appendix.

Exporting firms receive on average a 0.9 percentage points larger subsidy rate than non-exporting firms, all else equal. The effect is only weakly significant at the 10%-level. It signals, however, the importance of R&D projects undertaken by firms that are competing on international markets.

Firms that have already received a subsidy in the past receive on average a 1.7 percentage points lower subsidy rate, all else equal. This effect is moderated by a positive effect on the subsidy rate that increases with the amount of past subsidized R&D projects. Firms that have received five and more subsidized projects in the past have a higher subsidy rate on average when compared to firms that have not received funding in the past. In contrast, firms that have received funding previously for one to four projects receive a slightly lower subsidy rate than entirely unexperienced firms, all else equal. A look at changes over time reveals that this finding is true mostly for the years 2006 to 2011. It may reflect that very small firms which likely have not received any funding in the past could receive a higher maximum subsidy rate than medium sized firms from 2007 on. Starting in 2007, small firms with less than 10 employees and a maximum of 2 million euro sales per year, were allowed to receive a 20% mark-up on the maximum subsidy rate according to EU guidelines as compared to a 10% mark-up before (EC 2006).

Firms located in a region in eastern Germany receive a 3 to 4 percentage points higher subsidy rate on average, which corresponds to the possibility to grant firms located in economically disadvantaged regions an additional bonus of 10% on top of the maximum subsidy (Table 12 in the Appendix). A look at changes over time demonstrates that the mark-up for firms located in eastern Germany disappears for all regions in the period 2006/11 except for Thuringia.

Looking at the year dummies in model 1 shows that there are no substantial changes over time of the subsidy rate between 1994 and 2011, except for a mark-up in 1994 when compared to 2011 (Table 11 in the Appendix). This indicates that the decision of the German federal government on the R&D subsidy rate granted to industrial research remained very stable over time.

7.2 The application equation

The application cost parameters are identified by the joint estimation of the R&D investment equation (17) and the application equation (16). Recall from section 6 that one can identify the application probability for firms in the sample even though only the probability to receive a subsidy is observed. This can be done by estimating the probability to receive a subsidy conditional upon applying $\hat{P}_{S/A}$.

Results indicate that applications almost never get rejected. This finding is in contrast to evaluation reports of federal thematic R&D programs in Germany which report that the success rate for applicants is rather low and varies between 5-25% (Aschhoff et al. 2012, BMBF 2015, Geyer et al. 2006, Staehler et al. 2006).[20] One has to keep in mind, however, that overestimating the success probability, i.e. once applied a firm likely receives a subsidy, leads to underestimating the true number of applications of firms in the sample and hence to an overestimation of application costs. Most interesting is what this implies for findings of the estimated welfare effect of R&D subsidies to the German economy. If estimated application costs are too high the estimated social rate of return will be downward biased. While the estimate of the application probability deserves further scrutiny, the approach outlined in section 6 is employed in this paper. As this causes an upward bias of application costs and hence a downward bias of the social rate of return, presented results on the social impact of R&D subsidies in Germany in this paper may be seen as rather conservative.

The estimated application costs for all four model specifications are displayed in Table 3. Coefficients for time, regions and industries are displayed in Table 13 and Table 14 in the Appendix. The results show that application costs are on average and all else equal 20% higher for SMEs, which is significant at the 1%-level. Firm size affects application costs in an inverse u-shape, which is weakly significant at a 10%-level. First, application costs increase with firm

[20] See also an evaluation report of clusters of excellence by the RWI Essen http://www.rwi-essen.de/media/content/pages/publikationen/rwi-projektberichte/RWI-PB_Spitzencluster.pdf.

size up to the turning point of firms with 61 employees, and then decrease again. Firms with more than 3,754 employees have lower application costs than firms with one employee.

The results also provide evidence, that application costs are significantly lower for exporting firms and for firms that have received funding in the past. The latter finding highlights learning effects in applying for R&D funding and is in line with path dependency of receiving thematic R&D funding in Germany (Aschhoff 2010).

Table 3: Application cost function results

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
SME	0.195***	0.199*	0.145*	0.172**
	(0.045)	(0.107)	(0.080)	(0.071)
LNAGE	0.242	0.177	0.355	0.304
	(0.168)	(0.275)	(0.315)	(0.293)
LNAGE2	-0.029	-0.035	-0.038	-0.037
	(0.022)	(0.043)	(0.044)	(0.036)
LNEMP	0.107*	0.182	-0.014	0.146*
	(0.058)	(0.182)	(0.127)	(0.076)
LNEMP2	-0.013*	-0.007	-0.010	-0.014*
	(0.007)	(0.014)	(0.013)	(0.009)
SALESEMP	0.669*	1.640	1.207	-0.878
	(0.371)	(1.231)	(0.878)	(0.705)
SALESEMP2	-0.270	-0.864	-0.744	1.540*
	(0.275)	(1.386)	(0.895)	(0.883)
PREV_APPLICANT	-0.391	-0.187	-0.873*	-0.147
	(0.252)	(0.596)	(0.499)	(0.280)
LNPASTPROJ	-0.570**	-0.194	-1.119**	-0.423
	(0.228)	(0.408)	(0.462)	(0.286)
EXPORTER	-0.246*	-0.015	-0.097	-0.399**
	(0.128)	(0.223)	(0.181)	(0.195)
GROUP	0.082	-0.158	0.000	0.160
	(0.072)	(0.183)	(0.125)	(0.109)
constant	13.607***	11.932***	16.663***	12.681***
	(1.278)	(3.028)	(2.607)	(1.375)
Time dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes
No. of obs.	90,999	22,419	29,083	39,497

Note: Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01. The table displays coefficients of the cost function given by equation (8) $K_i = exp(Y_i\theta + \nu_i)$. Taking the log of equation (8) gives $\ln(K_i) = Y_i\theta + \nu_i$ and demonstrates that coefficients in the cost function can be interpreted as semi-elasticities. Estimation results for time, industry and region dummies are presented in Table 13 and Table 14 in the Appendix.

There is no significant effect of firm age and of affiliation to an enterprise group on the application costs. Labour productivity also does not significantly affect application costs. An F-test on joint significance of SALESEMP and SALESEMP2 is rejected at the 10%-level. Regarding regional aspects, I find that application costs are similar across regions, except for firms located in Saxony and Saxony-Anhalt, two regions in eastern Germany, in which application costs are significantly lower compared to firms located in Bavaria (see Table 14 in the Appendix).

Considering changes over time, the year dummies reveal that application costs were larger in the years 1994 to 2000 compared to application costs in 2011 (see Table 13 in the Appendix). There are only minor changes in firm characteristics over time, such as a stronger effect of internationally oriented firms (EXPORTER) on application costs in the period 2006/11 as compared to the years before.

Results for Finland for the period 2000 to 2002 reported by Takalo et al. (2013a) demonstrate as well that past experience (the number of past applications) and export activity reduces application costs, while firm age does not have any effect. In contrast to findings for Germany, application costs are not higher for SMEs in the Finland. Moreover, instead of an inverse u-shape relationship between firm size and application costs as found for Germany Takalo et al. (2013a) find a u-shape relationship for Finland. Besides, Finnish firms face higher application costs with increasing labour productivity, while labour productivity does not affect application costs in Germany.

7.3 The R&D investment equation

The effect of exogenous variables on marginal profitability of R&D is identified by the R&D investment equation (17) using a Heckman two-step procedure, where the first stage is the decision of a firm to apply with project i and the second stage is the project-level R&D investment decision (see section 6). Hence, the resulting coefficients presented in Table 4 display marginal effects. Estimation results for time, region and industry dummies are presented in Table 15 and Table 16 in the Appendix.

The results for model 1 demonstrate that both firm size and labour productivity (SALESEMP) increase the marginal profitability ceteris paribus. Both coefficients are significant at the 5%-level. In contrast, firm age, export status, past funding experience, or affiliation to an enterprise group do not affect the marginal profitability of R&D. In addition, looking at models 2, 3 and 4 there are no substantial changes over time in the impact of firm characteristics on R&D. Results are in line with findings for Finland where the marginal profitability of R&D projects increases as well in firm size and labour productivity.

The marginal profitability of projects conducted by firms located in eastern German regions is significantly lower than the marginal profitability of R&D projects conducted by firms in the reference group which are located in Bavaria (see Table 16 in the Appendix). This is also true for firms located in Hamburg and Schleswig-Holstein (REG2) as well as for firms from Lower Saxony and Bremen (REG3), which are regions in the north-west of Germany.

General changes over time identified by the year dummies (see Table 15 in the Appendix, model 1) show a significantly larger marginal profitability of subsidized research projects in the years 1994 to 2000 (except for 1997), as well as for the years 2002, 2004, 2009 when compared to the profitability of funded projects in 2011. Within the model framework this implies that the profitability of ideas decreased over time in Germany. Thinking outside the theory model this finding might reflect a change in German funding policies not reflected in the theoretical framework. A closer look to the R&D subsidy data reveals that the number of firms which received thematic R&D funding in the sample increased clearly since 2001. As these firms were mainly SME’s, the average size of the subsidized R&D project in the sample decreased. In addition, comparatively more very large projects, with a volume of more than one million euro, where funded in the years 2002 and 2009/10. The peaks in 2002 and 2009 may be explained by increased governmental support for industrial R&D in these years. In 2002 the German federal government profited a short-term increase in its budget due to the large revenues from the sale of UMTS-licenses and in 2009 governmental support for industrial R&D was expanded to combat the financial crisis.

Table 4: R&D investment estimation results

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
LNAGE	-0.072	0.144	0.018	-0.172
	(0.163)	(0.274)	(0.302)	(0.282)
LNAGE2	0.004	-0.034	0.003	0.011
	(0.021)	(0.044)	(0.041)	(0.034)
LNEMP	0.116**	0.217	0.045	0.139*
	(0.051)	(0.166)	(0.107)	(0.071)
LNEMP2	-0.004	0.001	-0.006	-0.003
	(0.006)	(0.014)	(0.011)	(0.008)
SALESEMP	0.693**	1.998	0.805	-0.149
	(0.323)	(1.262)	(0.752)	(0.708)
SALESEMP2	-0.404*	-1.009	-0.628	0.597
	(0.237)	(1.503)	(0.869)	(0.935)
PREV_APPLICANT	0.079	0.411	-0.423	0.253
	(0.246)	(0.560)	(0.481)	(0.280)
LNPASTPROJ	0.016	0.448	-0.486	0.172
	(0.226)	(0.397)	(0.463)	(0.282)
EXPORTER	-0.041	0.133	0.033	-0.137
	(0.126)	(0.226)	(0.169)	(0.192)
GROUP	0.078	-0.253	0.051	0.141
	(0.065)	(0.176)	(0.107)	(0.101)
constant	12.068***	9.688***	15.023***	11.490***
	(1.274)	(3.018)	(2.537)	(1.392)
Time dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes
Mills lambda	-0.208	0.571	-1.234	0.137
	(0.521)	(0.898)	(0.996)	(0.654)
R^2	0.186	0.308	0.209	0.170
No. of obs.	2,320	356	813	1,151

Note: Table displays coefficients of a Heckman-selection model. Bootstrapped standard errors in parentheses (400 replications). Exclusion restrictions are the SME dummy and $ln[-E(ln(1-s_i))]$, which is the expected increase in profits of firm i due to applying. *p<0.10, **p<0.05, ***p<0.01. Estimation results for time, industry and region dummies are presented in Table 15 and Table 16 in the Appendix.

7.4 The covariance structure

Table 5 presents the estimated standard deviations of the error terms and the covariance between unobservables in the application and investment equation for model 1, 2, 3 and 4 respectively. It shows that the standard deviation of the shock to the spillover rate per euro of R&D (σ_η) is pretty low in Germany with 0.08 on average and that it hardly varies over time. The standard deviation of the shock to the marginal profitability of a project (σ_ε) is on average 1.01. Interestingly it is slightly higher for the period 2000/05 compared to the periods before and after.

Recall that the error term of the application cost shock function is given by $\nu_i = (1+\rho)\varepsilon_i + \nu_{0i}$. Then $\sigma_{\nu 0}$ is the standard deviation of the uncorrelated part of the application cost shock and $\rho_{\varepsilon\nu}$ is the correlation between ε the shock to the marginal profitability of R&D and ν the application cost shock. It is identified from the joint estimation of the application decision and the R&D investment decision in the Heckman selection model and reflects how the unobserved marginal profitability of a project affects the application costs and hence the application probability of a firm. As Table 5 demonstrates $\rho_{\varepsilon\nu}$ is negative but insignificant in model 1, i.e. when looking at the total period of observation 1994 to 2011. Interestingly, this relationship changes over time. While $\rho_{\varepsilon\nu}$ is positive in the periods 1994/99 and 2006/11, it becomes negative and significant for the period 2000/05. This demonstrates substantial heterogeneity of the relationship between the unobserved profitability of ideas and application costs over time. A higher unobserved marginal profitability of ideas increased the application probability and decreased application costs in the periods 1994/99 and 2006/11, while it increased application costs in 2000/05.

Table 5: Covariance structure results

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
σ_ε Standard deviation of the investment equation	1.001*** (0.168)	1.022*** (0.358)	1.487** (0.601)	0.980*** (0.202)
σ_η Standard deviation of the spillover shock	0.081*** (0.001)	0.079*** (0.004)	0.075*** (0.002)	0.083*** (0.002)
$\sigma_{\nu 0}$ Standard deviation of the uncorrelated part of the application cost function shock	0.979*** (0.142)	0.829*** (0.247)	0.558** (0.276)	0.990*** (0.161)
$1+\rho$ Measure of the variance share of ε in ν	-0.204 (0.335)	0.547 (0.488)	-0.558** (0.271)	0.142 (0.411)
$\rho_{\varepsilon\nu}$ Correlation between ε and ν the application equation error term	-0.206 (0.402)	0.559 (0.612)	-0.830* (0.435)	0.139 (0.499)

Note: Bootstrapped standard errors in parentheses (400 replications). *p<0.10, **p<0.05, ***p<0.01.
σ_ε is identified in the estimation of the R&D investment equation, σ_η is identified in the estimation of the subsidy rate equation, and $\rho_{\varepsilon\nu}$ is identified from the joint estimation of the application decision and the R&D investment decision in the Heckman selection model.
By definition the correlation $\rho_{\varepsilon\nu} = \frac{cov(\varepsilon,\nu)}{\sigma_\varepsilon\sigma_\nu} = \frac{(1+\rho)\sigma_\varepsilon^2}{\sigma_\varepsilon\sigma_\nu} = \frac{(1+\rho)\sigma_\varepsilon}{\sigma_\nu}$, which allows to calculate the measure of the variance share of ε in ν: $(1+\rho)=\frac{\rho_{\varepsilon\nu}\ \sigma_\nu}{\sigma_\varepsilon}$.
$\sigma_{\nu 0}$ is calculated form of the application equation error term $\nu_i = (1+\rho)\varepsilon_i + \nu_{0i}$, so that $\sigma_{\nu 0} = \sqrt{(\sigma_\nu{}^2 - (1+\rho)^2\sigma_\varepsilon{}^2)}$.

Takalo et al. (2013a) find for Finland for the years 2000/02 that the unobserved marginal profitability of an R&D project increases application costs and therefore reduces the application probability significantly. The authors argue that this may reflect difficulties to write applications for very profitable and potentially also very complex project ideas. However, results for Germany reveal that this relationship may not be that straight forward since it can vary over time.

7.5 Robustness of the results

The model of the R&D subsidy process by Takalo et al. (2013a) assumes that the error term of the subsidy rate equation is uncorrelated with the error terms of the investment and application equation. To test if that assumption holds, I checked for potential selection bias in the subsidy rate equation. Therefore in the first step, the Probit model on the application decision was estimated leaving out the expected subsidy term. In a second step the subsidy rate equation was estimated including the inverse Mills ratio. As exclusion restriction I use the interaction terms between the SME dummy and several firm characteristics such as firm age, sales per employee, exporter as well as regions located in eastern Germany. In none of the applied specifications the coefficient of the inverse Mills ratio was significant. This validates the assumption that the shock to the spillover rate is uncorrelated to the shock of the application and R&D investment decision.

Another assumption is that spillovers are linear in the firms R&D investment ($\partial V/\partial RD_i = Y_i\delta + \eta_i$). I checked this assumption by including the project-level R&D investment and its interactions with firm characteristics and regions into the estimation of the subsidy rate decision. Neither the direct effect of RD_i, nor its interactions were significant at the 5%-level. This finding supports the assumption that spillovers are linear in R&D investment.

8. Effects of the subsidy

8.1 Firm effect, application costs and spillover effect

The model of the R&D subsidy process allows the calculation of the expected benefits of R&D subsidies for the firm and the German federal government. The firm benefits from an R&D subsidy by increased expected profits due to the subsidy (firm effect). All benefits not captured by the firm that spill over to the German economy are captured by the subsidy decision of the federal government (spillover effect). Assuming that the German federal government maximizes total welfare, the firm and the spillover effect constitute the overall increase in welfare due to R&D subsidies in Germany.[21]

The firm effect is estimated by plugging in the estimated coefficients into the firm's profit function (equation (1)), the optimal R&D investment decision (equation (2)), and the application cost function (equation (8)). The spillover effect is estimated by inserting estimated coefficients, the granted subsidy rates and R&D investments into $V_i = (Z_i\delta + \eta_i)RD_i = \big(s_i - (1-g)\big)RD_i$, which is retrieved from equations (5) and (6). The calculation of V_i is adjusted for firms at the lower and upper bound of the subsidy rate by integrating over the relevant domain of η_i.

In addition, the distribution of the shocks to the marginal profitability of a project ε_i and the shock to the application cost function ν_i, as well as their correlation have to be taken into account. Recall that $\nu_i = (1+\rho)\varepsilon_i + \nu_{0i}$. Therefore effects of the subsidies are calculated using two approaches. First, both effects are integrated over the domain of ε_i and ν_{0i}. Second,

[21] If one is not willing to believe that the federal government maximizes social welfare, at the minimum it is observed what the federal government itself gets out of funding a certain project. It is, however, likely that the variation in the subsidy rate reflects the valuation of a project to some extend and that the federal government will be sufficiently incentivized to pick socially valuable projects so that the subsidy rate reflects spillovers or at least differences between spillovers of projects.

the effects are calculated using the estimated value of ε_i which is identified from the R&D investment equation and then integrated over the domain of ν_{0i}.[22]

Results of the calculated effects of both approaches are displayed in Table 6 for the total sample from 1994 to 2011 (model 1). The first row shows the median and mean gross firm effect on subsidy receivers, i.e. the increase in firm profits due to the subsidy, gross of application costs. The increase in gross firm profits is estimated to be 207,644 euros for the median firm in the period 1994 to 2011 when integrating over the domains of ε_i and ν_{0i}. The effect is 40% lower when using the estimated ε_i. Estimated means are closer to each other, but again the value using the estimated ε_i is 10% lower.

The second row of Table 6 displays the net firm effect, i.e. the expected increase in firm profits due to the subsidy, net of application costs. Here the heterogeneity between the two approaches is even stronger. Now the estimated net firm effect is by 60% lower when integrating over the domains of ε_i and ν_{0i} compared to using the estimated ε_i. Differences in mean values are even more pronounced. The large difference in the net firm effect arises due strong differences in the estimated application costs, displayed in row three.

Table 6: Effects of the subsidies in euro

	Integration over domains of ε_i and ν_{0i}		**Estimated ε_i, integration over ν_{0i}**	
	median	mean	median	mean
Gross firm effect on subsidy receivers	207,644	227,283	123,078	204,443
Net firm effect on subsidy receivers	65,644	79,340	113,681	190,943
Application costs of subsidy receivers	138,360	147,943	7,238	13,500
Spillover effect generated by subsidy receivers	206,640	236,918	122,458	204,878

Note: Effects are calculated using the total sample from 1994 to 2011 (model 1).

Estimated application costs are 7,238 euros for the median firm when using the estimated ε_i, while integrating over ε_i yields much higher estimated application costs of 138,359 euros. Given the observation that applicant firms invest about 15 to 40 person days to file a full application (Aschhoff et al. 2012), the estimated application costs using the estimated ε_i seem more plausible.[23]

Estimated spillover effects to the German economy generated by subsidy receivers are displayed in row four of Table 6. In both approaches the estimated spillover effect is close to the estimate of the increase in firm profits. It shows that even though results show considerable heterogeneity between the *absolute* effect of a subsidy on firms' gross profits and spillovers, the *relative* estimate does not change. Firms appropriate about 50% of the total welfare increase induced by thematic R&D subsidies in Germany. This finding is in line with Peters et al. (2009),

[22] For a detailed description on how to calculate the two approaches the reader is referred to Takalo et al. (2013a, Appendix 8).

[23] The observation of Aschhoff et al. (2012) refers to applicants of the thematic R&D program "SME innovative".

who estimate the social return of R&D investments of firms in Germany in the period 1991 to 2005.[24]

Results for Finland found by Takalo et al. (2013) show a similar pattern as results for Germany. First, using the estimated ε_i, estimated application costs are also lower as compared to integrating over ε_i. Second, in Finland firms appropriate 60% of the total welfare effect, and hence slightly more than firms in Germany. The estimated spillover effect is more than three times larger though in Germany when compared to Finland. This is not surprising, given that the German economy is much larger than the Finnish economy. In the year 2000, for instance, the German economy was 15 times larger than the Finnish economy. According to the model assumptions, the federal government is only concerned about how spillovers of subsidized R&D projects affect the national economy. Hence, the German federal government can assume that more spillovers are realized within Germany, while the Finnish funding agency must take into account that a considerable share of spillovers will be realized outside of Finland.

8.2 *The social rate of return*

The expected rate of return on the subsidy rate is calculated assuming that the federal government behaves as a benevolent social planner. The social rate of return is calculated at the project-level by dividing the benefits due to subsidies (the project's net firm effect and spillover effect) by the cost of the subsidy (subsidy amount of the project). Thereby the opportunity costs of funding, i.e. tax distortions, are ignored. The expected rate of return of thematic R&D subsidies in Germany is positive with on average 1.34 using the estimated ε_i and negative with on average 0.88 when integrating over ε_i. As Figure 2 demonstrates, the rate of return is very centred demonstrating little heterogeneity across firms.

The different ways of calculating the benefits and costs of the subsidy leads to relatively large differences in the social rate of return. As Table 7 shows the main driver of these differences is the significant disparity in estimated application costs. Using the estimated ε_i the retrieved application costs amount to merely 5-10% of the estimated application costs when integrating over ε_i. As noted before, the estimated application costs using the estimated ε_i are more reasonable. Therefore, also the estimated rate of return of 34% seems more likely.

Note that the high estimated application costs, may also be driven by the fact that rejected applicants are not observed in the German subsidy database. Even though this specific feature of the data is accounted for in the empirical implementation, the high rejection rate of applicants in Germany is not reflected in the data (see section 7.2). Therefore the model may underestimate the application probability and hence overestimate application costs.

To complete the picture let us, in addition, consider differences in the social rate of return that may occur between small and large firms as well as between firms located in eastern and western Germany. Table 7 shows the estimated rate of returns for the different scenarios. It is obvious that the estimated rates of return do neither differ between small and large firms nor between West and East German firms. They are remarkable stable across different scenarios.

In summary, the estimated social rate of return using the estimated ε_i is highly plausible compared to the results when integrating over the domain of ε_i. Accordingly, one euro of thematic R&D subsidies yield on average a social return of 1.34 euros in Germany in the period 1994 to 2011. Recall that opportunity costs of funding, such as tax distortions and administrative costs, are not included in the calculation of the social rate of return. Following Takalo et al. (2013a) who assume opportunity costs of 20% for Finland, I find that with an

[24] Peters et al. (2009) find that if a firm invests one euro into R&D its productivity increases on average by 0.41 euros, while knowledge spillovers to other firms amount to 0.52-0.62 euros.

estimated rate of return of 34% thematic R&D subsidies increase opportunity costs of 20% in Germany and hence are welfare increasing in Germany.[25]

Figure 2: Distribution of the rate of return

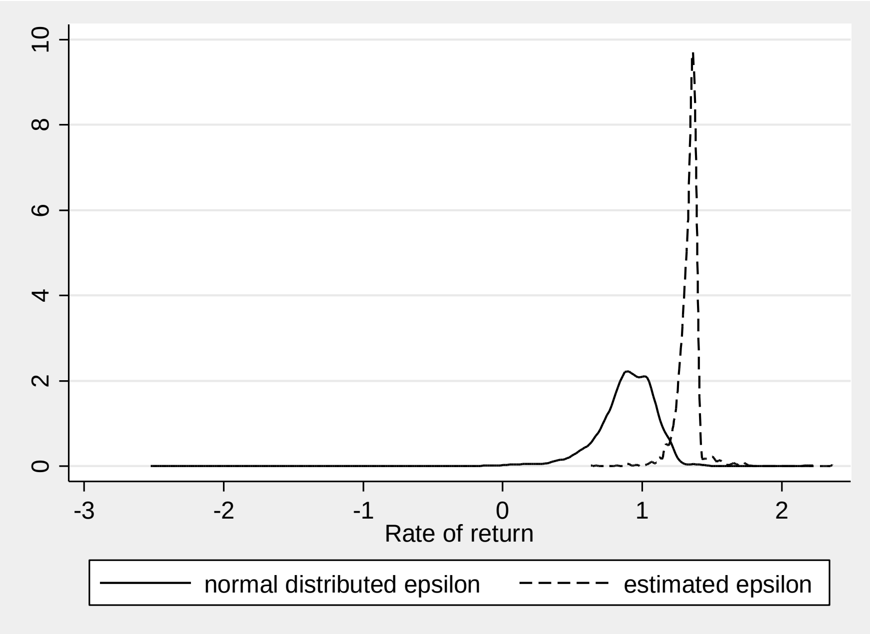


Table 7: Rate of return to the subsidy, 1994-2011

	All		**SMEs**		**Large**		**East**		**West**	
	median	mean	median	mean	median	mean	median	mean	median	mean
Integration over ε_i and ν_{0i}	0.91	0.88	0.91	0.89	0.92	0.87	0.92	0.91	0.91	0.87
Est. ε_i, integration over ν_{0i}	1.35	1.34	1.35	1.33	1.35	1.34	1.36	1.34	1.34	1.33
No. of obs.	2,320		1,401		919		748		1,572	

The estimated social rate of return for Finland is with 1.51 using the estimated epsilon slightly larger compared to the estimated value for Germany (see Takalo et al. 2013a). Note that the estimated rates of return are values at the margin, i.e. per euro of R&D subsidies. Recall that the spillover effect and the gross firm effect are larger for Germany than for Finland. Hence, the smaller social rate of return at the margin in Germany is due to higher subsidies in Germany. Note that within the model framework, the optimal social rate of return is estimated. Even though the social rate of return in Germany is smaller at the margin than in Finland, the total effect on welfare in Germany may be larger as subsidies in Germany are higher.[26]

[25] Note that as most tax distortions arise through income tax, the estimate of 20% may be too high for Germany, where income tax distortions are estimated to be between 3-4% (Blaufuss et al. 2011).

[26] While the average subsidy rate for Finland is 32% as compared to 48% in Germany, the average size of the subsidized R&D project is rather similar with on average 634,300 euros for Finland and on average 619,900 euros for Germany (see Takalo et al 2013a).

9. Conclusions

The majority of studies evaluating the effects of R&D subsidies analyse input and output additionalities and find that R&D subsidies in Germany increase both the innovative input and output of subsidized firms. In contrast, this study analyses the overall benefits and costs of distributing R&D subsidies in Germany covering a long period of 18 years from 1994 to 2011. The analysis is based on a structural model of the R&D subsidy process designed by Takalo et al. (2013a).

Employing project level R&D subsidy data of thematic R&D subsidies for Germany, the analysis shows that the subsidy rate decision remained remarkably stable over time. The spillover rate, i.e. spillovers per euro of R&D, is estimated to be larger for SMEs and firms located in eastern Germany and smaller for large firms and firms that are part of an enterprise group. Even though results show that SMEs generate higher spillovers per euro of R&D, total spillovers of SMEs are smaller than those of large firms, because the average project size of SMEs is in the dataset is smaller than the average project size of larger firms.

Estimated application costs are significantly lower for firms that have already received R&D funding in the past, demonstrating path dependency and a learning curve. With respect to firm size, results show that SMEs have to bear higher application costs compared to non-SMEs. Overall, application costs in Germany declined over time, being higher on average in the years 1994 to 2000 compared to 2011.

Considering the estimated profitability of R&D, results show that the profitability of R&D is significantly higher for large firms and for firms with a high labour productivity, but lower for firms located in eastern Germany. The profitability of R&D also declined over time, i.e. it was higher in the years 1994 to 2000 compared to the year 2011. Given the model framework, this finding indicates that the quality of ideas in Germany decreased over time. An alternative explanation for this finding is that the extended subsidy policy from 2001 on was targeted to rather small and medium-sized projects, while the number of large projects with a volume of more than one million euro remained rather constant over time in the sample.

Thematic R&D subsidies affect firms' profits to the same extent as spillovers to the German economy that are not captured by the firms' profits.[27] Assuming that the German federal government behaves as a benevolent social planner, the estimated social rate of return to the subsidy is 34%, which exceeds the assumed opportunity costs of 20%. Hence, results demonstrate that thematic R&D subsidies in Germany are welfare increasing. Interestingly, the estimated social rate of return does not differ with respect to firm size and location in western or eastern Germany.

Clearly, the conducted analysis of estimating the benefits of R&D subsidies for Germany has its limitations. First, the data does not contain rejected applicants. The analysis accounts for this fact, but it shows that the model does not reflect the actual rejection rates in Germany. Therefore estimates of the application cost should be considered with caution, as observing rejected applications would likely reduce the estimated application costs. It is up to future work to find a more accurate way of estimating the application costs for Germany. Second, subsidies from generic R&D programs are not observed which may bias results especially for SMEs and firms located in eastern Germany to whom generic subsidy programs are especially targeted. Third, the model of the R&D subsidy process does neither consider fixed costs of R&D nor external

[27] Recall that the term "spillovers" contains not only knowledge or technology spillovers to other firms but also increase in consumer surplus. In other words spillovers are all the good and bad things from an innovation project that flow to the German economy and are not reflected in the profits of the firm that conducts the innovation project.

finance of R&D, both of which will affect the optimal R&D investment decision of firms and the optimal subsidy rate and application decision. These shortcomings have been incorporated in an enhanced version of the theory model of the R&D subsidy process by Takalo et al. (2013b, 2017) and should guide future research in this area.

References

Aerts, K., and T. Schmidt (2006). Two for the price of one? Additionality effects of R&D subsidies: a comparison between Flanders and Germany. *Research Policy* 37(5), 806-822.

Almus, M., and D. Czarnitzki (2003). The effects of public R&D subsidies on firm's innovation activities. The case of Eastern Germany. *Journal of Business & Economic Statistics* 21(2), 226-236.

Arrow, K. (1962). Economic Welfare and the Allocation of Resources to Invention. In: R. Nelson (ed.), *The Rate and Direction of Incentive Activity*. Princeton: Princeton University Press.

Aschhoff, B. (2009). *The effects of subsidies on R&D investments and innovation success – Do subsidy history and size matter?* ZEW Discussion Paper 09-032, Mannheim.

Aschhoff, B. (2010). Who gets the money? The dynamics of R&D project subsidies in Germany. *Jahrbücher für Nationalökonomie und Statistik* 230(5), 522-546.

Aschhoff, B., M. Astor, D. Crass, T. Eckert, S. Heinrich, G. Licht, C. Rammer, D. Riesenberg, N. Rueffer, R. Strohmeyer, V. Tonoyan, and M. Woywode (2012). *Systemevaluierung „KMU-innovativ"*. ZEW Documentation 12-04.

Blaufus, K., S. Eichfelder, and J. Hundsdoerfer (2011). *The hidden burden of the income tax: Compliance costs of German individuals*. Discussion Paper Freie Universität Berlin, 2011/6.

Bloom, N., M. Schankerman, and J. van Reenen (2013). Identifying technology spillovers and product market rivalry. *Econometrica* 81(4), 1347-1393.

BMBF (2010). *Federal Report on Research and Innovation 2010: Abstract*. BMBF: Berlin.

BMBF (2012). *Bundesbericht Forschung und Innovation 2012*. BMBF: Berlin.

BMBF (2013). Projektträger in der Forschungsförderung. Accessed June 7 2013, http://www.foerderinfo. bund.de/de/262.php.

BMBF (2015). *InnoRegio - Das Programm*. Accessed May 1 2015, http://www.unternehmen-region.de/de/159.php.

Czarnitzki, D., and A. Fier (2002). Do innovation subsidies crowd out private investment? Evidence from the German service sector. *Applied Economics Quarterly* 48(1), 1-25.

Czarnitzki, D., E. Huergo, M. Koehler, P. Mohnen, S. Pacher, T. Takalo, and O. Toivanen (2015). *Shedding light on the R&D subsidy process: Evidence from 5 EU countries*. Unpublished manuscript.

Czarnitzki, D., and K. Hussinger (2017). Input and output additionality of R&D subsidies. *Applied Economics* published online 16 August 2017, 1-18.

Czarnitzki, D., and G. Licht (2006). Additionality of public R&D grants in a transition economy: The case of Eastern Germany. *Economics of Transition* 14(1), 101-131.

Czarnitzki, D., and C. Lopes-Bento (2014). Innovation subsidies: Does the funding source matter for innovation intensity and performance? Empirical evidence from Germany. *Industry and Innovation* 21(5), 380-409.

Creditreform (2013). *The Creditreform Databases*. Accessed 7 June 2013, https://www.creditreform.de/English/Creditreform/About_us/Keys_to_success/Creditreform_databases/index.jsp.

EC (1986). Mitteilung der Kommission – Gemeinschaftsrahmen für staatliche Forschungs- und Entwicklungsbeihilfen. *Official Journal of the European Union* 86/C 83/02 from 11 April 1986, p.2-5.

EC (1996). Mitteilung der Kommission - Gemeinschaftsrahmen für staatliche Forschungs- und Entwicklungsbeihilfen. *Official Journal of the European Union* C045 from 17 February 1996, p.5-16.

EC (2006). Mitteilung der Kommission – Gemeinschaftsrahmen für staatliche Beihilfen für Forschung, Entwicklung und Innovation. *Official Journal of the European Union* 2006/C 323/01 from 30 December 2006, p.1-26.

EC (2013). *Innovation Union Scoreboard 2013*. European Commission, http://ec.europa.eu/enterprise/policies/innovation/files/ius-2013_en.pdf.

Fier, A. (2002). *Staatliche Förderung industrieller Forschung in Deutschland: Eine empirische Wirkungsanalyse der direkten Projektförderung des Bundes*. Nomos Verlagsgesellschaft: Baden-Baden.

Geyer, A., J. Hafkesbrink, and S. Kinkel (2006). *Ex-post Evaluation des Forschungsprogramms "Forschung für die Produktion von morgen" für die Jahre 1999 bis 2004: Endbericht*. Duisburg, Karlsruhe, Wien: ARÖW GmbH, Fraunhofer-Institut für System- und Innovationsforschung, Technopolis.

Hud, M., and K. Hussinger (2015). The impact of R&D subsidies during the crisis. *Research Policy* 44(10), 1844-1855.

Hussinger, K. (2008). R&D and subsidies at the firm Level: An application of parametric and semiparametric two-step selection models. *Journal of Applied Econometrics* 23(6), 729-747.

OECD (2011). *OECD Science, Technology and Industry Scoreboard 2011: Innovation and Growth in Knowledge Economies: Highlights*. OECD Publishing, http://www.oecd.org/sti/sci-tech/48712591.pdf.

Peters, B., G. Licht, D. Crass and A. Kladroba (2009). *Soziale Erträge der FuE-Tätigkeit in Deutschland - Endbericht*. Vorgelegt für die Expertenkommission „Forschung und Innovation". Studien zum deutschen Innovationssystem Nr 15-2009.

Rammer, C. (2012). *Schwerpunktbericht zur Innovationserhebung 2010.* ZEW Dokumentation Nr. 12-03.

Staehler, T., D. Dohse, and P. Cooke (2006*). Evaluation der Fördermaßnahmen BioRegio und BioProfile*. Preetz, Kiel, Cardiff: CIR, IfW, CASS. http://www.e-fi.de/fileadmin/Evaluationsstudien/Evaluation_der_Foerdermassnahmen_BioRegio_und_BioProfile.pdf.

Takalo, T., T. Tanayama, and O. Toivanen (2013a). Estimating the benefits of targeted R&D subsidies. *Review of Economics and Statistics* 95(1), 255-272.

Takalo, T., T. Tanayama, and O. Toivanen (2013b). Market failures and the additionality effects of public support to private R&D: Theory and empirical implications. *International Journal of Industrial Organziation* 31(5), 634-642.

Takalo, T., T. Tanayama, and O. Toivanen (2017). *Welfare effects of R&D support policies*. CPER discussion paper 12155.

Zúñiga-Vicente, J. A., C. Alonso-Borrego, F. J. Forcadell, and J. I. Galán (2014). Assessing the effect of public subsidies on firm R&D investment: A survey. *Journal of Economic Surveys* 28(1), 36-67.

Appendix

Table 8: Regional dummies

Variable	Region
REG1	Bavaria
REG2	Hamburg & Schleswig-Holstein
REG3	Lower Saxony & Bremen
REG4	North Rhine-Westphalia
REG5	Hesse
REG6	Rhineland-Palatinate & Saarland
REG7	Baden-Württemberg
REG8*	Berlin, Brandenburg & Mecklenburg-West Pomerania
REG9*	Saxony & Saxony-Anhalt
REG10*	Thuringia

Note: * Regions in eastern Germany, including West Berlin.

Table 9: Definition of industry dummies

Variable	**Industry**
N1	Chemicals and plastics
N2	Mineral products (metal and non-metal)
N3	Machinery and equipment
N4	Office machinery, electrical machinery, and apparatus
N5	Radio, television, and communication equipment
N6	Medical, precision, and optical instruments
N7	Vehicles and transport equipment
N8	Other manufacturing
N9	Energy, water, and recycling
N10	IT and telecommunication
N11	R&D, architects, and engineers
N12	Other services, construction, and transport

Table 10: Descriptive statistics of regional, industry and year dummies

Variable	Subsidy receivers		Non-subsidy receivers	
	mean	s.d.	mean	s.d.
REG1	0.15	0.35	0.14	0.35
REG2	0.04	0.19	0.04	0.19
REG3	0.08	0.26	0.09	0.29
REG4	0.15	0.36	0.18	0.38
REG5	0.05	0.23	0.06	0.24
REG6	0.04	0.20	0.04	0.19
REG7	0.17	0.37	0.13	0.34
REG8[#]	0.09	0.29	0.10	0.30
REG9[#]	0.18	0.38	0.16	0.37
REG10[#]	0.05	0.23	0.06	0.24
N1	0.10	0.30	0.09	0.28
N2	0.08	0.27	0.12	0.33
N3	0.14	0.35	0.09	0.28
N4	0.05	0.22	0.04	0.20
N5	0.07	0.26	0.01	0.12
N6	0.14	0.35	0.05	0.22
N7	0.06	0.23	0.03	0.18
N8	0.04	0.21	0.18	0.38
N9	0.03	0.16	0.04	0.21
N10	0.08	0.27	0.05	0.22
N11	0.16	0.36	0.08	0.28
N12	0.06	0.24	0.20	0.40
YEAR1994	0.03	0.16	0.03	0.17
YEAR1995	0.02	0.13	0.05	0.22
YEAR1996	0.02	0.14	0.04	0.20
YEAR1997	0.03	0.16	0.03	0.18
YEAR1998	0.02	0.15	0.04	0.21
YEAR1999	0.04	0.20	0.05	0.22
YEAR2000	0.03	0.18	0.05	0.21
YEAR2001	0.08	0.27	0.05	0.21
YEAR2002	0.07	0.25	0.05	0.21
YEAR2003	0.04	0.20	0.06	0.23
YEAR2004	0.06	0.23	0.06	0.23
YEAR2005	0.07	0.25	0.07	0.25
YEAR2006	0.06	0.24	0.06	0.24
YEAR2007	0.08	0.26	0.08	0.27
YEAR2008	0.07	0.25	0.07	0.26
YEAR2009	0.12	0.33	0.09	0.28
YEAR2010	0.11	0.31	0.08	0.27
YEAR2011	0.06	0.23	0.05	0.22
No. of obs.	2,320		88,679	

Notes: [#]Regions in eastern Germany, including West Berlin. Columns with heading s.d. display the standard deviation.

Table 11: Subsidy rate estimation results for years of observation

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
YEAR1994	0.063***	0.034**		
	(0.014)	(0.017)		
YEAR1995	0.022	-0.002		
	(0.015)	(0.017)		
YEAR1996	0.014	-0.014		
	(0.015)	(0.016)		
YEAR1997	-0.002	-0.027*		
	(0.013)	(0.014)		
YEAR1998	0.011	-0.019		
	(0.013)	(0.015)		
YEAR1999	0.012			
	(0.011)			
YEAR2000	-0.001		0.012	
	(0.012)		(0.011)	
YEAR2001	0.015		0.027***	
	(0.009)		(0.008)	
YEAR2002	0.009		0.023**	
	(0.010)		(0.009)	
YEAR2003	0.013		0.020**	
	(0.011)		(0.010)	
YEAR2004	-0.003		0.007	
	(0.010)		(0.009)	
YEAR2005	-0.010			
	(0.010)			
YEAR2006	0.000			-0.001
	(0.010)			(0.010)
YEAR2007	-0.008			-0.008
	(0.009)			(0.010)
YEAR2008	-0.008			-0.010
	(0.010)			(0.010)
YEAR2009	0.002			0.001
	(0.009)			(0.009)
YEAR2010	-0.003			-0.004
	(0.009)			(0.009)
σ_η	0.081***	0.079***	0.075***	0.083***
	(0.001)	(0.003)	(0.002)	(0.002)
Wald	781***	107***	417***	404***
Log likelihood	2313.76	264.64	904.46	1198.65
No. of obs.	2,320	356	813	1,151

Note: Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 12: Subsidy rate estimation results for regions and industries

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
REG2	0.021**	0.031	0.002	0.035**
	(0.010)	(0.030)	(0.015)	(0.015)
REG3	0.014*	0.005	0.035***	0.009
	(0.008)	(0.019)	(0.012)	(0.012)
REG4	0.004	-0.007	0.006	0.005
	(0.006)	(0.016)	(0.011)	(0.009)
REG5	0.005	0.032	0.002	-0.000
	(0.009)	(0.022)	(0.015)	(0.012)
REG6	0.015	0.062*	0.023	0.008
	(0.010)	(0.037)	(0.015)	(0.013)
REG7	0.006	0.017	0.012	0.003
	(0.006)	(0.014)	(0.010)	(0.009)
REG8#	0.031***	0.064***	0.055***	0.008
	(0.007)	(0.021)	(0.011)	(0.011)
REG9#	0.034***	0.060***	0.054***	0.013
	(0.006)	(0.019)	(0.010)	(0.009)
REG10#	0.038***	0.019	0.048***	0.038***
	(0.009)	(0.024)	(0.014)	(0.013)
N2	-0.005	-0.006	-0.011	0.003
	(0.008)	(0.024)	(0.013)	(0.012)
N3	-0.004	0.001	-0.022*	0.006
	(0.007)	(0.018)	(0.013)	(0.010)
N4	-0.003	0.011	-0.016	0.003
	(0.010)	(0.023)	(0.016)	(0.014)
N5	-0.014	-0.016	-0.026*	0.004
	(0.009)	(0.022)	(0.015)	(0.012)
N6	-0.017**	-0.008	-0.022*	-0.014
	(0.007)	(0.021)	(0.012)	(0.010)
N7	0.005	-0.003	-0.012	0.019
	(0.009)	(0.024)	(0.016)	(0.013)
N8	0.008	0.017	-0.004	0.011
	(0.010)	(0.026)	(0.015)	(0.016)
N9	0.028**	0.074**	0.022	0.026
	(0.013)	(0.036)	(0.026)	(0.018)
N10	-0.014*	0.003	-0.016	-0.019*
	(0.008)	(0.038)	(0.014)	(0.011)
N11	0.012	0.030	0.009	0.011
	(0.007)	(0.024)	(0.012)	(0.010)
N12	0.005	0.027	-0.022	0.020
	(0.009)	(0.030)	(0.015)	(0.013)
σ_η	0.081***	0.079***	0.075***	0.083***
	(0.001)	(0.003)	(0.002)	(0.002)
Wald	781***	107***	417***	404***
Log likelihood	2313.76	264.64	904.46	1198.65
No. of obs.	2,320	356	813	1,151

Notes: #Regions in eastern Germany, including West Berlin. Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 13: Application cost function results for years of observation

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
YEAR1994	0.628*** (0.217)	-0.123 (0.203)		
YEAR1995	1.077*** (0.226)	-0.044 (0.254)		
YEAR1996	1.052*** (0.203)	0.016 (0.244)		
YEAR1997	0.106 (0.208)	-0.810*** (0.221)		
YEAR1998	0.725*** (0.185)	-0.308 (0.215)		
YEAR1999	0.862*** (0.174)			
YEAR2000	0.576*** (0.169)		0.545** (0.212)	
YEAR2001	-0.330 (0.236)		-0.677** (0.325)	
YEAR2002	0.163 (0.189)		-0.094 (0.217)	
YEAR2003	0.264 (0.191)		0.350 (0.256)	
YEAR2004	0.385** (0.148)		0.356** (0.174)	
YEAR2005	0.083 (0.140)			
YEAR2006	0.122 (0.153)			0.126 (0.140)
YEAR2007	0.071 (0.150)			0.110 (0.145)
YEAR2008	0.208 (0.145)			0.204 (0.139)
YEAR2009	0.240 (0.180)			0.346* (0.184)
YEAR2010	-0.023 (0.162)			0.045 (0.160)
No. of obs.	90,999	22,419	29,083	39,497

Note: Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 14: Application cost function results for regions and industries

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
REG2	-0.161	0.155	-0.327	-0.128
	(0.171)	(0.442)	(0.329)	(0.215)
REG3	-0.132	-0.040	-0.233	-0.176
	(0.119)	(0.269)	(0.242)	(0.165)
REG4	-0.081	0.098	-0.018	-0.203*
	(0.091)	(0.230)	(0.210)	(0.121)
REG5	0.128	0.699**	0.123	-0.073
	(0.127)	(0.282)	(0.290)	(0.159)
REG6	-0.046	1.039**	-0.400	-0.111
	(0.146)	(0.459)	(0.315)	(0.193)
REG7	0.054	0.214	-0.085	0.019
	(0.083)	(0.189)	(0.220)	(0.117)
REG8[#]	-0.170	0.296	-0.444**	-0.181
	(0.112)	(0.274)	(0.218)	(0.150)
REG9[#]	-0.428***	-0.308	-0.976***	-0.258**
	(0.091)	(0.243)	(0.289)	(0.128)
REG10[#]	-0.094	-0.077	-0.309	-0.075
	(0.150)	(0.349)	(0.282)	(0.151)
N2	-0.070	0.102	-0.210	-0.060
	(0.141)	(0.344)	(0.270)	(0.221)
N3	-0.369***	-0.661*	-0.251	-0.241*
	(0.098)	(0.378)	(0.241)	(0.131)
N4	0.096	-0.627	0.487	0.185
	(0.133)	(0.419)	(0.319)	(0.186)
N5	-0.424**	-0.656	-0.169	-0.392*
	(0.208)	(0.580)	(0.411)	(0.229)
N6	-0.366***	-0.359	-0.493	-0.308*
	(0.142)	(0.416)	(0.346)	(0.165)
N7	-0.170	-0.292	-0.005	-0.138
	(0.131)	(0.423)	(0.363)	(0.187)
N8	-0.179	-0.266	-0.168	-0.403
	(0.251)	(0.381)	(0.331)	(0.497)
N9	-0.155	-1.087*	0.684	-0.264
	(0.201)	(0.652)	(0.543)	(0.250)
N10	-0.176	0.124	-0.441	-0.174
	(0.141)	(0.537)	(0.362)	(0.160)
N11	-0.247*	-0.127	-0.354	-0.212
	(0.149)	(0.433)	(0.316)	(0.165)
N12	0.110	0.375	0.414	-0.119
	(0.181)	(0.485)	(0.363)	(0.244)
No. of obs.	90,999	22,419	29,083	39,497

Notes: [#]Regions in eastern Germany, including West Berlin. Standard errors in parentheses. *p<0.10, **p<0.05, ***p<0.01.

Table 15: R&D investment estimation results for years of observation

	Model (1) 1994-2011	**Model (2)** 1994-1999	**Model (3)** 2000-2005	**Model (4)** 2006-2011
YEAR1994	0.605***	-0.088		
	(0.191)	(0.196)		
YEAR1995	0.836***	-0.207		
	(0.212)	(0.243)		
YEAR1996	0.889***	-0.087		
	(0.184)	(0.238)		
YEAR1997	0.195	-0.673***		
	(0.190)	(0.214)		
YEAR1998	0.576***	-0.418**		
	(0.163)	(0.212)		
YEAR1999	0.837***			
	(0.150)			
YEAR2000	0.519***		0.397**	
	(0.144)		(0.172)	
YEAR2001	0.002		-0.440	
	(0.225)		(0.310)	
YEAR2002	0.358**		0.010	
	(0.168)		(0.185)	
YEAR2003	0.112		0.118	
	(0.177)		(0.229)	
YEAR2004	0.390***		0.276**	
	(0.129)		(0.139)	
YEAR2005	0.172			
	(0.124)			
YEAR2006	0.149			0.143
	(0.134)			(0.134)
YEAR2007	0.157			0.178
	(0.131)			(0.133)
YEAR2008	0.192			0.188
	(0.134)			(0.135)
YEAR2009	0.507***			0.599***
	(0.166)			(0.171)
YEAR2010	0.212			0.271*
	(0.149)			(0.152)
Mills lambda	-0.208	0.571	-1.234	0.137
	(0.521)	(0.898)	(0.996)	(0.654)
R^2	0.186	0.308	0.209	0.170
No. of obs.	2,320	356	813	1,151

Note: Bootstrapped standard errors in parentheses (400 replications). *p<0.10, **p<0.05, ***p<0.01.

Table 16: R&D investment estimation results for regions and industries

	Model (1) 1994-2011	Model (2) 1994-1999	Model (3) 2000-2005	Model (4) 2006-2011
REG2	-0.348**	-0.119	-0.342	-0.395**
	(0.156)	(0.381)	(0.291)	(0.195)
REG3	-0.226**	0.031	-0.294	-0.355**
	(0.107)	(0.274)	(0.200)	(0.161)
REG4	-0.133*	0.038	-0.071	-0.225**
	(0.080)	(0.222)	(0.176)	(0.113)
REG5	0.067	0.551**	0.077	-0.087
	(0.105)	(0.256)	(0.247)	(0.137)
REG6	-0.054	0.634	-0.315	-0.097
	(0.133)	(0.399)	(0.272)	(0.169)
REG7	0.035	0.160	-0.061	-0.016
	(0.072)	(0.180)	(0.183)	(0.101)
REG8[#]	-0.303***	-0.003	-0.513***	-0.278**
	(0.099)	(0.256)	(0.186)	(0.138)
REG9[#]	-0.484***	-0.450*	-0.862***	-0.352***
	(0.083)	(0.235)	(0.265)	(0.118)
REG10[#]	-0.310**	-0.350	-0.468*	-0.266*
	(0.132)	(0.324)	(0.244)	(0.139)
N2	-0.266**	-0.072	-0.221	-0.402*
	(0.132)	(0.322)	(0.223)	(0.216)
N3	-0.308***	-0.328	-0.131	-0.335***
	(0.088)	(0.359)	(0.197)	(0.123)
N4	0.053	-0.416	0.441*	0.050
	(0.118)	(0.381)	(0.267)	(0.169)
N5	-0.004	0.071	0.239	-0.138
	(0.201)	(0.580)	(0.366)	(0.212)
N6	-0.074	0.014	-0.139	-0.087
	(0.137)	(0.398)	(0.314)	(0.152)
N7	-0.225*	-0.006	-0.086	-0.316*
	(0.121)	(0.420)	(0.306)	(0.175)
N8	-0.590**	-0.575	-0.344	-1.030**
	(0.244)	(0.352)	(0.295)	(0.482)
N9	-0.304*	-1.345*	0.392	-0.372
	(0.184)	(0.688)	(0.481)	(0.233)
N10	0.051	0.022	-0.111	0.016
	(0.134)	(0.458)	(0.330)	(0.154)
N11	-0.067	0.158	-0.159	-0.072
	(0.143)	(0.415)	(0.284)	(0.160)
N12	-0.227	-0.046	0.191	-0.511**
	(0.174)	(0.475)	(0.338)	(0.241)
Mills lambda	-0.208	0.571	-1.234	0.137
	(0. 521)	(0.898)	(0.996)	(0.654)
R^2	0.186	0.308	0.209	0.170
No. of obs.	2,320	356	813	1,151

Note: [#]Regions in eastern Germany, including West Berlin. Bootstrapped standard errors in parentheses (400 replications). *p<0.10, **p<0.05, ***p<0.01.