Dynamic Effects of R&D Subsidies in Slovenia: Substitute or Complement to Private R&D Expenditures?

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Abstract

Few papers that evaluate the efficiency of research and development (R&D) subsidies analyze changes in the dynamics in firms' private R&D spending induced by R&D subsidies, but focus mainly on crowding-out and substitution effects. We study the effects of R&D subsidies on private spending in Slovenia and examine the changes in firms' R&D spending behavior ("additionality effect") due to R&D subsidies by applying propensity score matching methodology. Taking the difference-in-differences approach, we evaluate how much the supported firm would have spent on R&D had it not received the subsidy. The results show the presence of complementary effect of subsidies on private R&D expenditures. However, the positive effect of subsidization is diminished with the increasing frequency of public R&D funding.

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1 Introduction

The process of globalization puts firms under increased competitive pressures, and they face a growing need to permanently upgrade their competitiveness. One of the main sources of firms' competitiveness is their innovative capacity, which is to the main extent determined by their R&D expenditures. R&D and innovation behavior largely depends on incentives from the environment. Here is the room for economic policy. The government faces the question of whether to take any steps to increase firms' R&D, i.e., should the government subsidize firms' R&D expenditures or not, and if yes, to what extent? What are the arguments pro et contra R&D subsidization? The main issue of R&D subsidies is whether there are any positive spillovers from public to private R&D expenditures, i.e., from R&D subsidies given by the government to firms' own R&D expenditures (David et al.1999). The government should know, or at least have an idea, how much the firm would have spent on R&D had it not received the subsidy (Lach, 2000).

The standard rationale for government support of R&D is rooted in the belief that some form of market failure exists that leads the private sector to underinvest in R&D (Arrow, 1962; Nelson, 1959). Underinvestment in R&D occurs because the social benefits from new technologies are difficult to appropriate by the private firms bearing the costs of their discovery, and because imperfect capital markets may inhibit firms from investing in socially valuable R&D projects (Griliches, 1998; Romer, 1990). The output of R&D is characterized by its public good nature, which implies that benefits are not fully appropriable by the investor but generate spillovers that might be captured by competitors. Economic incentives therefore do not generally lead firms to undertake the first best level of R&D spending. The aim of government intervention in R&D activity is thus to increase investment in R&D to the socially optimum level.

Obviously, publicly supported R&D is supposed to augment or complement private R&D expenditures. Yet the empirical evidence does not offer a definite empirical conclusion regarding the sign and magnitude of the relationship between public and private R&D expenditures. Some studies report that R&D funding tends to expand private R&D expenditures, while others tend to claim that R&D subsidies behave as a substitute for private R&D investment. There are three principal reasons for the substitution effect of R&D subsidies on private R&D expenditures. The first is subsidizing of projects that firms would undertake even in the absence of subsidies. In principle, the government is suppose to subsidize projects with a large gap between the social and private rate of return (David et al. 1999), i.e., projects where firms would tend to most heavily underinvest in R&D. In practice, however, governments tend to "pick up the winners," i.e., to subsidize the most promising projects, which firms would usually undertake anyhow. The second reason is that firms tend to adjust their portfolio of R&D projects by closing or slowing down nonsubsidized projects; and the third reason is the increase of prices of R&D inputs due to increased demand arising from R&D subsidies (Lach, 2000; David et al. 1999; Aerts and Czarnitzki, 2005). The latter reason could be especially relevant for a small country such as Slovenia.

The aim of the paper is to find whether there are any positive spillovers from public R&D subsidies in Slovenia to firms' own R&D expenditures. In other words, is public R&D spending in Slovenia complementary and thus "additional" to private R&D spending, or does it substitute for and tend to "crowd out" private R&D? To answer the question, we use the combined dataset of 2,564 Slovenian companies based on (i) official Community Innovation Surveys (OECD methodology) carried out in 1996, 1998, 2000, and 2002 and (ii) the database of public R&D subsidies granted to companies in 1998-2003. To estimate the average causal effects (net effects) of public funds on R&D activity, we compare the receivers of public funds to nonreceivers by applying the matching approach. The paper is structured as follows. Section 2 provides a short literature review; Section 3 sums up Slovenian policy on R&D subsidies; Section 4 describes methodology;

Section 5 presents the results; and Section 6 concludes.

2 Literature Review

The issue of substitutability versus complementarity of R&D subsidies is an old issue in the literature. Still, existing empirical work does not offer a definite conclusion regarding the sign and magnitude of the relationship between public and private R&D. Overall, it seems that evidence is more in favor of the complementary than the substitution effect, but the crowding-out effect could not be excluded. For instance, Wallsten (2000) shows that a subset of publicly traded, young, technologically intensive U.S. firms reduced their R&D spending in the years following the award of Small Business Innovation Grant, while Busom (2000) finds that in about 30 percent of Spanish firms in her sample, public funding fully crowds out privately financed R&D. On the other hand, Klette and Moen (1997) claim that R&D subsidies significantly expanded R&D expenditures of a sample of high-technology Norwegian firms and there was little tendency for crowding out. Lach (2000) concludes that R&D subsidies to Israeli manufacturing firms stimulated long-run company-financed R&D expenditures; an extra dollar of R&D subsidies increases long-run company-financed R&D expenditures by 41 cents. Veugelers (1997: 311) estimates that the government sponsored R&D in the case of Flemmish R&D active companies as significantly positive, suggesting that subsidies stimulate internal R&D expenditures. She claims that the point estimate of 0.14 is similar to that found in other studies for Canada and the United States. Almus and Czarnitzki (2003) analyze the effects of public R&D policy schemes on the innovation activities of firms in Eastern Germany. They find that compared to the case in which no public financial means are provided, firms increase their innovation activities by about 4 percentage points. Aerts and Czarnitzki (2005) find that subsidized firms in Flanders would have invested significantly less in R&D activities, on average, if they had not received public R&D funding. The majority of studies discussing the crowding-out effect of R&D subsidies in Germany, Belgium, and Spain, overviewed by Aerts and Czarnitzki (2005: 6), and which use different methodological approaches, also report complementary effects of public R&D, but crowding-out effects—especially partial ones—cannot be ruled out.

Probably the most comprehensive overview of econometric evidence on the subject has been signed by David et al. (1999). One-third of the studies they analyzed report that R&D funding behaves as a substitute for private R&D investment. The substitution-effect result is far more prevalent among studies conducted at the line-of-business and firm levels than among those carried out at the industry and higher aggregation levels. Of 19 analyses at the firm level, 9 report substitution; however, this is mostly due to the United States: of 12 studies based on U.S. data, 7 report substitution, while of 7 studies on other countries' data, only 2 report substitution. Complementarity is thus much stronger in the case of non-U.S. studies and vice versa in the case of U.S. studies.

David et al. (1999) point to the methodological problems, which influence the results of econometric studies. The problems are related to (i) possible mutual interdependence of public and private R&D expenditures because of simultaneity and selection bias in the funding process, or because of omitted latent variables that are correlated with both the public and private R&D investment decisions; (ii) unobserved interindustry differences in the technological opportunity set, which are likely to induce positive correlation in the public and private components of total industry level R&D expenditures; and (iii) the likely positive effect on R&D input prices of expanded government funding at the aggregate level, which contributes to the appearance of complementarity movements in the private and public components of nominal R&D expenditures.

The selection bias problem is one of the most outstanding problems for public administrations deciding on whom to give R&D subsidies. How to assure that R&D subsidies given to firms would not substitute but complement and stimulate their private R&D expenditures? As demonstrated by David et al. (1999), this also has important implications for econometric analysis. The "picking-the-winner" approach of public administrations and persistency in subsidizing make public funding an endogenous variable with all the consequent problems (Busom, 2000: 114). Aerts and Czarnitzki (2005: 5) propose that to estimate the "real" effects of public subsidies, it is necessary to address the core evaluation question: "how much would the recipients have invested if they had not participated in a public policy scheme"? Studies that explicitly tackle the selection bias are Busom (2000), by applying an econometric selection model; Wallsten (2000), by using a simultaneous equations model; and Lach (2000), by applying different estimators (see Aerts and Czarnitzki, 2005: 5-6). An alternative method to tackle the selection bias problem is the matching approach. The matching approach has been applied by Almus and Czarnitzki (2003) in the case of Eastern Germany; Aerts and Czarnitzki (2005) in the case of Flanders; and Duguet (2004) in the case of France. According to Almus and Czarnitzki (2003: 227), "this approach can clearly identify the effect that goes back to the receipt of public R&D funding because it enables to approximate the situation with no differences between subsidized and nonsubsidized firms with respect to characteristics that influence the probability of receiving public support and carrying out private R&D." They quote Hausman (2001) in claiming that the matching methodology leads to more robust estimates of the treatment or causal effect, compared with alternative approaches. Interestingly all the authors that apply the matching method basically reject the crowding-out hypothesis for R&D subsidies. Our aim is not only to test the crowding-out phenomenon, but also to estimate the difference in R&D spending behavior between subsidized and nonsubsidized firms in time and thus evaluate how R&D subsidies can influence the dynamics of private R&D expenditures.

3 R&D Support and Firms' R&D Activity in Slovenia

3.1 R&D subsidies

R&D policy in Slovenia has been relatively modest. In the early and mid-1990s, state aid was to a great extent used for rehabilitation and restructuring of large, socially-owned enterprises. The number of R&D support programs has been increasing slowly since 1998 within broader competitiveness promotion programs. Subsidies for industrial research, precompetitive activities, and basic research are the most important kinds of subsidies.

Subsidies for precompetitive R&D activities and for industrial research are part of the Programme of Measures to Promote Entrepreneurship and Competitiveness 2002-2006—more precisely of the subprogram "Promoting enterprise investment in technological development and innovation." The objective of the subprogram is to increase enterprise investment in R&D and thus to reduce the gap between public and private resources for R&D as a share of GDP, and to approach to EU average in this regard. In principle, all enterprises are eligible for subsidies from the Programme, regardless of size, sector, type of registration, location, and ownership. Since 2002, a number of invitations for subsidization of projects have been called, for more general as well as for more specific purposes. In the second case, additional eligibility conditions may be imposed (Ministry of Economy, 2002).

Table 1 presents the complex set of general criteria used by the Ministry of Economy in granting R&D subsidies (as well as other subsidies for the improvement of enterprises' competitive capacity). The criteria relate to the company references and performance (40 out of 100 possible points), to the characteristics of the project to be subsidized (45 points), and to the financial framework of the project (15 points). Company performance in the last three years (sales, exports, employment, value added per employee) presents important criteria for receiving the subsidies (30 out of 100 possible points). The better the performance, the higher the possibility to get subsidies and the higher the share of project cofinancing received (Ministry of Economy, 2005). The maximum possible amount of project subsidization is 50 percent of eligible costs in the case of industrial research and 25 percent in the case of precompetitive R&D activities. Apart from the number of points received in the evaluation procedure, the share of cofinancing depends on some additional criteria; being a small or medium-sized company brings another 10 percentage points; being from a less-developed region, another 10-15 percentage points, etc. Ex post the success rate of the project is then measured by value added per employee, new employment, exports-to-sales ratio, and the share of products with high value added in exports (Ministry of Economy, 2002). These criteria were included in processing the propensity scores in the matching procedure.

Table 1. Criteria Used by the Ministry of Economy in Granting Subsidies for Projects Improving Enterprises' Competitive Capacity

Criteria	Points
A. Presentation of the company total (A.1.+A.2.)	40
A1. References of the company (A.1.1.+A.1.2.)	10
A.1.1. Partners, with which the company cooperates (e.g. companies, institutions . . .)	5
A.1.2. Successfully realized projects (R&D, marketing, employment, cost reduction ...)	5
A.2. Company performance in the last three years (total of A.2.1. to A.2.5.)	30
A.2.1. Sales	6
A.2.2. Sales on foreign markets (outside Slovenia)	6
A.2.3. Number of employees	6
A.2.4. Gross value added per employee	6
A.2.5. Assets	6
B. Presentation of the project (B.1.+B.2.+B.3.+B.4.+B.5.+B.6.+B.7)	45
B.1. Reasons for undertaking the project and its impact on the company	10
B.2. Description of the project activities	10
B.3. Interlinking of main project activities (e.g. impact of development activities on the knowledge level of employees in the company)	5
B.4. Cooperation with knowledge institutions in the project realization	5
B.5. Integration of all business functions of the company in the project	5
B.6. Presentation of the product commercialization	5
B.7. How realistic is it to realize the project (term and organizational aspect)	5
C. Financial framework of the project (C.1.+C.2.+C.3.)	15
C.1. Concordance of financial plan with plan of foreseen activities	5
C.2. Description of costs and argumentation of the level of eligible costs	5
C.3. Assured sources of finance, link to company's own resources, loans, etc.	5
TOTAL	100

Source: Ministry of Economy (2005).

Table 2 presents the amount and structure of public R&D subsidies to Slovenian enterprises in 1998-2003. The number of enterprises receiving R&D subsidies and the average value of various subsidies per year are presented. The number of firms subsidized in R&D decreased from 1988 to 2003, while the average amount of subsidy increased by 62 percent. Most of the enterprises receive subsidies for basic research and precompetitive R&D activities. Apart from subsidies for basic research, the number of receiving forms increased in all other purposes of subsidies from 1998 to 2003. The average annual subsidies were the highest in basic research and feasibility studies, followed by precompetitive activities. Subsidies for total industrial research and other purposes were lower, and average value did not change significantly during the studied period.

Table 2. Number of Receiving Firms and Average Annual Amount of Various Public R&D Subsidies to Slovenian Enterprises in 2001-2004 (in millions of Slovenian Tolars, current prices)

		1998	1999	2000	2001	2002	2003
Other purposes	N receivers	26	42	117	157	39	40
	average	3.73	4.38	2.22	3.03	4.27	4.45
Total industrial research	N receivers	112	134	148	172	155	163
	average	10.2	10.2	10.3	9.9	12.0	10.9
Total precompetitive activities	N receivers	145	221	230	234	268	242
	average	15.0	13.9	13.3	13.1	13.6	16.0
Basic research	N receivers	658	223	242	213	185	183
	average	21.5	55.3	50.6	57.6	65.3	54.7
Feasibility studies	N receivers	125	245	169	169	145	140
	average	37.1	20.4	26.6	27.0	32.2	23.7
All R&D subsidies	N receivers	658	399	405	422	357	350
	average	33.7	55.0	53.3	52.3	62.8	54.7

Source: Ministry of Finance (2005); Agencija Republike Slovenije za javnopravne evidence in storitve (AJPES); own calculations.

3.2 Firms' R&D and innovation activity in Slovenia

Since 1996, firms' R&D and innovation activity is monitored through the Community Innovation Survey (OECD methodology). Since then, three surveys have been carried out in two-year intervals. The first survey covered 1994-1996 and 1997-1998; the second, 1999-2000; and the third, 2001-2002. Innovation expenditure was increasing (see Table 3), though the share of innovative enterprises[1] and innovation intensity has not grown since 2000. In 2002, 21.1 percent of enterprises were innovation active (28 percent in manufacturing).[2] Introduction of innovation in the market was smaller; 5.6 percent of enterprises introduced only product innovation; 1.8 percent only process innovation, while both product and process innovations were introduced in the market by 12 percent of firms in the survey. Enterprises mostly developed a new product independently; less than one-third (32 percent) developed a new product in cooperation with another enterprise or institution, while only 3 percent left the development of a new product to other enterprises or institutions. Also, new processes were mostly developed independently; for 5 percent of enterprises, a new process was developed by others. The share of enterprises with own R&D activity fell after 1998; in 2001-2002, 17 percent of enterprises had their own

[1] In the survey, innovative enterprises are defined as an enterprise introducing product, process or service innovation. Product or service innovation is a good or service which is either new or significantly improved with respect to its fundamental characteristics, technical specifications, incorporated software or other immaterial components, intended uses or user-friendliness. Process innovation includes new and significantly improved production technology, new and significantly improved methods of supplying services and of delivering products. The outcome should be significant with respect to the level of output, quality of products (goods/services) or the costs of production and distribution. The innovation should be new to the enterprise, but not necessarily new to the market and not matter whether the innovation was developed by the enterprise.

[2] The highest was in manufacturing of medical and precision instruments and in transport, where half of all enterprises were active, followed by manufacturing of chemicals and chemical product with 47.5 percent of innovative firms.

R&D activity (66 percent were continuously engaged and 34 percent were occasionally engaged).

Table 3. Innovation Activity in Slovenia

	94-96	97-98	99-00	01-02
Total innovation expenditure (billion SIT)	33.6	48.4	81.1	78.0
Innovation expenditure in GDP (%)	1.15	1.5	2.0	1.4
Share of innovative enterprises (%)	n.d.	33.0	21.7	21.1
Share of enterprises with own R&D (%)	19.6	24.0	16.5	17.0
Innovation intensity (% of innovation expenditure in sales)	3.3	3.9	3.24	3.14

Source: SORS; Rapid Reports, No. 73/1998, No. 81/2000, No.307/2003, No. 370/2004.

Of all funds invested in R&D, 25 percent were invested in the development of new technologies and 68.5 percent in development of a new product and services. Investment in R&D is only part of investment in innovation activity (51.9 percent); expenditure for machinery and equipment (28.4 percent), external knowledge (2.6 percent), training (1.8 percent), expenditure for market introduction of the innovations (6.9 percent), and preparation for production (8.2 percent) are also included.

Innovation expenditures were, according to the survey, mostly covered from own funds (94 percent). Subsidies represented only 3 percent of total innovation expenditures of enterprises (3.7 percent in manufacturing).[3]

4 Methodology

Each individual firm has two potential outcomes regarding a treatment (receiving R&D subsidy in our case): Y_i^T is the result if firm i is treated, and Y_i^C is the outcome if it is not treated. Let the dummy $S_i = 1$ if firm i receives a subsidy and $S_i = 0$ if otherwise. We are interested in calculating treatment effect for firm i, that is, the difference between the outcome in the case of receiving and not receiving a subsidy:

$$\Delta_i = Y_i^T - Y_i^C \tag{1}$$

Unfortunately, we can only observe $Y_i = Y_i^C + S_i \left(Y_i^T - Y_i^C\right)$, that is either Y_i^T or Y_i^C but never both. Without imposing overly strong assumptions, one can therefore never estimate the treatment effect at the individual firm level. However, the average treatment effect on the treated can be estimated without bias if the selection bias is only due to observables, X:

$$\begin{aligned}\Delta_{TT} &= E\left(\Delta_i \mid S_i = 1, X_i = x\right) \\ &= E_{x|S_i=1}\left[E\left(Y_i^T \mid S_i = 1, X_i = x\right) - E\left(Y_i^C \mid S_i = 1, X_i = x\right)\right] \\ &= E_{x|S_i=1}\left[E\left(Y_i^T \mid S_i = 1, X_i = x\right) - E\left(Y_i^C \mid S_i = 0, X_i = x\right)\right]\end{aligned} \tag{2}$$

The last equality in the equation (2) follows from the following two assumptions introduced in Rosenbaum and Rubin (1983):

$$\left(Y_i^T, Y_i^C\right) \perp S \mid X \tag{3}$$

$$0 < \Pr\left(S = 1 \mid X\right) < 1 \tag{4}$$

[3] The majority from governmental funds; subsidies from abroad represented less than 0.8 percent.

Providing that the selection bias is only due to observables, X, unbiased estimate of $E\left(Y_i^C \mid S_i = 1, X_i = x\right)$ can be obtained from $E\left(Y_i^C \mid S_i = 0, X_i = x\right)$. In other words, for a given value of vector of observables, X, exposure to treatment is random, so the subsidized and nonsubsidized firms should be on average observationally identical. If there are no systematic differences in X between both groups, the outcome of nonsubsidized firms can be used to estimate the counterfactual outcome of subsidized firms had they not received an R&D subsidy. Remaining differences in the outcome variable between both groups of firms can then be attributed to an R&D subsidy.

With many conditional variables, however, the method becomes impractical and dependent upon arbitrary sorting schemes to select weights of matching variables. Rosenbaum and Rubin (1983) narrow this multidimensional problem down to a one-dimensional problem by introducing propensity score, $P(X) = \Pr(S = 1 \mid X)$. If matching on X is valid, so is matching solely on the probability of being selected to receive a subsidy, conditional on X. Then (3) and (4) imply:

$$\left(Y_i^T, Y_i^C\right) \perp S \mid P(X) \tag{5}$$

$$0 < \Pr\left(S = 1 \mid P(X)\right) < 1 \tag{6}$$

Any standard probability model can be used to estimate propensity scores, which are then used as a matching argument. Instead of controlling for a high-dimensional vector X, we only need to control for a scalar p:

$$\Delta_{TT} = E_{p|S_i=1}\left[E\left(Y_i^T \mid S_i = 1, P(X_i) = p\right) - E\left(Y_i^C \mid S_i = 0, P(X_i) = p\right)\right] \tag{7}$$

Now for each subsidized firm, one has to find a comparison firm or group of firms that have not received a subsidy. We chose to perform a caliper one-to-one matching and a Gaussian kernel matching estimator. Caliper matching (Cochran and Rubin, 1973) is a variant of the nearest neighbour matching for which we additionally impose a tolerance (caliper) on the maximum distance between propensity scores permitted. Subsidized firm i is matched with control firm j only if $\|P_i - P_j\| < \varepsilon$, $j \in S^C$, where ε is a predetermined caliper and $S^{T(C)}$ is the set of (non)subsidized firms. For caliper matching, the control group of firm i is defined as:

$$C(P_i) = \left\{ j : \|P_i - P_j\| = \min_{k \in S^C} \left\{\|P_i - P_k\|\right\} \right\}. \tag{8}$$

Subsidized firms for whom no matches were found within a prescribed caliper are excluded from the analysis. A drawback of caliper matching is that it is hard to determine reasonable tolerance value and that it is more prone to outliers than matching estimators from the group of smoothed weighted matching estimators. To control for possible shortcomings of caliper matching, we perform also the Gaussian kernel matching estimator described in Heckman et al. (1997, 1998):

$$\hat{\Delta}_{GK} = \frac{1}{N} \sum_{i \in S^T} \left\{ Y_i^T - \frac{\sum_{j \in S^C} Y_j^C G\left(\frac{P_j - P_i}{a_n}\right)}{\sum_{k \in S^C} G\left(\frac{P_k - P_i}{a_n}\right)} \right\}, \tag{9}$$

where $G(u) = e^{-\frac{u^2}{2}}$, a_n is a bandwidth parameter (set to 0.06 in the estimation), and N is the number of subsidized firms for which a matched counterfactual was found, again within a given caliper, ε. We impose common support on the subsidized firms in both matching estimators, so that only those values of propensity scores, P, are included that have positive density within both the S=1 and S=0 distributions. The above described procedure constructs a match for each subsidized firm using a kernel-weighted average over multiple firms in a comparison group.

Our primary goal is to determine the direction and size of the effect of R&D subsidies on firms' own R&D expenditures. The question is whether firms receiving a subsidy consequently increase, decrease or retain privately financed R&D activities; in other words, are we witnessing a complementarity or substitutability effect, or perhaps only a readjustment of R&D portfolio? Therefore, what we are trying to find out is the potential difference in year-to-year growth rates of private R&D expenditures between subsidized and nonsubsidized firms. Instead of the simple average treatment effect on the treated (1), we introduce the difference-in-differences estimator introduced in the literature by Blundell and Costa Dias (2000):

$$\delta_{DID} = \frac{1}{N_t} \sum_{i \in S^T} \left[\left(Y_{i,t}^T - Y_{i,t-1}^T \right) - \left(Y_{j(i),t}^C - Y_{j(i),t-1}^C \right) \right], \text{ for } t = -1, 0, 1 \tag{10}$$

where t is time index, N_t is the number of subsidized firms in period t for which a matched counterfactual was found, i denotes firms receiving an R&D subsidy in period t, and $Y_{j(i),t}^C$ is the outcome of control firm (group) j corresponding to subsidized firm i. Year $t = 0$ is the year when a firm received an R&D subsidy. We include also previous and subsequent periods to monitor the excess outcome growth for the subsidized firms compared to the nonsubsidized firms in years prior to and following subsidy absorption.

The matching algorithm starts with the calculation of propensity scores, the probability that firm i with observable characteristics x receives public assistance in period t:

$$E\left(S_{i,t} \mid X_{i,t} = x\right) = \Pr\left(S_{i,t} = 1 \mid X_{i,t} = x\right) = \Phi\left(x'\beta\right) \text{ for } i = 1, 2, ..., N^T + N^C, \tag{11}$$

where $\Phi(\bullet)$ is a cumulative density function and $N^{T(C)}$ is the number of (non)subsidized firms. We experimented with different binary outcome models varying in probability distributions, pooled vs. panel data techniques, and fixed vs. random effects models. At the end, the model with the best predictive power was chosen. After (11) is estimated, we calculate the unbounded propensity score for every observation, $x_{i,t}'\hat{\beta}$. We use this index instead of estimated probabilities because the former has better distribution properties (Hujer et al., 1997). Now that we have our propensity scores at hand, we can perform the two matching procedures described above. For each subsidized firm in a given year, a control firm (or group of firms) was found from the same 2-digit industry and the same year according to propensity score and caliper limitations. The caliper was set to ε =0.1, which corresponds to about 2 percent of the common support region.

Having the privilege to work with panel data covering the years 1996, 1998, 2000, and 2002, we can investigate the dynamics of private R&D expenditures in subsidized firms relative to the matched counterfactuals. Following Girma et al. (2004), we employ the following difference-in-differences regression:

$$\delta_{i,t} = \alpha Y_{i,t-1}^T + \sum_{\tau=0}^{1} \beta_\tau S_{i,t-\tau} + \beta X_{i,t} + D_t + D_{ind} + \varepsilon_{i,t}\ , \tag{12}$$

where $\delta_{i,t} \equiv \left(Y_{i,t}^T - Y_{i,t-1}^T\right) - \left(Y_{j(i),t}^C - Y_{j(i),t-1}^C\right)$ is the difference-in-differences measure for firm i at time t, $Y_{i,t-1}^T$ is the level of R&D expenditures of a subsidized firm one period ago, and $S_{i,t-\tau}$ is a dummy variable equal to 1 if firm i received a subsidy τ periods ago. We include additional explanatory variables to control for firm-specific factors that affect private R&D behavior. We therefore attempt to control for a large part of variation in R&D changes that cannot be attributed to subsidies. Vector X includes the number of employees and total sales by which we are capturing the effects of firm size and liquidity constraints, respectively. To control for shocks common to all firms, time dummies are included in difference-in-differences regression in addition to 2-digit industry dummies. Note that in equation (12), observations for difference-in-differences are included also for years without subsidy to treated firms. This gives us room for the estimation of sign and significance of the R&D subsidy effect. Coefficients β_τ are therefore of our primary interest as they capture the dynamic effects of R&D subsidies. β_0 will give us the contemporaneous effect of receiving a subsidy, compared to the observations where neither subsidized nor nonsubsidized firms received a subsidy. On the other hand, β_1 will tell us whether the effect persists through the next period after a subsidy was given.

5 Results

5.1 Data and descriptives

To combine the best available dataset, we combine three different sources: financial data from the AJPES database; the Community Innovation Survey (CIS) conducted by the Slovenian Statistical Office (SORS) in 1996, 1998, 2000, and 2002; and the State Aid Evidence on R&D subsidies compiled by the Ministry of Finance. The AJPES panel dataset covers 1994-2004, while CIS limits our sample framework to 1996-2002 and omits firms with less than 10 employees. As firms' private R&D expenditures data are available only in the CIS, we could not avoid these limitations.

The merged database used in further analysis thus could not involve micro firms below 10 employees. These firms might frequently be among the receivers of public R&D subsidies. To test the sample bias, we compare the receivers of public subsidies between sample and population data. Table 4 illustrates differences in structure of frequency and persistency of R&D subsidy receivers. The majority of firms received R&D subsidies only once. The population data include a much larger share of persistently (permanently) subsidized firms than the sample data. Among firms that were subsidized for more than a year, most of them received public R&D funds for 5 consecutive years. Those firms indeed would have been the most relevant target for our analysis, but we lack data on their own R&D spending. Without any further analysis, we are unable to estimate the direction and extent of sample bias; those (most probably micro-sized) firms might have closed down without R&D subsidies (small high-tech firms, firms in technological parks, incubators), which would speak in favor of the "additionality effect," or they could as well invest in any case.

Table 4. Frequency and Persistency of R&D Subsidy Receivers

N-times receiving subsidy	No. firms in the sample	No. firms in the population	Share in the sample (%)	Share in the population (%)
1	276	910	52	66
2	77	176	15	13
3	44	77	8	6
4	32	66	6	5
5	41	600	8	44
6	33	89	6	6

Note: Total number of receivers of public R&D subsidies was 1,378 (in population data), while the sample includes 503 receivers of (any kind of) public subsidies.
Source: Own calculations.

Next, we present the descriptives of our sample. We separate our sample with respect to participation in public R&D programs into the treatment group (subsidized firms) and potential control group (nonsubsidized firms). We allow firms to enter the potential control group only if they had not previously participated in any R&D support programs. The empirical analysis assesses whether firms that received public R&D funds are different in a number of observable characteristics. The results (Table 5) confirmed that the subsidized firms are statistically significantly larger in terms of total sales, assets, and number of employees. Subsidized firms spend significantly more on R&D compared to nonsubsidized firms. A subsidy does not only affect the amount of R&D expenditure but also innovation status. The share of innovative firms is four times as large among subsidized firms than among nonsubsidized firms. Nonsignificant differences between the averages of both groups were only found in the labor productivity.

Table 5. Mean Comparisons for Subsidized Firms and the Potential Control Group Without Subsidization

	Subsidized firms	St. dev.	Potential control groups	St. dev.	P-value of T-test on mean equality
Sales	4,151,790	9,265,641	952,183	4,155,878	P < t = 0.0000
Exports	2,781,722	7,555,192	348,438	2,918,504	P < t = 0.0000
Export share	0.49	0.32	0.22	0.31	P < t = 0.0000
Labor productivity	3,801.0	2,524.4	3,515.9	12,318.7	P < t = 0.2241
Assets	3,048,664	7,796,808	775,705	4,956,731	P < t = 0.0000
Debt/sales ratio	0.46	0.40	0.56	0.61	P > t = 0.0000
Employment	345.0	593.1	73.6	264.8	P < t = 0.0000
R&D/sales	0.02	0.07	0.01	0.04	P < t = 0.0000
Innovative firms (%)	39.6%	N=309	9.3%	N=1409	P < t = 0.0000
N*	1077		17668		

Note: Numbers of observations are smaller in calculation of R&D/sales ratio (780 subsidized and 10,681control firms).

Source: Own calculations.

5.2 Estimation of propensity scores

The first step of the evaluation method is to choose the attributes. For probability scores, we take the variables that influence both the probability to get public support and to invest privatly in R&D. Table 1 presents a full set of variables that increase the probability to get R&D subsidy according to officially denounced criteria. In computing the propensity score ($Pr\,[S=1]$), we include the following variables:

1. *Sales* (lagged real sales). Sales is taken as an indicator of a firm's market success and potential funds for R&D spending.
2. *Export intensity* (the share of exports in sales). International orientation and foreign competition increases R&D intensity.
3. *Labor productivity* (value added per employee).The level of labor productivity is expected to be related to firms R&D capacity
4. *Employment* (lagged number of employees). According to theory and empirical facts, R&D investments are related to firms size. Large firms also get subsidies more often than small firms.
5. *Debt-to-sales ratio* (lagged). On the one hand, it influences R&D spending through financial constraints and, on the other hand, it influences subsidy applications by firms or subsidy granting by the ministry.

6. *Private R&D-to-sales ratio* (lagged). Previous R&D spending influenced (i) current R&D spending because research programs normally last more than several years before completion; (ii) the granting of subsidies, as firms with own R&D are the most likely applicants for R&D subsidies; and (iii) the probability to get subsidy due to "cherry-picking effects," as public funds are more likely transferred to the "winners." An additional argument is that we study the growth rate of private R&D so that one needs to include its lagged value among the regressors in order to obtain estimates that are robust to fixed effects (see Duguet, 2003: 20).

7. *Past subsidies* (one year lagged, dummy variable). It influences private R&D spending, since the research is made on several years, and also public support can be granted on several years: As Table 5 demonstrates, there is relatively high persistency on the Slovenian population data. It thus summarizes unobservable characteristics linked to the ability of firms to get public support.

8. *Industry* (2-digit industry dummies). This variable summarizes different technological opportunities, different conditions of demand, market conditions, technology, and the appropriations that determine R&D investments. It also influences the attribution of public support, as the policy objectives are related to technological and demand conditions.

9. *Time-specific shocks* (time dummies). These capture shocks common to all firms in a given year.

As noted above, all the explanatory variables taken are lagged one and two years in order to avoid simultaneity issues and to comply with the official inspection period. Table 6 presents the results of the preferred probability estimation. We find four determinants that significantly influence the subsidization probability:

1. *Firms size.* The larger the firm (measured by the number of employees), the better the chances to receive public funds.

2. *R&D intensity.* The higher the private R&D expenditure in sales, the higher the probability for subsidy.

3. *Past subsidies.* Subsidy in the previous years increases probability for more public R&D grants.

4. *Labor productivity.* Past productivity (due to criteria) increases the chances for receiving public R&D funds.

5. *Export share.* The higher the export share, the higher the probability for public R&D funds.

Table 6. Determinants of R&D Subsidies (dependent variable: subsidy indicator, S)

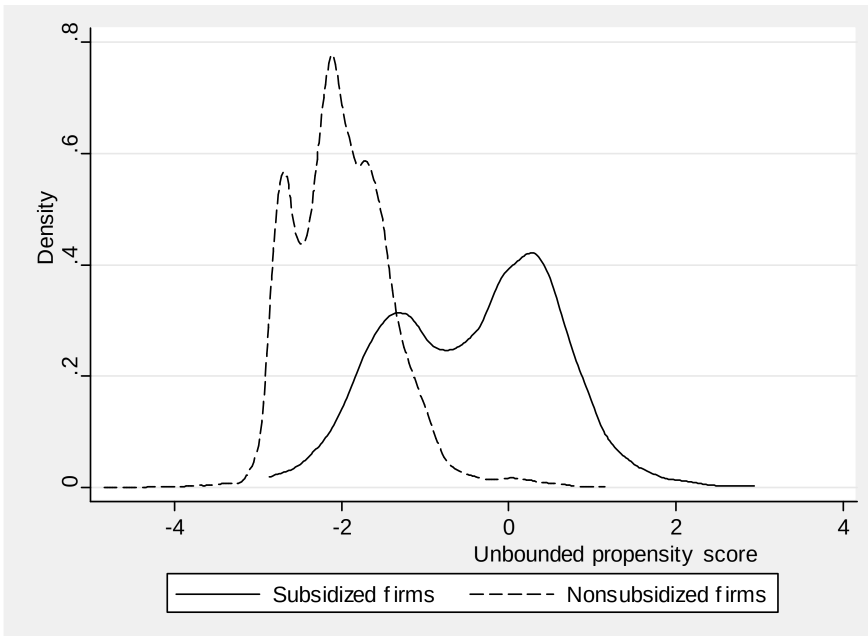
Method: random effects panel probit			
	Coef.	Std. Err.	P>z
sales $_{t-1}$	1.98E-08	1.58E-08	0.210
sales $_{t-2}$	-1.70E-08	1.68E-08	0.311
export share$_{t-1}$	0.48334	0.20863	0.021
export share $_{t-2}$	0.04038	0.20904	0.847
$\frac{valueadded}{employee}_{t-1}$	-6.42E-07	2.47E-06	0.795
$\frac{valueadded}{employee}_{t-2}$	0.000013	5.85E-06	0.022
assets $_{t-1}$	1.58E-08	2.12E-08	0.457
assets $_{t-2}$	-1.72E-08	2.12E-08	0.419
$\frac{debt}{sales}$	-0.096268	0.046147	0.037
employment$_{t-1}$	-0.000484	0.000307	0.116
employment $_{t-2}$	0.000823	0.0003	0.006
$\frac{R\&D}{sales}_{t-1}$	2.2283	0.3116	0.000
subsidy $_{t-1}$	1.54305	0.05783	0.000
LR test of rho=0: chibar2(01) = 0.00			
Prob >= chibar2 = 1.000			

Source: Own calculations.

Figure 1 presents the unbounded propensity score for subsidized and nonsubsidized firms for every observation before the matching process. Epanechnikov kernel density estimates instead of histograms serve as tools to show the similarity in the relative frequencies (probability densities) between both groups of firms. Actually, subsidized firms have on average higher estimated propensity scores, which is in line with our chosen criteria function. The domain of both graphs overlap to a great extent, giving us a broad span of common support. However, due to the distribution of nonsubsidized firms' unbounded propensity scores, we are unable to find matches for the most probable subsidizers.

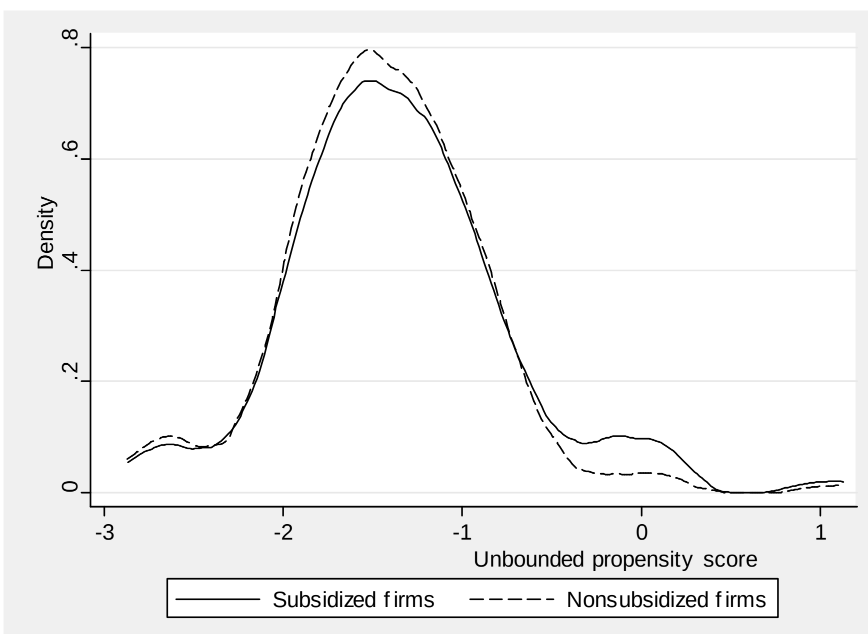
Figure 2 contains kernel density estimates of the unbounded propensity scores for both groups after the caliper matching. There are nearly no differences on the left, and smaller differences in the middle and right part of the distribution. Due to the small number of nonsubsidized firms on the right tail (Figure 1), it is difficult to find adequate matching pairs. There is a possible bias to our further analysis stemming from the omission of a large part of the most probable subsidized firms. If these firms are better in several key characteristics as shown in Table 5 and if we further assume that indeed these are the firms that would have performed R&D regardless of a subsidy grant, then the bias would be in favor of complementarity between private and state-funded R&D.

Figure 1. Frequency Distribution of the Unbounded Propensity Scores of the Initial Dataset (based on probit model)



Source: Own calculations.

Figure 2. Frequency Distribution of the Unbounded Propensity Scores after the Matching Process (based on probit model)



Source: Own calculations.

5.3 The effects of subsidies on private R&D spending

Public subsidies caused a significant increase in private R&D spending (see Table 7). Both methods yielded higher average difference-in-differences value for the subsidized periods, which implies that firms increased their own R&D expenditures more than the control firms (group) after receiving a subsidy. A simple one-sided t-test confirmed positive relative growth of R&D expenditures in subsidized firms, while the difference between the subsidized and nonsubsidized periods turned out to be significantly positive only for kernel estimates.

Table 7. Values of Difference-in-Differences in R&D Spending for Subsidized Firms in Subsidized (S=1) and Nonsubsidized (S=0) Periods.

	S=0		S=1	
	Kernel	Caliper	Kernel	Caliper
Mean	22,710.7	-13,510.9	72,427.3	35,912.5
Std. dev.	268,509.5	629,922.9	443,051.9	324,989.2
N	407	158	179	251
H_0: $\bar{\mu} > 0$	0.0444	0.6061	0.0150	0.0406
H_0: $\bar{\mu}^S - \bar{\mu}^T > 0$ (one-sided)			0.0825	0.1812

Source: Own calculations.

The efficiency of public R&D subsidies is evaluated by comparing the average growth in R&D spending (total deflated value) between the groups of subsidized and nonsubsidized firms. The estimations by kaliper and kernel matching are presented in Tables 8 and 9. According to R-squared values, the studied variables explain a relatively modest share of R&D spending behavior variability, but provide some significant relations.

R&D subsidies proved on average positive and a large impact on the firm's private R&D spending behavior regardless of the matching method. Among all tested variables, R&D subsidies (current and lagged) were confirmed as the most influential and explanatory for private R&D behavior. Apart from the specification without other control variables, all four specifications of the model that uses kernel matching estimates proved significantly positive and a large impact of current R&D subsidy to difference in year-to-year growth rates of private R&D expenditures between subsidized and nonsubsidized firms. Regression using the kernel matching estimations (Table 9) proved this relationship even more robustly. Lagged subsidies, though positive and still large, were not found as significant if other control variables were taken into account. All in all, complementary effect of public R&D is confirmed.

Past private R&D spending significantly reduces the effect of public R&D subsidies on further private R&D expenditures. The larger the previous private R&D spending, the smaller the increase in current R&D spending of subsidized firms. This effect as well was confirmed with both matching estimations and in every specification. The additionality effect of public subsidies turns to substitution for firms that invest more in R&D.

The opposite is valid for sales. The larger the sales, the higher the increase in private R&D spending for subsidized firms. Larger firms (measured by sales) experience stronger complementary effects of public R&D subsidies. Employment, on the other hand, was not found as an incentive for increasing private R&D spending. Some specifications using kernel matching estimations, which proved a significant impact of the number of employees on difference in R&D spending behavior even point to a negative relation. The larger the firm, the smaller the difference in R&D spending rate between subsidized and nonsubsidized firms.

The effect of public R&D decreases with persistency in subsidizing significantly. Firms that received public subsidies more than twice in the past increased their R&D expenditures slower than nonsubsidized firms. Though the opposite in sign, the magnitude of this effect is relatively large in kaliper estimations (close to the effect of the current R&D subsidy); the kernel estimate of persistency impact, however, does not prove to be significant.

Table 8. Effects on Difference in Growth Rate of Private R&D Expenditures (Kaliper matching)

	(1)	(2)	(3)	(4)	(5)
R&D$_{t-1}$	-1.1981***	-1.0880***		-1.1279***	-1.1909***
	(0.2875)	(0.3031)		(0.2564)	(0.3018)
S	111,827.9**	123,907.8**	93,545.8	36,788.5	139,378.5**
	(57,184.0)	(61,798.8)	(64,095.9)	(43,995.3)	(74,105.0)
S$_1$	64,824.9	77,768.6	128,753.1*		100,445.1
	(57,559.2)	(63,486.3)	(88,367.5)		(71,565.6)
Employment	-949.3			-511.0	-918.95
	(609.2)			(369.6)	(632.8)
Sales	0.0913*			0.0631*	0.09095
	(0.0473)			(0.0356)	(0.0483)
Persistency					-103,827.6*
					(71,872.3)
Time dummies	yes	yes	yes	yes	yes
Ind. dummies	yes	yes	yes	yes	yes
Adj. R^2	0.3649	0.2597	-0.0858	0.3350	0.3652
N obs.	283	283	283	409	283

Source: Own calculations.

Table 9. Effects on Difference in Growth Rate of Private R&D Expenditures (Kernel matching)

	(1)	(2)	(3)	(4)	(5)
R&D$_{t-1}$	-1.220**	-0.3700		-1.023**	-1.2218***
	(0.578)	(0.3518)		(0.450)	(0.5765)
S	141,710.1***	131,208.9***	119,758.9***	58,611.2*	132,481.2***
	(51,715.1)	(50,906.3)	(48,851.9)	(37,546.2)	(53,877.5)
S$_1$	54,910.8	53,508.1	50,207.2		46,567.3
	(62,599.4)	(66,979.7)	(71,538.9)		(63,814.5)
Employment	-831.7*			-428.9	-835.6*
	(498.4)			(285.6)	(475.3)
Sales	0.0840*			0.0542**	0.0840**
	(0.0423)			(0.0301)	(0.0409)
Persistency					67,477.1
					(191,641.4)
Time dummies	yes	yes	yes	yes	yes
Ind. dummies	yes	yes	yes	yes	yes
Adj. R^2	0.2152	0.0994	0.0992	0.1482	0.2135
N obs.	357	357	357	586	357

Source: Own calculations.

6 Conclusions

In Slovenia, the average subsidies to private R&D have been increasing in recent years though the number of receivers decreased and the amount remained relatively modest. Firms mostly covered their R&D expenditures with their own funds, yet the population data indicate a relatively high persistency among receivers. This raises questions on the efficiency of R&D subsidies.

The analysis found five factors which influence the probability of firms to receive R&D subsidies. The larger the firm, the more export oriented, the more productive, the higher R&D intensity it has and the more subsidies it received in the past, the higher the probability to receive R&D subsidies. The empirical investigation confirmed the complementary effect of public subsidies to private R&D spending and proved R&D subsidies as a influential variable for private R&D spending increase. These results shold though be taken with care as the most probable receivers of R&D grants were excluded from the matching analysis after imposing a common support restriction. The results are therefore most probably biased upward and present the upper limit of actual effect of R&D subsidies on private R&D expenditures. Persistency in subsidizing, on the other hand, reduces the effect of public funds. Firms that received public subsidies more than twice in the past increased their R&D expenditures less than not so frequently subsidized firms.

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