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Do Public Subsidies Add to Private Sector R&D Activity? Microeconometric Evidence for Regional Innovation Policy in East Germany

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Abstract

In this paper we analyse the effect of public subsidies on private sector research and development (R&D) as well as innovation activity for a cross-section of East German firms. We use microeconomic survey data for the federal state of Thuringia from 2003, which captures a broad variety of structural firm-level characteristics as well as detailed information about their intra- and interregional input-output relations. We apply a two-step matching approach that starts by estimating a probit model for programme participation and then uses the obtained propensity score to compare the difference between subsidized and non-subsidized firms for a set of private sector R&D outcome variables. Our empirical results for Thuringia indicate that the subsidized firms on average indeed show higher research activity measured in terms of R&D intensity and patent application. This supports earlier evidence of the additionality of regional innovation policies in the East German economy. Our empirical findings are robust to alternative matching estimators and sub-sample comparisons (e.g. restricting the sample to those firms that are regularly engaged in R&D activity). Finally, given the fact that the East German innovation system is particularly driven by small firms we put a special focus on the effectiveness of the R&D subsidies for this group. Compared to the overall results here the effect is tested to be only weakly significant and seems to be highly heterogeneous for specific sectoral innovation patterns since only matching routines that additionally control for industry classification (in addition to the propensity score) turn out to be significant for firms up to 50 employees.

JEL-Classification: H25, H54, C14, C21

Keywords: Propensity Score Matching, R&D Subsidies, East Germany

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1 Introduction

Our aim is to analyse the effects of public R&D subsidies on private sector R&D activity using regional data for a cross-section of East German firms in Thuringia in 2003. Our motivation is to quantify the impact of R&D subsidies on private sector R&D activity as a major driver of long-run economic growth. Thus, most OECD countries have adopted a variety of R&D policies to promote R&D investments (see OECD, 2003).

In this sense it is of vital interest to look at the additionality of R&D policy programmes both at the national (see e.g. David et al., 2000, Garcia-Quevedo, 2004, for recent surveys) as well as in our case at the regional level. The international evidence on R&D policy evaluation thereby hints at an on average positive stimulus of public subsidies for different private sector target variables such as R&D expenditures and R&D employment (input oriented) as well as innovation activity and patent application (output oriented).

Our study examines the effectiveness of public R&D funding in Eastern-Germany using representative regional data for the Federal State of Thuringia (NUTS1 level) and thus puts our focus to a regional in-depth case study, which has not been analysed so far. As Almus and Czarnitzki (2003) point out, the special situation faced by the East- German economy in the process of economic transformation from a planned to a free market economy brings up some challenging research questions: Although the Eastern German economy and especially its manufacturing sector made considerable progress throughout the last two decades, it still shows some key characteristics of a transition economy with average labour productivity and innovation activity being lower and firm size in Eastern Germany being smaller on average than in the Western part.¹

One of the potential pitfalls for the East German regional system of innovation is the fact that it still shows a very large dependency upon public R&D support: As Ebbing et al. (1999) reported for the mid-1990s, about 60% of all innovating firms in Eastern Germany received public funding - a share which is six times higher than the one for Western Germany. This dependency ratio has not changed much during the past years (see e.g. Rammer & Czarnitzki, 2003, as well as Czarnitzki & Licht, 2006). Compared to the Western German average the share of small and medium-sized enterprises engaged in continuous R&D activity is much higher in East Germany (36 % of all SME relative to 9 % in West Germany) and considering the amount of roughly 1.1 billion per year being spent on R&D subsidies by the federal government, this might be seen as a direct effect

¹While the share of business sector R&D expenditure (BERD) as a share of regional GDP was about 1,9% in West Germany in 2006 it added up to only 1% in the East German economy. The relative share of patent applications per inhabitant in East Germany is only 70% of the Western average. In addition, the average firm size is 87 employees per firm in East Germany compared to 137 in West Germany for the year 2008.

of these subsidies (for details see e.g. Bradley et al. 2006).

Given the high relevance of public support to private sector R&D in the East German economy, analysing its impact on firms' behaviour is a highly prevailing and necessary task. Here we focus on the additionality of public support to private sector R&D activity: Do firms actually increase their R&D efforts or does public funding crowd out private financing? Answering this question is an important step in the identification of the main transmission channels from R&D and innovation output to overall regional growth and development in the case of the regional innovation system in Thuringia. As mentioned above, thereby a special emphasis shall be given to analyse the effectiveness of R&D grants for small firms as they make up a significant part of the regional innovation system in East Germany: Do small firms really increase their R&D efforts – consistent to the findings on medium and large firms – or does public funding crowd out private investment in R&D of small firms? Since our data is the first to be used as regional in-depth case study below the macroregional level for East Germany, this may shed new light on the effectiveness of R&D and innovation policy in the East German states.

The remainder of this paper is organised as follows: In section 2 we briefly review the empirical literature quantifying the impact of public R&D support schemes on the private business sector. We focus especially on recent microeconomic evidence. Section 3 discusses the econometric specification and section 4 presents the regional dataset based on the GEFRA-Business-Survey in Thuringia as well as defines the variables used for estimation. Section 5 reports the main empirical results in analysing the determinants of R&D programme participation and the additionality effect of R&D subsidies measured as the difference in R&D and innovation activity between subsidized and non-subsidized firms for different subsamples (including only those firms running an R&D department as well as small firms with less than 50 employees). This section also tests for the robustness of our results using alternative matching routines. Section 6 then finally concludes.

2 Literature Review

Looking at the empirical literature on public R&D support we can broadly distinguish between macroeconomic studies, dealing with the impact of R&D economic aggregates on the one hand and micro econometric evidence quantifying the effect of R&D subsidies on private research activities on the other hand.² The advantage of investigations at the firm

²At the macro level most of the previous studies find that both private and public R&D are important factors driving economic growth and development (see e.g. Guillec and van Pottelsberghe, 2001 and 2003). For direct subsidization to private sector R&D the empirical literature at the macro level confirms additional effects.

level is the capacity to explicitly identify treated and non-treated firms and to control for industry as well as firm-level heterogeneity. In this sense micro data helps to establish control groups more precisely and thus give a more robust answer with respect to policy programme effectiveness.

Here the empirical evaluation literature is especially interested in answering the question whether the principle of additionality is fulfilled (see e.g. Garcia-Quevedo, 2004). Additionality of a policy programme demands that subsidies to firms really transform into an increase in their research and innovation effort and do not substitute private expenditures. Since from a theoretical point of view we may find arguments for both the complementary as well as the substitutive nature of public R&D subsidies, the answer to this question has to be given carefully in empirical terms with respect to the policy programme under evaluation.³

In an extensive literature survey David et al. (2000) found that econometric results tend to find complementarity between public and private R&D investments. However, the authors also show that the results may vary significantly for different levels of aggregation. In their literature review only 2 out of 14 studies at the macroeconomic level found public R&D funding to crowd out private investments. On the microeconomic level however 9 out of 19 studies found an effect ranging from partial to complete substitution. Similar results were also obtained by Garcia-Quevedo (2004) when performing a meta-analysis for the additionality of public subsidies complementing private sector R&D. The author finds weak statistical support for the tendency to report crowding out effects of public spending at the microeconomic level.

Taking a closer look at the general setup of most evaluation studies the dependent variable of interest is usually private R&D expenditure and employment, R&D intensity (defined as R&D expenditure per employee or value added) and the research question is whether public R&D subsidies succeed in raising private R&D expenditure or influence patenting behaviour. Some studies also use innovation intensity as a dependent variable (number of patents). A wide range of microeconomic tools has been applied to guarantee an appropriate identification strategy from a methodological perspective. The methods range from simple OLS in cross-section or panel data settings to more sophisticated IV regression or Heckman selection models accounting for endogeneity and sample selection bias in the specified equation or system of equations. As a further alternative to stan-

³As Garcia-Quevedo (2004) points out, on the one hand the existence of R&D subsidies could constitute a stimulus to firms to begin R&D or increase its effort, since it is assumed that this leads to a reduce in marginal costs or increases profitability. On the other hand firms may get an incentive to simply shift own financing in favour of public funding for a desired level of R&D activity.

dard OLS regression different non-parametric matching estimators have gained attention during the last decade (see e.g. Heckman et al., 1997, with a reference to job training programmes).

A large bulk of microeconomic studies in the field of public R&D support has emerged during the last decade:⁴ For R&D policy in France (Duguet 2003), Spain (Busom 2000 and Gonzales et al. 2005), Israel (Lach 2002), Germany (Licht and Stadler 2003) and East Germany (Fier 2002, Almus and Czarnitzki 2003 and Czarnitzki and Licht 2006) found positive effects. Kaiser (2004) however found no significant effects in Denmark and Wallsten (2000) even found crowding out effects for the USA.

In the following we will focus on the literature for Germany as benchmark case for our own empirical application: All studies here find positive effects of public grants to stimulate private sector R&D activity - both averaged for the total economy as well as at the industry-level. Czarnitzki and Fier (2002) examine the service sector while most of the research concentrates on manufacturing. Authors like Czarnitzki and Hussinger (2004) also use the obtained results for additional private sector R&D activity due to public grants to estimate a knowledge production function with innovation output as the dependent variable and input-oriented R&D activities (such as R&D expenditures or intensities) as relevant factor inputs. The empirical results indicate that there is indeed a positive transmission channel from public support over private sector R&D input activity to private sector innovation output (e.g. patenting).

Among the few references concentrating on Eastern Germany Fier (2002), Almus and Czarnitzki (2003) as well as Czarnitzki and Licht (2006) find that public R&D support has a significant positive effect on private sector R&D intensity. Using nonparametric matching estimation Almus and Czarnitzki (2003) report an increase in the innovation activity of East German firms receiving public funding of about 4 percentage points on average relative to the non-subsidized control group. In a similar setup Czarnitzki and Licht (2006) compare the degree of additionality in public R&D grants with regard to private sector innovation inputs between the Eastern and Western German economy. The authors find a higher effect in Eastern Germany compared to Western Germany throughout the 1990s, which supports the hypothesis of high absorptive capacities in East Germany during the period of transition. Thuringia is one of the six Federal States in East Germany. Among them, Thuringia is the third leading location for innovation activities in East Germany (after the city-state Berlin and Saxony). Thuringia holds 18 % of all East German patents and its share in total R&D personnel and in total R&D

⁴Here only selected results are reported.

investments amount to 13 % and 18 %, respectively (for a detailed analysis of regional R&D activities in East Germany see e.g. Guenther et al., 2010).

Though the above results seem to be much in line with the international evidence, one potential sensitivity of all studies so far is that they rely on exclusively the same data set: The Mannheim Innovation Panel (MIP) as the German part of the Common Innovation Survey (CIS), which is restricted to firms with more than five employees.⁵ One of the central aims of our study is to check whether the obtained results for East Germany hold, when using an alternative database.⁶ Using micro-data for the German Federal State of Thuringia we are able to reconsider the above described recent findings on East Germany from the perspective of a specific regional innovation system. Both surveys – the MIP and the GEFRA-Business-Survey – ask for the receipt of R&D subsidies from the federal government, the federal state and the European Union so that we cover a complete and exhaustive list of relevant R&D funding programmes. In the next section we turn our methodological approach and then discuss the dataset and the variables used.

3 Econometric Specification

One of the major advantages of the estimation of the treatment effect for a certain policy programme by a matching procedure is the fact that it can be applied to situations of non-random selection into the analysed policy programme (in our case R&D).⁷ The aim is the comparison of firms in the treatment group (firms receiving R&D subsidies) with equivalent firms that did not receive public R&D subsidies. We use the potential outcome framework and assume that there are two potential outcomes, denoted (Y_1, Y_0) , which present situations for persons being with $(D = 1)$ and without treatment $(D = 0)$.

As sketched above, the fundamental problem to overcome is that the counterfactual situation is not observable and non-subsidized firms cannot be observed in the case of an R&D subsidy receipt as $E[Y^0|D = 1]$ with $E(\cdot)$ as the expectational operator. To solve this problem we have to rely on the conditional independence assumption (CIA). Following Rubin (1977) the CIA assumes that the potential outcome (R&D intensity, patenting etc.) is independent from the treatment (receipt of a subsidy) for two individuals with the same structural characteristics X . Although it is not possible to apply a formal test

⁵The MIP has been raised for the manufacturing sectors since 1993, and for the service sectors since 1995 (Janz, Ebling, Gottschalk and Niggemann 2001). Some authors harmonize the MIP with patent information from the German Patent Office (see e.g. Carnitzki & Licht, 2006, as well as Aerts & Schmidt, 2006)

⁶For instance, one possible drawback of the MIP is that it only covers firms with at least five employees (Janz, Ebling, Gottschalk and Niggemann 2001).

⁷Given the limitations in our database with respect to the time dimension here we focus on cross sectional matching estimators. Hausman (2001) finds that matching routines lead to robust results compared to other methods.

for the validity of the CIA, our dataset contains a rich set of firm-level information which make the CIA likely to be fulfilled. We additionally also check for the appropriateness of our model by using balancing tests ex-post to the matching estimation. Assuming that the CIA is true, the causal effect from receiving the subsidy θ can be measured by the outcome-difference between subsidized ($D=1$) and nonsubsidized firms ($D=0$) as

$$\theta = E[Y_1 - Y_0|D = 1] = E[Y_1|D = 1, X = x] - E[Y_0|D = 1, X = x]. \quad (1)$$

The next step is then to find treated and untreated firms showing the same characteristics X . Following Rosenbaum and Rubin (1983) if all variables influencing Y_i (with $i = 0, 1$) are at our disposal, we can consider the CIA to be valid and thus use the so-called propensity score (PS) to reduce the dimension of X since it aggregates the vector of exogenous variables into a single scalar measure. In practical terms the PS is estimated as fitted values of the first step probit model bound on the interval between $[0, 1]$. In this case for firm i with given a set x_i of individual characteristics the propensity score then represents the probability to receive a subsidy $Pr(D_i = 1|X = x_i)$. Compared to the most restrictive case of balancing scores, where the matched firms would need to show identical characteristics, the propensity score is a more relaxed form of matching.

Finally, in order to apply the matching estimator a second assumption has to be fulfilled, the so called stable unit treatment value assumption (SUTVA), which states that individual causal effects may not be influenced by the participation status of other firms (Angrist, Imbens and Rubin 1996). In this case we follow Almus & Czarnitzki (2003) and argue that the presence of such indirect effects, which may alter the relative price for R&D factor inputs, is not likely. The main reason may be seen in the fact that the pricing mechanisms for R&D factor inputs are assumed to be driven by national and international rather than regional factors. R&D input prices should largely be determined by market forces and rather be independent from policy distortions such as R&D subsidies.

Taken together we follow Todd (2007) and set up a prototypical propensity score based matching estimator as

$$\hat{\theta}_M = \frac{1}{n_1} \sum_{i \in I_1 \cap S_{PS}} [Y_{1i} - \hat{E}(Y_{0i}|D = 1, PS_i)] \quad (2)$$

$$\text{with: } \hat{E}(Y_{0i}|D = 1, PS_i) = \sum_{i \in I_1 \cap S_{PS}} W(i, j) Y_{0j}, \quad (3)$$

where I_1 is the set of program participants, I_0 the set of non-participants. S_{PS} is a generally defined region of common support for the propensity score, n_1 is the number

of persons in the set $I_1 \cap S_{PS}$. Then, the match of each programme participant i is constructed as a weighted average over to outcomes of non-participants, where the weights $W(i, j)$ depend on the distance between PS_i and PS_j . As in Todd (2007) we can define a neighbourhood $C(PS_i)$ for each i in the participant sample. Neighbours for i are non-participants $j \in I_0$ for whom $PS_j \in C(PS_i)$. The individuals matched to i are those in set A_i where $A_i = [j \in I_0 | P_j \in C(P_i)]$.

For empirical application we then have to decide, which alternative matching routine should be applied to the prototypical propensity score matching estimator from above. There are several types of matching criteria available, which differ by the use of the weighting functions $W(i, j)$. Most criteria match a treated firm with only a part of the untreated firms like nearest-, k -nearest neighbour and radius matching, while other use a weighted average of some or all control observations available. Among the most common criteria is the nearest neighbour matching estimator. In the group of all potential control units it searches for the control unit j that is most similar to the treated observation i according to the obtained propensity score PS . The resulting weighting function in the nearest neighbour matching can be summarized as

$$W(i, j) = \begin{cases} 1/n_j & \text{for } j \in \min ||PS_i - PS_j||, \\ 0 & \text{otherwise.} \end{cases} \quad (4)$$

Further it is possible to restrict the search for a control unit in terms of a pre-defined tolerance level, which is typically chosen in relation to the standard deviation σ of the propensity score as $\eta \leq |P_i - P_j|$, where η is typically chosen as $\eta = (0.25\sigma_{PS})$. This matching routine based on the restricted propensity score is also referred to as caliper matching and attempts to avoid "bad" matches (that is, where PS_i is far away from PS_j). The caliper matching can be seen as one way to impose a common support restriction. As Todd (2007) points out, one potential drawback of caliper matching is that it is difficult to know a priori what choice for the tolerance level is reasonable. An alternative way to apply a common support is to partition the estimated PS into a set of k intervals and treatment effects are then only calculated within each interval. This matching approach is also known as stratification matching. Here the weighting function is an simple average of $1/n_j$ for $j \in k$.

Other routines like kernel and mahalanobis matching use a weighted matching approach based on averaging procedures of the outcomes for all non-treated units rather than rely on individual neighbour matches. A detailed account of different kernel matching routines is given in Todd (2007). Likewise the mahalanobis metric matching estimator aims at

finding a control that resembles the observation in a balancing score vector X consisting of the propensity score and further variables like industry or firm-size:

$$W(i, j) = \frac{[(X_j - X_i)C_X(X_j - X_i)]^{-1}}{\sum_{k \in C} [(X_k - X_i)C_X(X_k - X_i)]^{-1}}. \quad (5)$$

C_X denotes the variance-covariance matrix of the vector of covariates X . The use of several controls j for each observation i causes the variance to decrease but the potential bias to increase. The more information is used to find a non-treated firm that has the same characteristics as the treated, the better the approach of the counterfactual situation.

The power of these procedures can again be enhanced by applying further options for common support restrictions. As described above the underlying idea is that if every observation is allocated to a control one might match observations that are relatively unequal because of a lack of observations being more similar and this might cause biased results especially in the border regions of the propensity score distribution. In consequence the matching procedure can be restricted to those in the group of PS observations, where also controls are observed in, while treated units whose PS_i is larger than the largest PS_j in the non-treated pool are left unmatched (for details see e.g. Lechner, 2000).

We will apply the k -nearest neighbor estimator as our benchmark empirical tool throughout the estimation exercise and use the other matching routines to check for the robustness of the results. In the following section we will first discuss our empirical database and then present the empirical results for different research and innovation related outcome variables based on propensity score matching.

4 Data and Variable Definition

To assess the impact of direct support measures for R&D and innovation we use data from the GEFRA-Business-Survey (GEFRA et al., 2004 and 2005). This survey was conducted for the evaluation of two direct enterprise support schemes (the "Joint Task for the Promotion of Industry and Trade" offering mainly physical investment grants and the "Promotion of Joint Research Projects" offering R&D grants) on behalf of the Thuringian Ministry of Economics and the Thuringian Ministry of Science, Research and Arts. In the context of the above described evaluation studies the GEFRA contacted a total of 6.861 Thuringian firms in the manufacturing and production-oriented service sector. The return rate was about 21%, so the survey contains a total of 1.484 firms of which 284 firms received public R&D grants. The questionnaire of the GEFRA-Business-Survey refers to

firm-specific data for 2003.⁸

Before we use the data of the GEFRA-Business-Survey we first check for the representativeness of the data. Representativeness thereby expresses the degree to which sample data accurately and precisely represents a population's characteristics. As the target population is known we can test for the samples likelihood to be drawn from that population. Here we are especially concerned about the sectoral distribution as well as distribution by size classes. The latter stems from our particular focus on small firms. Detailed graphical presentations of the distribution of our sample data and the total population of Thuringian firms is given in the appendix. We also test for the deviations of proportions a using a Z-statistic for the sample distribution relative to the overall distribution of the population. Both the graphical presentations as well as the results of our statistical testing approach support the hypothesis of sample representativeness.

The questionnaire of the GEFRA-Business-Survey incorporated different variables representing innovation and economic activity at the firm level. It implicitly relies on a model of a production function. Therefore, data is available for factor inputs of labour, intermediate inputs, and inputs of human and physical capital and for outcome variables such as sales, labour productivity, or number of patents. The explanatory variables to control for programme selection in the first-step probit estimation include input variables that represent (i.) basic information about the firms' research activities, (ii.) the degree of firms' internationalization, (iii.) the skill structure of the workforce, as well as (iv.) standard control variables for observed firm heterogeneity such as firm size and age plus a set of 2-digit industry dummies. In order to account for possible non-normality of the variables' distribution we first log-linearize variables whenever they are not binary or calculated as percentage shares in order to account for the potential problem of heteroscedasticity in the error term.⁹ The full list of continuous and binary variables used to estimate the firms' probability of receiving R&D subsidies is given in the appendix.

With respect to variables representing R&D activity at the firm level the dataset includes a binary dummy variable for general patenting activity (*dpat*), R&D intensity as the ratio of R&D expenditure to sales (*rdint*) as well as alternatively to employees (*rdintb*) and the R&D quota defined as number of R&D employees relative to total employment (*rdquota*). With respect to our treatment variable in the GEFRA-Business Survey firms were asked whether they received funding by any R&D support programmes of the federal

⁸For some variables also additional information for the year 2001 and 2002 is available. Using this information did not change the results though.

⁹For cases where the value on the variable was zero before the log -linearization we replace the log value by the very small number of 0.001.

government, the federal states or the European Union. Since all possible R&D programmes launched by public authorities are covered by the survey this study is not restricted to a particular policy measure but reflects the joined effect of the available set of public R&D policies. Details about the institutional setup of different R&D programmes are given in the appendix. Many studies deal with only one specific public R&D program and cannot control for possible effects of other sources of public R&D funding (Almus and Czarnitzki 2003). In contrast, our approach is able to construct a treatment group consisting of those firms that received subsidies at the regional, national and EU level.

Among the standard firm-specific economic control variables next to firm size in terms of total employment (*size*) we also include the inverse of the firm age (*age*), which might play an important role in receiving R&D subsidies because younger firms might be more likely to receive subsidies in start-up programs to conquer their poor access to the capital market and their lack of own financial capacity. The founding year of a firm usually indicates innovative activity and young firms are expected to be faster in doing their research. Older firms however dispose of a greater experience in R&D and the application for subsidies. We further use the capital-intensity (*capint*) defined as tangible assets per employee to control for the technology used in the production process. We also test for the effect of the investment intensity defined as total investments per sales made in 2003 (*invshare*).

The skill structure of a firm's workforce is an important determinant of research activity and also is likely to influence a firm's ability to attract public funding in a significant way (Kaiser 2004). We thus add the variable *hchigh* indicating the share of highly educated employees, i.e. those who have a university degree or a one of a university of applied sciences, relative to total employment at the firm level. Contrary *hclow* indicates the share of unskilled labour.

The role of competition usually is taken into account by several variables like the *export* and *import* ratio as well as market shares (see e.g. Czarnitzki & Hussinger, 2004, Aertz & Schmidt 2006, Almus & Czarnitzki, 2003 as well as Licht & Stadler, 2003). On a firm bases we use the ratio of inputs from the region within thirty kilometers around the firm *inregn*, the rest of Thuringia *inthrg*, East Germany *ineast* and West Germany *invest* to all inputs as well as the same output variables in relation to all sales in order to capture international activity as an indicator for competitiveness and regional embeddedness. One might assume that exporting firms are more likely to face innovative pressure due to international competition and are in consequence more likely to receive R&D subsidies. On the other hand it might be a specific motive for policy makers to foster R&D activities of small Thuringian firms without a parent enterprise outside the

region in order to strengthen the regional firm base.

With respect to the set of binary dummy variables we include the following variables: First, we define a measure for the legal form of each firm (*dlbty*), which turns to be 0 in the case of limited liability and 1 for the remaining legal forms (i.e. joint partnerships). Our ex-ante theoretical expectation is that firms with limited liability are more likely to receive public funding, because the government will verify the existence of an operating industrial plant. As all firms have to prove their existence and those with a liability limiting legal form in Germany have to be recorded in the trade register while other legal forms do not, and ministry officials might take risk-averse decisions, liability limiting firms might be more likely to receive public funding. Further dummy variables indicate the affiliation to a parent company: Here we classify firms as belonging to a proprietary company either in West Germany (*dwgroup*), East Germany (*deast*) or abroad (*dforeign*) compared to self-contained firms. We assume that firms with a parent company might have better access to information and experience in applying for subsidies.

Finally, the questionnaire asks whether the firm was doing research regularly and is running an own R&D department (*drddpmt*).¹⁰ This latter variable should particularly reflect the absorptive capacity and R&D experience in a firm. We expect those firms to be innovative and more likely to receive R&D subsidies. The pool of binary variables is completed by the dummy variable to indicate the receipt of an R&D subsidy (*drd*), which covers the whole range of regional, national and supranational R&D programmes as discussed above, and a set of sector dummies (*dind15* to *dind72*). Finally, we further constructed dummy variables for size classes with firms with up to 20, 50, 250 and more than 250 employees. As motivated above, we are particularly interested in quantifying the impact on small firms. Descriptive statistics for the variables used in the empirical analysis are given in appendix.

5 Empirical Results

In order to identify the effects of R&D policies for firms in Thuringia as the difference between the average outcome of the treated and untreated units of observation based on propensity score matching, we first calculate the propensity score through a binary

¹⁰Concerning the question of the frequency of R&D (*drdact*) being conducted, the GEFRA-Business-Survey asks whether a firm is either "regularly", "sporadically" or "not at all" engaged in own R&D activities. When using this variable for the propensity score estimate there is of course the potential risk of endogeneity, however we assume that the impact of a subsidy is not that big that a firm would actually change its structural behaviour. This is even more reasonable for the case of an R&D department (*drddpmt*). We thus take the latter variable as default proxy for regular R&D activity at the firm level.

response model for programme participation. We choose a probit estimation to do so. The obtained linear index can then be used as input in the second step matching algorithm. Our resulting model specification for the probability of a firm to receive subsidies depending on firm specific characteristics is reported in table 1. In order to check for the proper specification of the probit model we interpret the estimated coefficients with respect to our a-priori theoretical expectations and take into account whether the balancing properties of the model are fulfilled. As table 1 shows, the probability to receive an R&D subsidy, is most importantly influenced by the question whether a firm permanently runs an R&D department *drddpmt* and by the share of highly skilled workers. For both variables we get the a-priori expected significant positive effect. Firms with an increasing share of low skilled workers *hclow* have a significantly lower probability of receiving R&D funding.

The inverse of the firm's age has a significantly negative influence on the probability to receive subsidies. The younger the firm is the lower is its probability to receive a subsidy. Firms that are affiliated to West German enterprises also have a significantly lower probability to receive public grants. As discussed above this may indicate that the programme is especially designed to strengthen the endogenous knowledge base in East Germany and thus firms that have a higher probability of doing sustainable research and development in Thuringia. The variables for input linkages show that strong regional input-ties increase the probability of receiving R&D subsidies. This may indicate the role of regional embeddedness for joined research projects might improve chances for the receipt of R&D funding and innovation activity. Looking at the output linkages we see that contrary to inputs, a higher proportion of regional sales relative to total sales lower the probability of receiving funding. This in turn may indicate that regionally operating firms are in general less innovative compared to nationally or internationally operating enterprises. We further included industry dummies that show a statically significant heterogeneity among sub-sectors to receive R&D subsidies. We use as simple Wald-test to prove the joined significance of the industry dummies.¹¹

We also test for differences in the behavioural parameter coefficients of differently sized firms by adding interaction terms of key variables in the probit specification (like firm age, capital, R&D department, human capital and input-output linkages) and a dummy variable for firms with less than 50 (*dsize* < 50). The results in table 1 however show, in terms of the R^2 criterion the augmented specification improves the fit only marginally by the inclusion of the interaction terms. Most of the coefficients turn out to be insignificant, except for the variable of high skilled labour input. The latter may indicate

¹¹For brevity the industry dummies are not reported here, results can be obtained from the authors upon request.

that conditional on the generally positive effect of highly skilled labour on the probability of receiving R&D grants this effect is smaller for small firms. However, we have to be very careful in interpreting these regression coefficients (and their significance) in non-linear models as e.g. shown by Ai & Norton (2003). To sum up, the interaction effects do not seem to significantly improve the probit specification and we use the parsimonious form disregarding the interaction effects for computing the matching estimators. This result is finally also confirmed jointly by a likelihood ratio test for the validity of the parameter restrictions indicating that the coefficients of the interaction term do not statistically differ from zero.

Using the fitted values from the probit specification we first run a robust matching routine – the k -nearest neighbour matching algorithm with replacement and $k = 5$ – for the R&D intensity (R&D expenditures relative to total firm turnover) and a binary dummy for any patent application in 2003. Since we are dealing with rather small numbers of observations we compute bootstrapped standard errors (SE) for statistical inference. We tried both bootstrapping for just the second step of the matching estimator as well as simultaneously bootstrapping for both steps including the first step probit estimation. We set the number of bootstrap replications equal to 500. Since both empirical approaches yield similar results we only report coefficients for the second step bootstrapped standard errors. Compared to the results with standard errors based on asymptotically normal statistical inference (not reported, results upon request) the bootstrapped SE are somewhat more restrictive and may thus be seen as the more conservative benchmark in evaluating programme effectiveness. The idea of using bootstrapped SE is to account for the extra variation, which is added well beyond the normal sampling variation by the estimation of the propensity score and the application of the non-parametric matching procedure. Lechner (2002) suggests that bootstrapping is a convenient way to remove this bias.¹² The results for the 5-nearest neighbour matching approach are shown in table 2.

First we look at the effect for the full sample. Here get evidence for a significant positive difference between the R&D activity of treated and control firms. This is an important finding since R&D subsidies do not seem to lead to a pure substitution effect, but instead lead to higher R&D intensities and patenting activity. Regarding the R&D intensity our estimation results show that the average R&D activity of treated firms relative to the control group is about 10 percentage points higher. Almus and Czarnitzki

¹²Nevertheless, Imbens (2004) notes that there is so far little formal evidence to justify bootstrapping.

Table 1: Estimation results of the binary Probit model for R&D programme participation

Dep. Var.: <i>drd</i>	Coef.	Sign.	Coef.	Sign.
	Model 1		Model 2	
<i>log(size)</i>	-0.16		-0.01	
<i>log(1/age)</i>	-0.30	**	-0.12	
<i>log(capint)</i>	-0.06		-0.07	
<i>invshare</i>	-0.001		-0.001	
<i>hchigh</i>	2.31	***	4.12	***
<i>hclow</i>	-1.19	*	-1.37	*
<i>ouregn</i>	-0.01	**	-0.02	
<i>outeast</i>	-0.001		0.002	
<i>outwest</i>	-0.004		0.01	
<i>export</i>	-0.002		-0.001	
<i>inregn</i>	0.01	**	0.01	
<i>ineast</i>	0.01	*	0.01	
<i>inwest</i>	0.003		0.002	
<i>import</i>	0.01	*	0.01	
<i>dlbty</i>	0.26		0.23	
<i>dwgroup</i>	-0.50	**	-0.63	***
<i>dforeign</i>	-0.31		-0.30	
<i>deast</i>	-0.15		-0.23	
<i>drddpmt</i>	1.29	***	1.29	***
<i>dsize</i> < 50 × <i>log(1/age)</i>			-0.30	
<i>dsize</i> < 50 × <i>log(capint)</i>			-0.02	
<i>dsize</i> < 50 × <i>log(invshare)</i>			-0.002	
<i>dsize</i> < 50 × <i>log(hchigh)</i>			-1.96	*
<i>dsize</i> < 50 × <i>log(ouregn)</i>			0.004	
<i>dsize</i> < 50 × <i>log(outeast)</i>			-0.004	
<i>dsize</i> < 50 × <i>log(outwest)</i>			-0.02	
<i>dsize</i> < 50 × <i>log(export)</i>			0.002	
<i>dsize</i> < 50 × <i>log(inregn)</i>			0.004	
<i>dsize</i> < 50 × <i>log(ineast)</i>			0.005	
<i>dsize</i> < 50 × <i>log(inwest)</i>			0.004	
<i>dsize</i> < 50 × <i>log(import)</i>			0.01	
<i>dsize</i> < 50 × <i>log(drddpmt)</i>			0.02	
<i>dsize</i> < 50			-0.13	
<i>N</i>	529		529	
<i>Pseudo R</i> ²	0.35		0.37	
<i>Log likelihood</i>	-206.67		-197.74	
<i>LR – test</i> All $\chi^2(36)$	221.1	***	239.1	***
<i>LR – test</i> Interaction $\chi^2(14)$			19.61	
$\sum_{i=15}^{74} d_{ind_i} \chi^2(11)$	59.8	***	33.1	***

Note: ***, **, * = denote significance levels at the 1%, 5% and 10% level respectively. Coefficient results of the sector dummies are skipped for brevity and can be obtained from the authors upon request.

Table 2: Propensity score based k-nearest neighbour matching for R&D activity

	All Firms		R&D Department		Small Firms (< 50)	
$k = 5$	R&D intensity	Patent activity	R&D intensity	Patent activity	R&D intensity	Patent activity
$\hat{\theta}$	0.11	0.17	0.11	0.18	0.15	0.08
SE	0.052	0.067	0.069	0.086	0.095	0.096
Test statistic	2.01**	2.57**	1.71**	2.10**	1.58	0.85
No. Treated	145	150	106	110	77	83
Total	515	524	185	193	300	309

Note: ***, **, * = denote significance levels at the 1%, 5% and 10% level respectively. We present bootstrapped standard errors are calculated based on 500 repetitions for the second-step matching estimation, while the first step probit estimation for the propensity score was held fixed.

(2003) found the R&D intensity to differ by roughly 4 percentage points for subsidized firms in East Germany between 1996 and 1998. Our results found for the Thuringian system of innovation are thus somewhat higher compared to studies on the average effect for East Germany. Given the rather good position of Thuringia within the East German macro-region our obtained results seems to be quite plausible. The results are qualitatively supported by standard OLS regression for R&D activity with a treatment dummy for the receipt of R&D subsidies as additional right hand side regressor. Results for different specifications can be found in the appendix. As an alternative variable we also look at the binary dummy variable for any patent application in 2003. Here the results in table 2 show that the probability that a treated firm applies for any patent is 17% higher compared to the control group.

As the probability to receive subsidies rises for firms who have an R&D department we then also restrict the sample to cover only those firms. This makes the comparison to the control group tougher, but at the same time we lose a large part of our observations which might have an disadvantageous impact on the results. However, the results show that even for this more competitive control group R&D subsidies are found to have an additional effect of roughly the same size as compared to the overall sample.

As the East German system of innovation especially rests on the research and innovation activity of small enterprises and many of the R&D programmes are especially designed to foster the research activity of these firms. Thus we calculate the effects on small firms with less than 50 employees. For both variables the effect is of the same direction as for the other samples, nevertheless the difference between treated and control group is found to be statistically insignificant.

As a first check for the robustness of our results we perform a mean comparison for the explanatory variables used in our sample. This allows us to see whether the estimations

have been successful in terms of balancing differences for the set of covariates. The results for the sample of all firms and the binary variable for patent activity are reported in table 3. The test searches for a statistical significance of differences in the mean of the variables based on a two-tailed t-test between the supported firms (Treated) and either firms from the potential control group (Unmatched) or from the selected control group (Control). The results shows that the $k = 5$ nearest neighbour based propensity score matching is able to successfully control for differences between the treated and the control group. For the sample before matching the null hypothesis of equality in the means could be rejected for key variables such as the existence of an R&D department, the share of high skilled workforce, age, capital intensities and input-output linkages among others.

Table 3: Mean comparison of subsidized firms, firms without subsidization and selected control group based on the k-nearest matching procedure ($k = 5$) for $dpat$

Variable	Treated	Unmatched	Sign.	Control	Sign.
PS	0.55	0.17	***	0.055	
$\log(size)$	3.61	3.56		3.76	
$\log(ageinv)$	-2.27	-2.17	*	-2.34	
$\log(capint)$	3.27	3.57	**	3.27	
$invshare$	0.09	0.47		0.07	
$hchigh$	0.34	0.15	***	0.29	
$hclow$	0.03	0.07	***	0.04	
$outregn$	0.11	0.18	***	0.08	
$outeast$	0.12	0.11		0.13	
$outwest$	0.42	0.44		0.43	
$export$	0.25	0.15	***	0.27	
$inregn$	0.19	0.18		0.17	
$ineast$	0.12	0.12		0.15	
$inwest$	0.41	0.44		0.41	
$import$	0.14	0.11		0.14	
$dlbty$	0.06	0.09		0.03	
$dwgroup$	0.14	0.18		0.17	
$dforeign$	0.06	0.06		0.05	
$deast$	0.03	0.03		0.01	
$drddpmt$	0.73	0.22	***	0.75	

Note: ***, **, * = denote significance levels at the 1%, 5% and 10% level respectively. Statistical significance was tested in a two-tailed t-test between the supported firms (column 2) and either firms from the total of controls (column 3) or from the selected control group (column 4). Results for industry dummies upon request.

Given the fact that the nearest neighbour matching routine is a somewhat conservative estimator, we run a set of alternative matching routines on the binary dummy for patenting activity ($dpat$) in table 4 to check for the robustness of the results. The procedures we run are $k = 5$ nearest-neighbour matching with an additional caliper restriction in terms of one fourth of the standard error of the bounded propensity score, as well as

stratification and kernel based matching (with different bandwidths). Finally we also apply Mahalanobis metric distance matching, which has the major advantage that it allows to include additional information to match treated and control observation apart from the propensity score (such as the 2-digit industry classification and firm size categories). All the procedures are subject to the common support restriction as described in detail throughout the econometric specification section.

The matching results in table 4 show that the estimated coefficient for the whole sample varies from 17 to 21 % being highly significant for all matching routines. The results thus support our interpretation that the various sources of R&D funding for Thuringian firms significantly increase the probability of applying for any patent registration. The subsample of firms regularly engaged in R&D show a broader variation in the effect: 15 to 23 %. However we get slightly bigger standard errors for our oint estimator. For the subgroup of small firms with less than 50 employees the effectiveness of R&D subsidies is tested to have weaker statistical grounds for our Thuringian case study. However, the Mahalanobis metric distance approach shows that the results turn significant when additionally controlling for 2-digit industry heterogeneity (above the propensity score). This may indicate that different sectoral innovation trajectories are highly important for small firms. This result is also supported by our benchmark OLS estimates for small firms presented in the appendix.

Table 4: Sensitivity analysis for $dpat$

Bootstrapped SE						
Dep. Var.: $dpat$	5-NN Caliper	Stratification	Kernel		Mahalanobis	
	$\eta = 0.25 \times \sigma_{PS}$	$blocks = 7$	$bw = 0.06$	$bw = 0.12$	$PS, Industry$	$PS, Ind, Size$
All Firms						
$\hat{\theta}$	0.20	0.18	0.17	0.18	0.18	0.21
SE	0.063	0.067	0.063	0.073	0.075	0.068
Test statistic	3.19***	2.57***	2.6***	2.85***	2.47**	2.87***
No. Treated	150	152	147	147	150	150
No. Total	524	434	521	521	524	524
Firms with R&D Department						
$\hat{\theta}$	0.17	0.15	0.17	0.17	0.23	0.18
SE	0.077	0.086	0.084	0.079	0.091	0.101
Test statistic	2.30**	1.80*	2.06**	2.15**	2.47**	1.77*
No. Treated	110	112	110	110	110	110
No. Total	83	75	83	83	83	83
Small Firms						
$\hat{\theta}$	0.14	0.12	0.08	0.12	0.21	0.23
SE	0.079	0.109	0.094	0.096	0.101	0.094
Test statistic	1.86*	1.06	0.93	1.24	2.12**	2.42**
No. Treated	83	83	83	83	83	83
No. Total	309	242	309	309	309	309

Note: ***, **, * = denote significance levels at the 1%, 5% and 10% level respectively. For the kernel matching we use the Epanechnikow kernel as default, where bw is the chosen bandwidth. PS denotes Propensity Score.

6 Conclusion

We analyse the role of public support to private R&D activity for a large cross-section of firms in Thuringia in 2003. Using a representative regional dataset our results may be seen as a crucial robustness check for earlier empirical work on East Germany (see e.g. Almus & Czarnitzki, 2003). Our results based on a propensity score matching approach confirm the positive policy effects on private R&D activity already found in previous work. The estimated models show that subsidized firms for instance have an on average around 10 to 11 percentage points higher R&D intensity compared to non-subsidized firms. This effect is larger than the 4 percentage points found by Almus and Czarnitzki (2003) for the total East German economy between 1996 and 1998. Given the rather good position of Thuringia within the East German system of innovation this higher additionality effect hints to a higher absorptive capacity of Thuringian firms compared to the East German average.

The same qualitative result is also found for other outcome variables such as the intensity of R&D as well as patenting activity. The results for the overall sample also hold,

if we apply different matching routines. We are especially interested to analyse whether subsidies still add to private R&D inputs when restricting the sample to those firms that are regularly engaged in R&D activity (proxied by running an own R&D department). Moreover, given their special role in the East German system of innovation we put a focus on the effectiveness of the R&D subsidies for small firms. While the results for firms with an own R&D department mirror the overall results, the quantitative effect for small firms is tested to be only weakly significant. The additionality effect seems to be highly heterogeneous for different sectoral innovation patterns since only matching routines that additionally control for industry classification (above the propensity score) turn out to be significant.

Looking at the results of the probit estimation for programme selection of Thuringian firms we additionally find that the share of highly skilled workforce, the permanent engagement in R&D activity through an R&D department, specific input-output linkages as well as the age of the firm are important determinants of the probability to receive R&D subsidies. In sum, the obtained results support the complementary nature of public subsidies concerning private sector R&D activity in the regional innovation system of Thuringia. This result could help policymakers optimize government spending. However, though the effectiveness of R&D subsidies is indicated, further research effort should be devoted to the analysis of its efficiency. Additionally the link between innovation input/output on the one hand and overall regional growth and development on the other hand should further be investigated.

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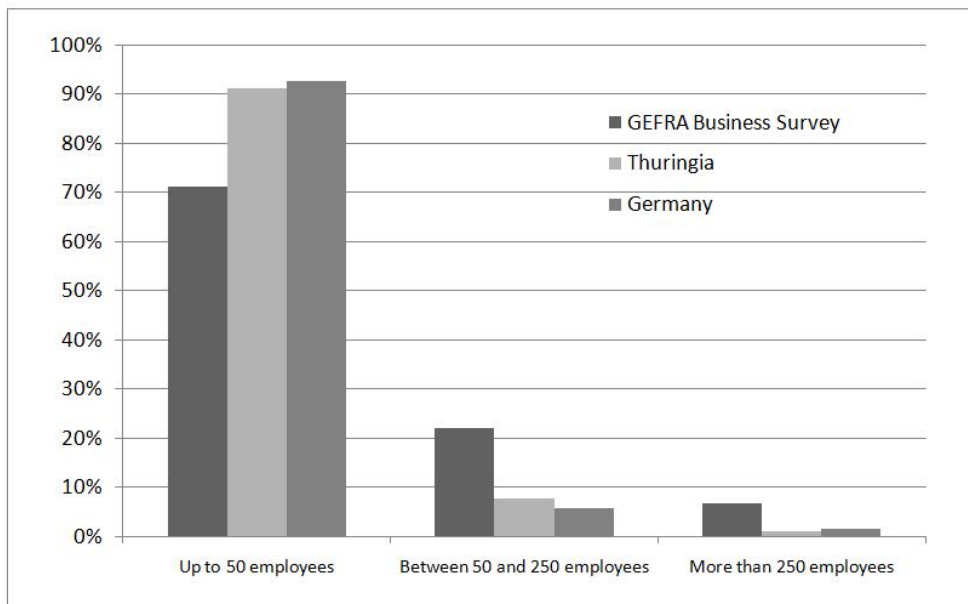
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A Testing for Sample Representativeness

Testing sample representativeness is an important pre-condition for empirical estimation. We use both graphical and statistical approaches to check for the representativeness of the GEFRA-Business-Survey. To start with, figure A.1 plots the proportion of firms for the size classes "up to 50 employees", "between 50 and 250 employees" as well as "more than 250 employees" in the GEFRA Business-Survey as well as the total population of firms in the Manufacturing Sector in Thuringia for the year 2003. As the figure shows, though the response rate of small firms in the survey is somewhat smaller than for the two firm populations in Thuringia and Germany, however the GEFRA Business-Survey still covers a large number of small firms with up to 50 employees. Further information about the samples representativeness can be found in the appendix. Additionally, figure A.2 plots the proportion of firm for each 2-digit manufacturing subsector relative to the total manufacturing sector for both the sample distribution and the total population of all firms in Thuringia for the year 2003. As the figure shows the sample distribution closely follows the pattern of the total population of Thuringian employees in decending order of their relative importance.

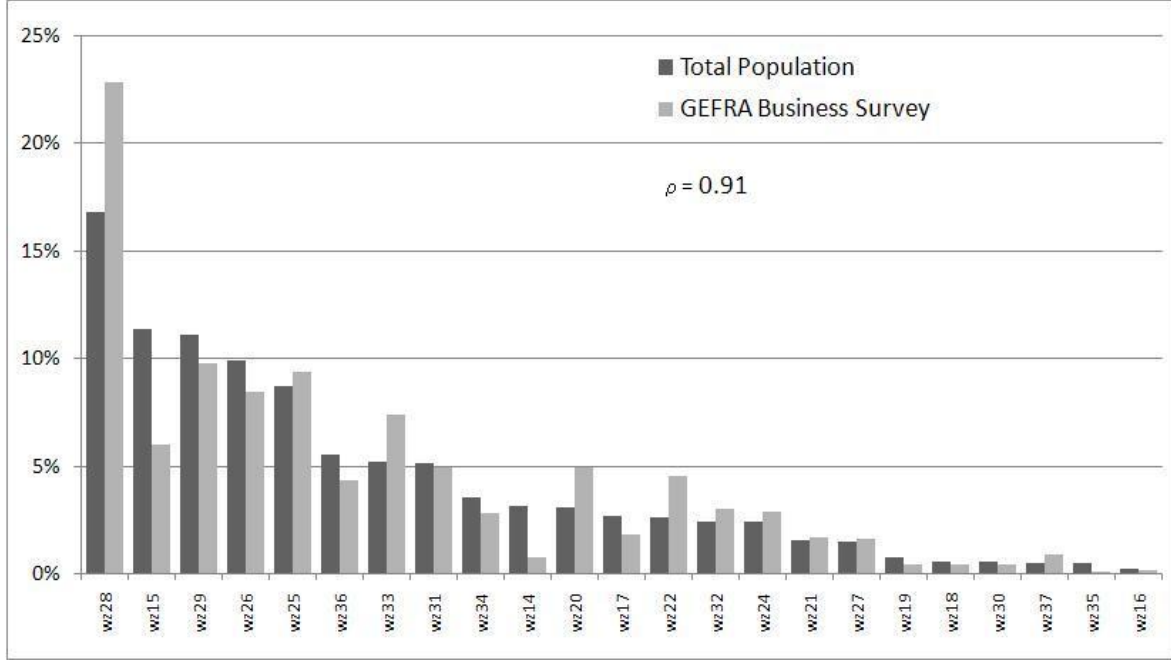
Figure A.1: Proportions of Firms by Size Class



Source: Data from the German Statistical Office, GEFRA-Business Survey 2004.

Next to the above described descriptive statistics we also test for sample deviations

Figure A.2: Proportions of firms per 2-digit Manufacturing subsectors



Source: Data from the German Statistical Office, GEFRA Business-Survey 2004.

Note: Based on 2-digit Manufacturing Sector data for the year 2003.

from the total population using a standard Z-statistic based test, which compares the sample distribution relative to the overall distribution of the population. Since the total population of Thuringian Manufacturing Sector firms in 2003 is known the proportion based test is given by:

$$Z = \frac{\rho - P}{\sigma_\rho}, \quad (6)$$

where ρ is the sample population proportion, P is the population proportion and σ_ρ is the standard error of the proportion given by $\sigma_\rho = \sqrt{\frac{P(1-P)}{n}}$, where n is the number of observations in the respective (sub-)sample. We apply the test for for sample and population proportions of each 2-digit industry. Table A.1 plots the respective sector shares together with the standard error of the sample proportion and the corresponding Z-statistic. As the results show, the Z-statistic indicates a statistically significant deviation of the sample distribution from the overall population only for one single sub-sector, WZ28 "Manufacture of fabricated metal products, except machinery and equipment" being overrepresented in the GEFRA Business-Survey. However, taken together the results support the representativeness of our survey data.

Table A.1: Test for Sample Representativeness based on Manufacturing Sector Firm Data

WZ Code	Pop.	Share Pop.	Sample	Share Sample	σ_s	Z-Statistic
14	59	3,15 %	10	0,76 %	0,06	-0,43
15	213	11,38 %	79	6,04 %	0,04	-1,50
16	4	0,21 %	2	0,15 %	0,03	-0,02
17	51	2,73 %	24	1,83 %	0,03	-0,27
18	11	0,59 %	6	0,46 %	0,03	-0,04
19	14	0,75 %	6	0,46 %	0,04	-0,08
20	58	3,10 %	65	4,97 %	0,02	0,87
21	29	1,55 %	22	1,68 %	0,03	0,05
22	49	2,62 %	60	4,58 %	0,02	0,95
23	0	0,00 %	0	0,00 %	0,00	0,00
24	45	2,41 %	38	2,90 %	0,02	0,20
25	163	8,71 %	123	9,40 %	0,03	0,27
26	186	9,94 %	111	8,48 %	0,03	-0,51
27	28	1,50 %	21	1,60 %	0,03	0,04
28	314	16,78 %	299	22,84 %	0,02	2,80***
29	208	11,12 %	128	9,78 %	0,03	-0,48
30	11	0,59 %	6	0,46 %	0,03	-0,04
31	96	5,13 %	65	4,97 %	0,03	-0,06
32	46	2,46 %	40	3,06 %	0,02	0,24
33	97	5,18 %	97	7,41 %	0,02	0,99
34	66	3,53 %	37	2,83 %	0,03	-0,23
35	9	0,48 %	1	0,08 %	0,07	-0,06
36	104	5,56 %	57	4,35 %	0,03	-0,40
37	10	0,53 %	12	0,92 %	0,02	0,18

Note: ***, **, * = denote significance levels at the 1%, 5% and 10% level respectively. The test is based on the sectoral proportion of employees in the total population and sample proportion. For details about the applied Z-statistic see text.

B Variable Definition and Descriptive Statistics

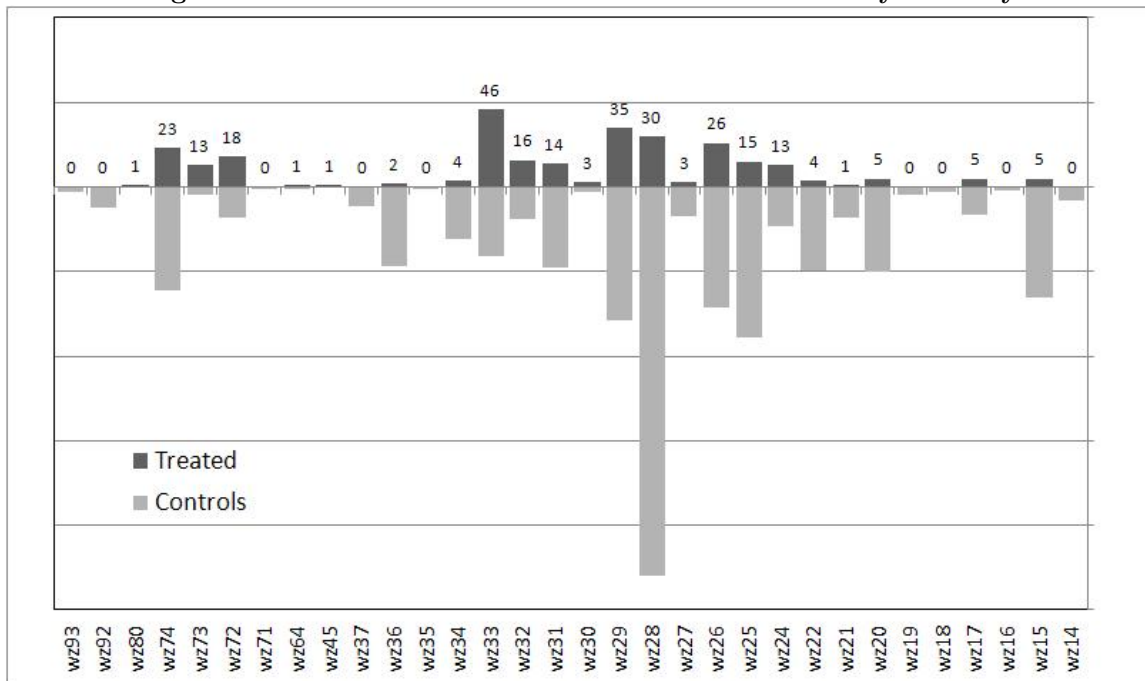
Table A.2: Variable definition

Variable		Description
Variables measuring R&D activity		
<i>dpat</i>	=1	if firm has applied for patent registration during the years 2001 to 2003
<i>pat</i>		Total number of patents obtained by firm during the years 2001 to 2003
<i>rdint</i>		R&D intensity defined as R&D expenditures relative to total turnover (net of intermediate inputs) in 2003
<i>rdintb</i>		R&D intensity defined as R&D expenditures (in 1000 Euro) relative to the number of all employees in 2003
<i>rdquote</i>		R&D quote defined as the number of R&D employees relative to the number of all employees in 2003
Treatment variable		
<i>drd</i>	=1	if firm received a subsidy either from the federal state Thuringia, national or EU wide programmes; 0 otherwise
Standard firm specific control variables and skill structure		
<i>size</i>		Firm size in terms of total employment
<i>age</i>		Number of years since firm was created, relative to 2004
<i>capint</i>		Capital intensity defined as total capital stock per employees
<i>inputquot</i>		Input quote defined as inputs divided by sales
<i>invshare</i>		Investment intensity defined as total investment per sales in 2003
<i>hchigh</i>		Share of high skilled employees as share of total employment
<i>hclow</i>		Share of low and (un-)skilled employees as share of total employment
Internationalization and regional input-output relations		
<i>import</i>		Import share defined as imports relative to total inputs, in %
<i>inregn</i>		Input from suppliers within the core region (30km) relative to total inputs, in %
<i>ineast</i>		Input from suppliers from East Germany relative to total inputs, in %
<i>inwest</i>		Input from suppliers from West Germany relative to total inputs, in %
<i>export</i>		Export share in percent, defined as total exports relative to sales, in %
<i>outregn</i>		Sales within the core region (30km) relative to total sales, in %
<i>outeast</i>		Sales within East Germany relative to total sales, in %
<i>outwest</i>		Sales within West Germany relative to total sales, in %
Binary dummy variables		
<i>dlbty</i>	=1	if firm owner has full legal liability, 0 for limited liability
<i>dwgroup</i>	=1	if firm belongs to a parent company in West Germany
<i>dforeign</i>	=1	if firm belongs to a parent company abroad
<i>deast</i>	=1	if firm belongs to a parent company in East Germany
<i>dsmall</i>	=1	if firm has less than five employees
<i>drddpmt</i>	=1	if firm has R&D employees within a fixed R&D department

Table A.2 (continued): Variable definition

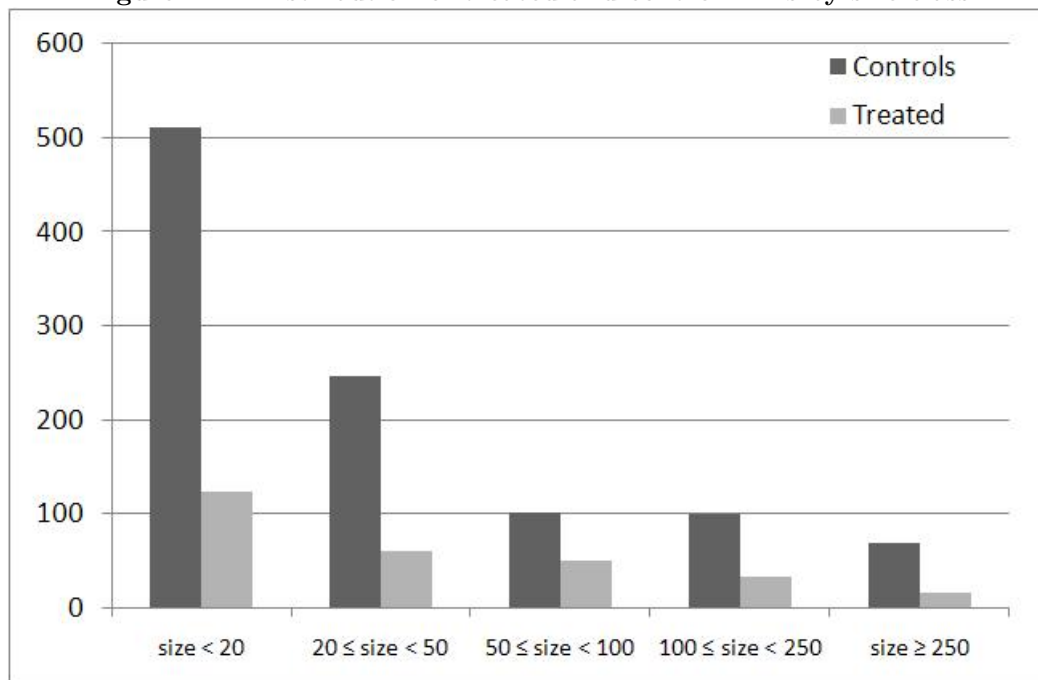
Variable		Description
Sizes Classes		
<i>dsize</i> < 20	=1	if the firm has less than 20 employees; 0 otherwise
<i>dsize</i> < 50	=1	if the firm has between 20 and 50 employees; 0 otherwise
<i>dsize</i> < 100	=1	if the firm has between 50 and 100 employees; 0 otherwise
<i>dsize</i> < 250	=1	if the firm has between 100 and 250 employees; 0 otherwise
<i>dsize</i> > 250	=1	if the firm has 250 or more employees; 0 otherwise
2-digit Industry dummies		
<i>dind15/16</i>	=1	if firm belongs to industry 15 and 16 according to the German classification of Economic Activities WZ2008 (Manufacture of food products and beverages and tobacco products)
<i>dind17/19</i>	=1	if firm belongs to industry 17 to 19 Manufacture of textiles, of wearing apparel; dressing and dyeing of fur; Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear)
<i>dind20</i>	=1	if firm belongs to industry 20 (Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials)
<i>dind21/22</i>	=1	if firm belongs to industry 21 and 22 (Manufacture of pulp, paper and paper products; Publishing, printing and reproduction of recorded media)
<i>dind24</i>	=1	if firm belongs to industry 24 (Manufacture of chemicals and chemical products)
<i>dind25</i>	=1	if firm belongs to industry 25 (Manufacture of rubber and plastic products)
<i>dind26</i>	=1	if firm belongs to industry 26 (Manufacture of other non-metallic mineral products)
<i>dind27/28</i>	=1	if firm belongs to industry 27 and 28 (Manufacture of basic metals; of fabricated metal products, except machinery and equipment)
<i>dind29</i>	=1	if firm belongs to industry 29 (Manufacture of machinery and equipment n.e.c.)
<i>dind30/33</i>	=1	if firm belongs to industry 30 to 33 (Manufacture of office machinery and computers; of electrical machinery and apparatus n.e.c.; of radio, television and communication equipment and apparatus; and of medical, precision and optical instruments, watches and clocks)
<i>dind34/35</i>	=1	if firm belongs to industry 34 and 35 (Manufacture of motor vehicles, trailers and semi-trailers; of other transport equipment)
<i>dind36/37</i>	=1	if firm belongs to industry 36 and 37 (Manufacture of furniture; manufacturing n.e.c.; recycling)
<i>dind72/74</i>	=1	if firm belongs to industry 72 to 74 (Computer and related activities; Research and development; Other business activities)

Figure A.3: Distribution of treated and control firms by industry



Note: For the definition of different industry dummies used see table 2.

Figure A.4: Distribution of treated and control firms by size class



Note: For the definition of different size classes used see text.

Table A.3: Descriptive Statistics for continuous variables

Variable	N	Mean	Std. Dev.	Min	Max
<i>rdint</i>	1265	0.047	0.24	0	6.6
<i>rdintb</i>	1345	2.68	8.09	0	97.06
<i>rdquote</i>	1065	0.05	0.17	0	1.81
<i>size</i>	1431	56.67	148.03	1	2947
<i>age</i>	1279	11.07	7.79	1	73
<i>capint</i>	1238	70.97	178.26	0	3875
<i>invshare</i>	986	32.05	364.80	0	10831
<i>hchigh</i>	1385	0.19	0.24	0	1
<i>hclow</i>	1431	0.07	0.39	0	13.79
<i>outregn</i>	1382	23.64	30.69	0	100
<i>outeast</i>	1387	11.50	16.89	0	100
<i>outwest</i>	1391	39.45	31.50	0	100
<i>export</i>	1365	12.70	22.21	0	100
<i>inregn</i>	1261	23.42	28.79	0	100
<i>ineast</i>	1265	11.83	17.14	0	100
<i>inwest</i>	1269	39.76	29.68	0	100
<i>import</i>	1242	9.82	18.66	0	100

Table A.4: Descriptive Statistics for binary variables

Variable	No. of firms with $X = 1$	Percentage Share
<i>dpat</i>	199	14.09
<i>drd</i>	283	22.34
<i>dlybt</i>	392	27.49
<i>dwgroup</i>	163	14.00
<i>dforeign</i>	58	4.98
<i>deast</i>	50	4.30
<i>drddpmt</i>	377	27.68
<i>dind15</i>	80	5.43
<i>dind17</i>	36	2.44
<i>dind20</i>	64	4.34
<i>dind21</i>	80	5.43
<i>dind24</i>	38	2.58
<i>dind25</i>	123	8.34
<i>dind26</i>	105	7.12
<i>dind27</i>	320	21.71
<i>dind29</i>	128	8.68
<i>dind30</i>	208	14.11
<i>dind34</i>	38	2.58
<i>dind72</i>	154	10.45

C R&D Incentives at the regional, national and EU level

R&D projects can count on numerous forms of financial support. There are many programmes allocating R&D grants, interest-reduced loans, and special partnership programmes. Financing is provided by the German government, the individual German states, and the European Union (EU).

- German Federal Government R&D Grants 1: Most research programmes financed by the German federal government focus on specific industry sectors with a high dependency on ongoing hightech research and development (so called *Fachprogramme*). Each defined industry sector consists of a number of different R&D programmes which support specific R&D projects by non-repayable project grants. Grant rates can reach up to 50 percent of eligible project costs. Higher rates may be possible for SMEs or projects settling in East Germany. Cooperation between project partners, especially between enterprises and research institutions, is usually required. The federal government periodically calls for R&D project proposals followed by a competition of best project ideas.
- German Federal Government R&D Grants 2: In addition, a number of national programmes without a specific technological focus also exist. Some of them explicitly target SMEs. Application for incentives available under these programmes is possible at all times, without any prior calls for proposals or application deadlines. On the other hand, also competition based national R&D programmes have been launched recently starting with the BioRegio and BioProfile competitions in the field of biotechnology throughout the 1990s. Here the BioRegio Jena in Thuringia also belongs to the winning regions. The BioRegio competition has recently been extended to the 'Excellence Cluster Competition' ('*Spitzencluster-Wettbewerb*') of the Federal Government, which subsidizes research cooperations with strong regional ties without being restricted to specific technologies.
- German Federal State Funding: In addition to programmes run by the federal government, each German state has R&D grant programmes in place. Some states put particular focus on specific industry clusters, but programmes without specific technological focus also exist. Cooperation between project partners is not always necessary. Mostly industrial research (research with a specific practical objective aimed at improving existing products, processes, or services).
- EU R&D Incentives: The EU's Research Framework Programmes offer financial support to R&D projects at the European level. Support is allocated in the form

of grants covering up to 75 percent of project expenditures for small and medium-sized enterprises (SMEs). Support is usually provided to R&D projects working on a transnational level with different project partners. The EU usually issues a call for proposals announcing the research area, eligibility guidelines, and the available budget.

R&D incentives programmes generally provide money for R&D project personnel expenditure. Other costs for instruments and equipment may also be eligible if they can be clearly assigned to the relevant R&D project (if such instruments and equipment are used beyond the lifetime of the R&D project, only the depreciation costs for the duration of the R&D project are considered eligible). To participate in R&D funding programmes, companies must define an R&D project with clear objectives and a fixed time line.

The project application should highlight the innovative character of the project and the technological risks involved. An application for R&D funding also has to set out a commercialization plan, detailing how research results will be transformed into products, processes or services which generate additional turnover and/or employment in the region where the R&D project is located.

The total amount of incentives a project may receive depends on the size of the company (small, medium-sized, or large), whether the project is conducted in cooperation with other companies or research institutes, and the research category of the project. The research category expresses the scope of the intended project. There are three basic research categories:

1. Basic research (experimental or theoretical work aimed at gaining new knowledge),
2. Industrial research (aimed at improving existing products, processes, or services),
3. Experimental development (aimed at producing drafts, plans, and proto-types).

R&D loans can be an alternative to R&D grants and entail several specific advantages: they are usually not attached to a specific technology field, application is possible at all times (no deadlines), and they can cover higher project costs. R&D loans are provided by different governmental programmes. For instance, the ERP Innovation Programme offers 100 percent financing of eligible R&D project costs up to EUR five million. Public (silent) partnerships are offered by both the KfW Banking Group and state-owned venture capital companies to technically oriented companies. Direct shareholding by a public investment company is also possible. Conditions are negotiated on a case-by-case basis.

Table A.5: OLS Estimation Results for R&D Intensity

Dep. Var.: $\log(rdint)$	Total Sample		<i>drddpmt</i> = 1	<i>size</i> < 50
<i>drd</i>	0.71***	0.71***	0.80***	0.78***
<i>log(size)</i>	-0.21***	-0.17**	-0.32**	-0.22**
<i>log(1/age)</i>	-0.04	-0.17	0.23	0.02
<i>log(capint)</i>	-0.03	0.04	-0.08	-0.05
<i>invshare</i>	0.0004***	0.0004***	0.0004***	0.00
<i>hchigh</i>	0.95***	2.05***	0.64	0.46
<i>hclow</i>	-0.14	-0.21	-0.27	-0.28
<i>outregn</i>	0.003	0.02*	0.02*	0.001
<i>outeast</i>	0.007	0.02**	0.02	0.002
<i>outwest</i>	0.007***	0.02*	0.02**	0.004*
<i>export</i>	0.01***	0.02*	0.02**	0.01***
<i>inregn</i>	-0.0004	0.0007	0.01	0.0002
<i>ineast</i>	-0.001	-0.01**	0.003	0.005
<i>inwest</i>	-0.002	-0.001	0.01	-0.001
<i>import</i>	-0.002	-0.001	-0.0002	-0.001
<i>dlbty</i>	-0.21*	-0.15	-0.72	-0.25***
<i>dwgroup</i>	-0.02	-0.0003	-0.006	-0.30
<i>dforeign</i>	0.01	-0.08	0.77	-0.21
<i>deast</i>	-0.10	-0.17	0.20	-0.11
<i>drddpmt</i>	0.64***	0.16		1.07***
<i>dsize</i> < 50 \times <i>log(1/age)</i>		0.20		
<i>dsize</i> < 50 \times <i>log(capint)</i>		-0.11		
<i>dsize</i> < 50 \times <i>log(invshare)</i>		-0.0004***		
<i>dsize</i> < 50 \times <i>log(hchigh)</i>		-1.51**		
<i>dsize</i> < 50 \times <i>log(outregn)</i>		-0.02*		
<i>dsize</i> < 50 \times <i>log(outeast)</i>		-0.02		
<i>dsize</i> < 50 \times <i>log(outwest)</i>		-0.01		
<i>dsize</i> < 50 \times <i>log(export)</i>		-0.01		
<i>dsize</i> < 50 \times <i>log(inregn)</i>		-0.0002		
<i>dsize</i> < 50 \times <i>log(ineast)</i>		0.02***		
<i>dsize</i> < 50 \times <i>log(inwest)</i>		0.001		
<i>dsize</i> < 50 \times <i>log(import)</i>		0.0003		
<i>dsize</i> < 50 \times <i>log(drddpmt)</i>		0.94***		
<i>dsize</i> < 50		1.79*		
<i>N</i>	540	540	189	316
<i>R</i> ²	0.44	0.48	0.46	0.56
<i>Industry Dummies</i>	Yes	Yes	Yes	Yes

Note: ***, **, * = denote significance levels at the 1%, 5% and 10% level respectively. Heteroscedasticity robust standard errors are reported.