R&D Subsidies and Firm-Level Productivity: Evidence from France

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R&D SUBSIDIES AND FIRM-LEVEL PRODUCTIVITY: EVIDENCE FROM FRANCE

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Abstract

This paper provides a new insight into the relationship between research & development (R&D) subsidy policy and productivity. The empirical analysis evaluates the productivity of firms involved in a European program called Eureka. This program subsidizes the formation of research joint ventures. The findings suggest that the subsidized firms experience on average a productivity gain towards the end of the four-year period of subsidization. Interestingly, less productive firms appear to gain more from R&D subsidies. Matching combined with difference-in-differences evaluation is used in order to address the potential endogeneity linked to this evaluation.

Keywords. R&D subsidies, research joint ventures (RJVs), total factor productivity and proximity-to-the-frontier.

JEL Classification. O32, L11, C23.

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1 Introduction

R&D subsidy policy can be designed to enhance innovative activities and correct market failures associated with such activities.[1] In particular, innovative activities can depend on the sector and firm productivity. They can also depend on market failures. It is possible that firms with good ideas cannot conduct research & development (R&D) due to financial constraints. It is also possible that R&D spillovers, i.e. knowledge that flows to rivals and other firms without payment,[2] make innovation less privately profitable. Some innovative firms and firms benefiting from spillovers tend then to invest less in R&D.

One way of overcoming market failures is to subsidize research joint ventures.[3] Specifically, subsidies for research joint ventures aim at supporting firms to bear the high cost of innovation. Such subsidies also aim at shrinking the issue linked to undesirable R&D spillovers since the eventual beneficiaries of the innovation share the R&D cost.

The paper investigates empirically whether subsidies for research joint ventures influence firm performance. The results suggest that the subsidized firms register higher productivity towards the end of the four-year period of subsidization. Interestingly, less productive firms appear to experience a higher increase in productivity. The results also suggest that R&D subsidies increase employment and R&D expenditures during the period of subsidization. No subsidy effect is found on physical capital and wages.

This paper aims specifically at deepening the understanding of the relationship between R&D subsidies and firm performance. Several studies provide evidence that the subsidy effect differs according to firm characteristics. In particular, it has been shown that firm size matters. In general,

[1]Public R&D subsidies can be debatable since they are not protected against moral hazard. The providers of public subsidies cannot always disentangle the extra-marginal firms, i.e. the firms that do not need subsidies to perform R&D, from the intra-marginal ones, i.e. the firms that cannot perform R&D without subsidies (Wallsten, 2000).

[2]See Jaffe (1986).

[3]Research joint ventures are likely to be characterized by negative selection. More precisely, less productive firms can self-select. It might be expected that R&D spillovers created within the research joint ventures give incentives to less productive firms to enter such ventures (Cassiman & Veugelers, 2002). It might also be that less productive firms tend to enter research joint ventures to work with more productive firms. In so doing, they expect to register higher market power, as suggested by Roller et al (2007). Specifically, the authors show in a duopoly setting without R&D spillovers that the less productive firm forming a research joint venture with the more productive firm registers a higher market power.

the subsidy effect seems to be positive for smaller firms.[4] Our results on subsidies for research joint ventures suggest that firm productivity can also matter. More precisely, the results indicate that initial firm productivity can create a differential subsidy effect while little evidence is found on a differential effect driven by firm size.

To conduct our empirical study, we use a unique dataset of French firms that includes the subsidy status, employment, R&D expenditures and productivity and covers 8 years of data (1998-2005). The subsidized firms are the firms involved in a European program of public R&D subsidies called Eureka, a program that has received little attention so far.[5] The program, launched in 1985, aims at setting up research joint ventures of firms, universities and research centers from 38 countries, mainly EU members. We focus specifically on France, one of the main supporters of the Eureka program.[6]

Matching and difference-in-differences evaluation is applied to identify the causal relationship between R&D subsidies and productivity. Such an evaluation is likely to provide accurate estimates since it addresses the endogeneity inherent to the evaluation of subsidies. More precisely, matching provides a key missing control group that gives some information on the behavior of the Eureka firms if they had not been subsidized.

The rest of the paper proceeds as follows. Section 2 presents the related empirical papers and the theoretical motivation on the effect of subsidies for research joint ventures. Section 3 presents the Eureka program. Section 4 describes the data and explains the empirical strategy. Section 5 provides the results and robustness checks on the effect of the Eureka R&D subsidies on firm performance. This section also opens a discussion on the differential subsidy effect. Section 6 draws conclusions from the study.

[4] No effect is found for larger firms. See Lach (2002), Gonzalez et al (2005), Bronzini and Iachini (2011) and Criscuolo et al (2012) that study the subsidy effect on firm R&D expenditures, employment and entry.

[5] To our knowledge, the papers by Benfratello and Sembenelli (2002) and Bayona-Sáez and García-Marco (2010) are the only papers investigating the effect of the Eureka R&D subsidies. As these authors, we find a positive overall subsidy effect on firm performance.

[6] France and Germany are the two main supporters of the Eureka program. Since the creation, France provided around 5 billion euros to the program. In particular, innovative activities are well supported by the government in this country. For instance, the French gross domestic R&D expenditures is worth 37.9 billion euros in 2006 of which 25% are financed by the government. More precisely, the French government financed 11% (2.667 billion) of all R&D expenditures carried out by French firms. See the National profile of France (section Research Funding System) on the European Commission website: http://cordis.europa.eu/erawatch.

2 Related literature and theoretical motivation

2.1 Related empirical literature

Evaluating the efficacy of public intervention has attracted attention. A broad empirical literature assesses the effect of public intervention on the economic activity of individuals, firms and areas.[7] In particular, many papers evaluate R&D subsidies and tax credits (See for instance David et al. 2000, Hall & Van Reenen 2000, Klette et al 2000 and Wieser 2005 for literature surveys). Nowadays, there is a growing body of literature on R&D subsidies and tax credits that addresses endogeneity, an issue inherent to empirical studies on R&D activities.

The evolution of the R&D activities of the subsidized firms is a key issue for the evaluation of public intervention for R&D. This issue has been thoroughly studied empirically. The papers based on various types of subsidies and empirical strategies report mixed results. For instance, Hall and Van Reenen (2000) survey the papers on R&D tax credits. These papers mainly provide evidence that such credits spur R&D activities. On the other hand, Wallsten (2000) examines whether the SBIR program,[8] an R&D subsidy program, can increase employment and private R&D expenditures of firms in the US.[9] Simultaneous equations and instrumental variables are used to control for endogeneity. The results suggest that the subsidized firms have lower private R&D expenditures.[10] Little evidence is found on employment.

Lach (2002) tests the effect of R&D subsidies on the private R&D expenditures of Israeli manufacturing firms ($1990-1995$) using difference-in-differences (DID) estimation.[11] Interestingly, the results differ according to firm size. In particular, R&D subsidies seem to increase R&D expenditures for smaller firms. No effect is reported for larger firms. This suggests that

[7] See for instance Irwin and Klenow (1996), Girma et al (2008), Takalo et al (2008), Arque (2009) and Busso et al (2013).

[8] SBIR is for small business innovation research.

[9] The dataset ($1990-1993$) comprises SBIR firms, firms that apply for the SBIR subsidies and do not receive the subsidies and eligible firms that never apply.

[10] This means that R&D subsidies seem to crowd out private R&D expenditures. The crowding out effect is one possibility. Two other ones are found. First, the subsidies may allow firms continuing ongoing projects rather than stopping them. In this respect, the firms perform R&D at a constant level. Second, it is possible that with the subsidies the firms can postpone the private refinancing of R&D activities. More precisely, it might be that the firms stop spending private funds in R&D during the subsidized years. In so doing, they are able to perform research after the period of subsidization.

[11] To shrink the endogeneity bias, control variables are included in the DID estimation.

R&D subsidies crowd out R&D private expenditures for larger firms, i.e. R&D subsidies and private expenditures seem to become substitutes.

Almus and Czarnitzki (2003) collect manufacturing firm-level data on all R&D public subsidies provided by the EU, the German government and the federal states for the years 1994, 1996 and 1998 in Eastern Germany. They perform matching combined with DID evaluation. They report no crowding out of private R&D expenditures. In particular, they find that the R&D intensity[12] is 4% higher for the subsidized firms.

Gonzalez et al (2005) build a structural model with barriers to R&D and expected R&D subsidies. The model predicts that the expected subsidies can support firms to conduct R&D activities. The expected subsidies can also stimulate the R&D activities of the firms that would conduct such activities in the absence of subsidies. The predictions of the model are tested against data on Spanish manufacturing firms $(1990 - 1999)$. A fraction of these firms report R&D expenditures. The empirical evaluation estimates the parameters of the model and gives support to the predictions. The authors provide evidence that R&D subsidies spur R&D expenditures of Spanish firms by 8%. In particular, the results report that R&D subsidies can support non-performing firms to start R&D activities. This effect is larger for smaller firms. Moreover, they report that some firms would not continue performing R&D if they stopped receiving subsidies. Additionally, they report that most subsidized firms can conduct R&D without subsidies. For such firms, the subsidies appear to foster their R&D activities.

Bronzini and Iachini (2011) study to what extent R&D subsidies influence R&D expenditures of firms in northern Italy $(2003 - 2005)$. Applying regression discontinuity design evaluation, they report no overall subsidy effect. They also report a differential effect. A positive effect for smaller firms is found with no effect for larger firms.

The literature on R&D subsidies additionally examines the effect on firm performance. Girma et al. (2007), for instance, test whether Irish governmental subsidies can create a gain in total factor productivity (TFP) at the firm level $(1992 - 1998)$.[13] The results of the GMM evaluation suggest that only the productivity enhancing subsidies drive a gain in TFP.[14] The results also suggest a concave relationship between the effect of such productivity

[12] The R&D intensity is defined as R&D expenditures over sales.

[13] The panel data used provides information concerning all public support for capital, employment, maintenance, feasibility study, loan guarantees and interest, R&D, rent, technology acquisition and training.

[14] The productivity enhancing subsidies are the subsidies on capital, R&D, technology acquisition and training. GMM is for generalized method of moments.

enhancing subsidies and financial constraints.

Criscuolo et al (2012) investigate the effect of the regional selective assistance (RSA) program in the UK ($1986-2004$). The program supports the capital expenditures for property, plant and machinery of firms located in specific areas. Using instrumental variables estimation, they find no overall effect on employment, investment, entry and TFP. They also point out that firm size matters. Evidence shows that subsidies increase employment, investment and entry for smaller firms. No effect is found for larger firms.

Several empirical papers examine specifically the effect of subsidies for the formation of research joint ventures (RJVs) on firm performance. Branstetter and Sakakibara (1998) quantify the effect of subsidies for RJVs supported by the Japanese government (1983-1989). With two stage least squares estimates, they document that such subsidies increase R&D expenditures and patents. They also create knowledge spillovers between the RJV firms.

Benfratello and Sembenelli (2002) compare the EU framework programs and Eureka.[15] Employing statistical tests, they investigate whether R&D subsidies for RJVs enhance the performance of firms ($1992-1996$). The results suggest that Eureka firms register a higher labor productivity and price cost margin[16] in the post-subsidy period. Little evidence is found for the firms in the EU framework programs. Bayona-Sáez and García-Marco (2010) use the Eureka program ($1994-2003$) to study the effect of subsidies for RJVs on return over assets.[17] The results based on GMM estimation show a positive overall subsidy effect that emerges after the period of subsidization for the European manufacturing firms. The overall effect starts from the last year of subsidies for the European non-manufacturing firms.

The empirical literature evaluating R&D subsidies reports a positive effect on R&D expenditures for smaller firms with no effect for larger firms. At the same time, the studies focusing on subsidies for RJVs document a positive overall effect on firm performance. This paper aims at contributing to the literature by evaluating the differential effect of such subsidies for RJVs. Our results suggest that Eureka subsidies for RJVs result, on average, in a TFP gain. Interestingly, less productive firms seem to experience a larger

[15] The EU framework programs generally support pre-competitive RJVs while Eureka supports commercial RJVs, i.e. RJVs for product and process innovation. Benfratello and Sembenelli (2002) utilize the Amadeus accounting database and two EU commission datasets on the RJVs' characteristics.

[16] Price cost margin is defined as value added net of labor cost over sales.

[17] In the same way as Benfratello and Sembenelli (2002), Bayona-Sáez and García-Marco (2010) use information data on the Eureka RJVs' characteristics and the Amadeus accounting database.

gain than more productive firms. This particular finding emerges also when firm size is controlled for.[18]

2.2 Theoretical motivation

From a theoretical point of view, the differential effect of subsidies for RJVs can be driven by the decrease in the cost of innovation. This decrease raises the likelihood of introducing new products and processes that drives a TFP gain. The subsidy effect can be larger for less productive firms located far from the technology frontier because they conduct less complex R&D.

The differential effect can also be driven by R&D spillovers and changes in comparative advantages and market power. The subsidized RJVs might include less and more productive firms. Specifically, it is not likely that there is a strong "assortative matching" such that firms collaborate only with firms registering exactly the same productivity. Hence, R&D spillovers in the Eureka RJV are assumed. This means that the R&D effort of one RJV member affects positively the other members. It might also be expected that less productive firms attract R&D spillovers from their RJV partners (Cassiman & Veugelers, 2002). Due to these spillovers, they can copy and adopt existing technologies (Acemoglu et al 2006). They can then experience a higher gain in TFP. This is close to the model of Roller et al (2007). In a duopoly setting without R&D spillovers, their model predicts that a less productive firm forming a RJV with a more productive firm experiences higher market power and profit.

The R&D spillovers arising between members suggest the presence of strategic aspects related to the RJV formation.[19] This yields to see the Eureka RJV as a R&D coalition or network with endogenous formation. Our study then relates to coalition and network formation in game theory (Hart & Kurz 1983, Bloch 1995, Ray & Vohra 1997, Yi 1997, Yi & Shin 2000, Goyal & Moraga-Gonzalez 2001 and Mauleon et al 2008).[20] The study

[18] To provide further robustness to the results, we test whether initial firm size creates a differential subsidy effect (section 5.4). Additionally, we control for firm size in the specification on the differential effect associated with initial productivity. These robustness checks support that the subsidy effect differs according to initial firm productivity. Little evidence is found concerning a firm size effect.

[19] In their pioneering paper on R&D collaboration with spillovers in duopoly, d'Aspremont and Jacquemin (1988) derive a static model where R&D collaboration affects positively R&D expenditures and production quantity. The model also suggests that R&D collaboration can be a strategy to internalize R&D spillovers for firms with large market share.

[20] In the coalition approach, the producing sector is a partition of the set of firms.

is specifically linked to the work by Song and Vannetelbosch (2007) on R&D subsidies and the incentives of firms to create international R&D networks. The authors show that R&D subsidies shrink the conflict between societal welfare[21] and the stability of the international networks. They also show that R&D subsidies improve societal welfare when public spillovers[22] are not very small or very high.

3 The Eureka program

The description presented in this section is the only information we were provided with on Eureka, a program designed as a tool of European innovation policy. Eureka was launched in 1985 to promote RJVs for commercial innovation, i.e. product and process innovation.[23] From 1985 to 2004 there were 8,520 participants from 38 countries forming 1,716 RJVs. Among these participants, 4,698 were European firms and 1,937 were European universities and private research institutes.[24] A Eureka RJV can run for between one and eight years. On average, it runs for three and a half years, costs 34,000 euros a month per partner and comprises five partners, of which three are firms.

Eureka aims at promoting the formation of cross-border RJVs through private and public support. In particular, Eureka promotes international RJVs across Europe since it is required that each Eureka RJV draws partners from at least two different countries. Furthermore, R&D subsidies provided by the national governments, take the form of interest-free loans or public support.[25] Following the European community treaty, public support for such cross-border pre-competitive R&D does not exceed 50% of the RJV total cost.[26]

Each firm pertains only to one coalition, i.e. an element of the partition. This approach considers multi-player links. The network approach focuses on two-player links. This allows considering various types of collaboration, such as the star and partially connected architectures. In the star architecture, the 'hub' firm forms a direct bilateral link with every other firm while the other ('spoke') firms are not directly linked. In the partially connected architecture, some firms form links and others are singletons (Goyal & Joshi, 2003).

[21] The societal welfare is the sum of the social welfare of the countries.

[22] Public spillovers are knowledge flows associated either with an indirect R&D collaboration or no collaboration. These spillovers are smaller than the ones created by direct collaboration.

[23] Product innovation includes also service innovation.

[24] The remainder comes from outside EU member countries.

[25] The loans need not to be repaid even if a RJV fails, except in France.

[26] See the European community treaty on the community framework for state aid for

The selection of subsidized firms and research institutes is based on the quality of the application. Generally, the firms and research institutes form the RJV themselves and apply for Eureka subsidies afterwards. To apply, the RJV partners describe the RJV outline, the type of expected innovation, the impact of the innovation on the market as well as its estimated market size and market share. They also estimate the RJV total cost and duration. Each RJV partner presents its financial and technological contribution and accounting information data. Each RJV partner also explains its goal in entering the RJV and the expected economic impact.

Eureka is a program for existing firms. New firms are not chosen. In particular, high performing firms are more likely to be subsidized. Additionally, the program supports mainly manufacture but research in agribusiness and services is also funded.

4 Data description and empirical strategy

4.1 Data description

The database is the merger of the Eureka database and Amadeus. The former database surveys the name, the identification code SIREN and the RJV characteristics of Eureka firms that started being subsidized between 1998 and 2004 and the firms in termination case, i.e. firms that applied for but did not obtain subsidies. The RJV characteristics reported are for instance total cost inclusive of subsidies, duration and the number of partners.[27] Unfortunately, the amount of Eureka subsidies is not provided. Although the Eureka database reports total cost, it does not however disentangle subsidies from the private financial contribution of the partners to the RJV.

Our empirical analysis focuses on France. The country provides a suitable framework to assess the effect of Eureka subsidies on productivity, as France is one of the main participants in Eureka.[28] Additionally, detailed firm-level information is available from Amadeus, a pan-European database (1997-2006) that surveys annual accounts of EU public and private firms. Amadeus includes one million French firms for which key variables are reported, including employment, physical capital, R&D expenditures and value added. Importantly, for the case of France, Amadeus provides information

R&D and innovation.

[27]The name and the identification code SIREN for the Eureka firms and the firms in termination case were provided by the Eureka secretariat in Brussels. The RJV characteristics are available on the Eureka website: www.eurekanetwork.org.

[28]France and Germany are the Eureka main participants and supporters.

on export revenue, which is not available for firms from other countries.[29]

The resulting database (1998-2006) registers 207 Eureka firms,[30] the firms in termination case and the firms in close industries located in the same NUTS three regions.[31] Value added and physical capital are deflated respectively by the price index from EU Klems and the price index of the gross formation of fixed capital from INSEE. The regional GDP is from Eurostat.

Particular geographic and industrial patterns of Eureka can be observed from French data. Specifically, firms located in some high-density and backward areas appear to be more likely to be subsidized.[32] The concentration of subsidized firms in backward areas suggests that the Eureka R&D subsidy policy in France[33] aims at improving the competitiveness of regions with low density. Firms operating in some specific industries seem also to have a higher probability of being subsidized (see table 1).[34]

These industrial and geographical patterns motivate our choice to build the control group from the firms in close NACE four-digit industries located in the same NUTS three regions as the Eureka firms. In turn, firms in the control group operate in the same NACE two-digit industries as the Eureka firms, but not in the same NACE four-digit industries. The firms in the same four-digit industries were excluded so as not to capture R&D spillovers which might benefit firms selling similar goods or services as the Eureka firms.

Concerning the geographical pattern, the location of subsidized firms seems to be weakly correlated. This is shown in table 2 on concentration indexes. The index in column 1 is the $\hat{\gamma}_{MS}$ firm-based index proposed by

[29] The export revenue is defined as the quantity exported times the unit price. The database includes the intangible fixed assets (proxy for the R&D expenditures of the balance sheet) but we have no data on the R&D expenditures of the income statement. These expenditures are accounted for in the income statement because they do not generate value (knowledge). The R&D expenditures creating value are accounted for in the balance sheet.

[30] We use the identification code SIREN to merge the two databases. Employment, physical capital and value added are available for 152 Eureka firms in the period 1998-2006. The export revenue is available for 108 firms.

[31] France consists of 94 continental NUTS three regions. The Nomenclature of Territorial Units for Statistics (NUTS) in Europe is available on the EUROSTAT website: http://ec.europa.eu/eurostat/ramon/nuts.

[32] See the figure $A1$ in appendix.

[33] Although Eureka is a European program, the R&D subsidies are provided by the national governments. Each national government selects the domestic firms and research institutes that join the Eureka program. This selection is based on the national R&D subsidy policy and follows the European community treaty.

[34] Table 1 indicates that Eureka in France covers the half of the 62 NACE two-digit industries. NACE is a classification of economic activities in Europe. The NACE classification is available from the EUROSTAT website: http://ec.europa.eu/eurostat/ramon.

Table 1: NACE two digit Eureka industries

NACE	Industries	Number of French firms
01	Agriculture	3
05	Fishing	1
15	Food Products and Beverages	13
17	Textiles	3
18	Wearing Apparel	1
20	Manufacture of Wood	3
21	Manufacture of Paper Products	1
22	Publishing and Printing	2
24	Chemicals	12
25	Rubber and Plastic Products	5
26	Other Non-metallic Mineral Products	1
27	Basic Metals	4
28	Fabricated Metal Products except Machinery and Equipment	7
29	Machinery and Equipment	17
30	Office Machinery and Computers	2
31	Electric Machinery and Apparatus	4
32	Radio, Television and Communication Equipment	14
33	Medical Instruments, Watches and Clocks	18
34	Motor Vehicles, Trailers and Semi-Trailers	3
35	Other Transport Equipment	10
36	Furniture	1
40	Electricity, Gas, Steam and Hot Water Supply	1
45	Construction	4
50	Sale and Repair of Motor Vehicles and Motorcycles	2
51	Wholesale Trade and Commission Trade	4
52	Retail Trade except of Motor Vehicles and Motorcycles	2
63	Supporting and Auxiliary Transport Activities	1
64	Post and Telecommunications	1
67	Activities Auxiliary to Financial Intermediation	1
72	Computer and Related Activities	25
73	Research & Development	17
74	Other Business Activities	26

Maurel and Sedillot (1999). The index in column 2 is the $\hat{\gamma}_{EG}$ employment-based index proposed by Ellison and Glaeser (1997). Specifically, table 2 reports that the locations of any two Eureka firms are positively correlated. Tests on the variance of the concentration indexes show a 95% confidence level (Maurel & Sedillot, 1999). Given the magnitude of the indexes, the correlation is weak. Furthermore, the difference between the estimators is large. The $\hat{\gamma}_{MS}$ firm-based estimator is four times greater than the $\hat{\gamma}_{EG}$ employment-based estimator. Such facts show that the French Eureka firms are heterogeneous in terms of employment (Lafourcade & Mion, 2007).

Next, turning to the descriptive statistics in the pre-treatment period,[35]

[35]For the subsidized firms, the pre-treatment period is the year before they start receiv-

Table 2: Concentration indexes of Eureka firms[‡]

	2006	
	$\hat{\gamma}_{MS}$	$\hat{\gamma}_{EG}$
Value	0.0227	0.0044
Standard deviation	0.0007	0.0009
Number of firms	522,592	522,592
Number of industries	2	2
Number of spatial units	94	94

‡ $\hat{\gamma}_{MS}$ is the plant-based index and $\hat{\gamma}_{EG}$ is the employment-based index. The spatial unit is the NUTS three region.

Columns 1 and 2 in table 3 report that the subsidized firms are not representative of the average firms. The former firms are larger in terms of employment, value added and exports compared with the other firms.[36] Moreover, the magnitude of the standard errors shows that the Eureka firms are not homogeneous.

Finally, column 3 reports that the firms in termination case register a low level of value added compared with the Eureka firms. This pattern on the firms in termination case can be linked to the Eureka selection process. It appears that firms with better growth expectations are more likely to be subsidized.

4.2 Empirical strategy

We apply propensity score matching[37] and difference-in-differences (DID) evaluation to investigate the causal relationship between R&D subsidies and productivity in the same way as Almus and Czarnitzki (2003) and Arnold and Javorcik (2009). Matching combined with DID evaluation is likely to provide accurate estimates since this approach aims at addressing endogeneity. Specifically, matching technique provides a key missing control group that gives some information on the behavior of the Eureka firms if they had not been subsidized. Matching then decreases the endogeneity bias linked to the selection of the firms entering subsidized RJVs. This selection is not

ing the subsidies. For the firms in termination case, it is the year before that the Eureka application is rejected. For the other firms, the pre-treatment period is the 1998 - 1999 period.

[36]The other firms are the French firms in close NACE four-digit industries located in the same regions.

[37]We perform one-to-one nearest neighbour matching without replacement. The Mahalonabis distance is used.

Table 3: Summary statistics of key variables in the pre-treatment period‡

	Other firms	Eureka firms	Firms in t.c.
Employment	43	2,132	914
	(528)	(11,349)	(2,532)
Value Added	2,213,000	198,057,700	5,812,000
	(22,737)	(1e+06)	(21,969)
Total Sales	9,660,000	493,619,900	124,520,000
	(78,697)	(1e+06)	(3e+05)
Exports	1,400,550	69,754,920	31,358,370
	(2e+06)	(2e+07)	(8e+06)
Number of firms	37,296	109	35

‡ The table reports the mean of key variables. Firms in t.c. are the firms in termination case, i.e. firms that applied for R&D subsidies and did not obtain them. For the Eureka firm, the pre-treatment period is the year before it starts receiving the subsidies. For the firm in t.c., it is the year before that the subsidies application was rejected. For the other firms, the pre-treatment period is the 1998 − 1999 period. Value added, exports and region GDP are in euros. The standard errors are in brackets.

random and can be linked to the ability to present good proposals. This selection in turn can be related to firm performance measures such as employment and physical capital. The selection can be specifically linked to firm productivity since less productive firms tend to self-select in applying for subsidies. Accounting for time trends, DID technique also shrinks the endogeneity issue related to the natural propensity of some firms to grow.[38]

As a first step, we run logit models on the firm characteristics that drive the allocation of subsidies, i.e. on the characteristics likely to give proper information on firm performance on which the Eureka selection relies. In table 4, the models compare the subsidized firms during the pre-subsidy period[39] with the firms in close industries located in the same regions. In table 5, the models compare the subsidized firms with the firms in termination case.

The outcome of the dependent variable is 1 if the firm obtains the subsidies and 0 otherwise. The seven independent variables are age, size in terms of employment, TFP,[40] the growth rate of TFP and physical capital, the

[38] The standard errors of the OLS DID models are clustered by firm in order to account for potential autocorrelation, issue likely to arise with such models (See Bertrand *et al.* 2004).

[39] The pre-subsidy period is the year before the start of the subsidies. This period varies across the subsidized firms. New subsidies are granted every year and then new Eureka firms appear every year.

[40] We compute TFP following the approach of Levinsohn and Petrin (2003). This semi-parametric approach corrects the simultaneity bias in the production function estimation

Table 4: Characteristics of firms getting R&D subsidies - Eureka firms versus firms in same regions and close industries[‡]

	1	2	3	4
Age_{t-1}	0.002	0.007**	0.002	0.008*
	(0.004)	(0.003)	(0.004)	(0.004)
$ln(Employment)_{t-1}$	0.715***	0.405***	0.710***	0.431***
	(0.061)	(0.060)	(0.063)	(0.061)
TFP_{t-1}	0.063	0.438**	0.048	0.406**
	(0.133)	(0.179)	(0.135)	(0.197)
Δ TFP	0.248	0.341	0.223	0.303
	(0.184)	(0.237)	(0.185)	(0.235)
$ln(Exports/Sales)_{t-1}$	3.680***	1.805***	3.696***	2.083***
	(0.382)	(0.524)	(0.389)	(0.542)
$ln(Loans/Sales)_{t-1}$	0.289	0.184	0.244	0.232
	(0.245)	(0.450)	(0.319)	(0.530)
Δ Capital	0.001***	0.001**	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Year FE	YES	YES	YES	YES
Region FE	NO	YES	NO	YES
Industry FE	NO	NO	YES	YES
Intercept	-14.193***	-11.164***	-13.928***	-13.834***
	(1.131)	(1.319)	(1.437)	(1.250)
R^2	0.197	0.321	0.215	0.351
Observations	326,404	235,550	266,085	192,652

[‡] The table reports the regression results of the logit models where the control group comprises the firms in the Eureka regions operating in the NACE four digit industries close to the Eureka ones. FE stands for fixed effects. Standard errors are reported in brackets. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

export share defined as exports over sales and loans over sales.

The preferred specifications controlling for both industry and region fixed effects are in column 4. This column in table 4 reports a positive and significant coefficient for size. It suggests that large firms are more likely to be subsidized. This can have several meanings. Size can be seen as a performance outcome. Large firms are likely to have large R&D expenditures. They are then more likely to innovate and to submit a good research proposal to Eureka. Size can also reflect the firm's lobbying power. More specifically, large firms can have more bargaining power to obtain public subsidies. They are hence more likely to be selected. Column 4 also reports that TFP controlling for firm technology, the export share accounting for the ability to operate on foreign markets, age accounting for firm experience, and the growth rate of physical capital controlling for the influence of the firm's growth trend are

linked to unobserved firm productivity and input levels. We use the value-added TFP version. See Appendix for more details.

key firm characteristics for predicting Eureka subsidies.

Industry and region fixed effects are omitted in column 1 of table 4. In column 2, region fixed effects change the positive and insignificant coefficient of TFP to a positive and significant one. This suggests that the Eureka firms are productive firms in less productive regions. Column 3 with industry fixed effects and no region fixed effects gives similar results to column 1.

Table 5 shows that the Eureka firms register in the pre-subsidy period a better TFP trend than firms in termination case. The growth in TFP is positive and significant across columns. This suggests that the Eureka firms were on a faster growth track than the firms in termination case. This reflects the Eureka rule of supporting firms with higher potential for growth. Given this fact, we will not provide DID results for the firms in termination case.[41]

As a second step, the estimated probability of being subsidized conditional upon the seven firm characteristics (propensity score) is derived and the firms in the control group are selected according to this probability. Matching provides 87 subsidized firms and 87 firms in the control group. The two groups of firms are on the common support, region where the propensity score distributions of both groups overlap (Heckman *et al.* 1997).[42]

As a last step, DID technique is applied to study the gap in outcome between the two groups of firms in the period of subsidization and post-subsidy period.[43] The outcome of the DID specifications is TFP and labor productivity defined as value added per worker. Specifications are also performed on other outcomes such as physical capital, employment and R&D expenditures.

[41]Export share is positive and significant in column 1 when industry and region fixed effects were excluded. With industry fixed effects or region fixed effects, it becomes insignificant (columns 2 and 3). This indicates that the Eureka firms are located in industries and regions that exported more than the firms in termination case. The export share becomes significant when both industry and region fixed effects are controlled for (column 4).

[42]We assume that the conditional independence assumption of matching estimation is satisfied. This means that we assume that all the firm characteristics that determine the treatment (i.e. the allocation of Eureka subsidies) are observable and accounted for. This in turn implies that the treatment is the only factor affecting the outcome gap between the subsidized firms and the matched counterfactuals (Caliendo & Kopeinig, 2008). For each subsidized firm, the matched counterfactual is selected such as it is similar to the subsidized firm the year before the latter firm starts to be subsidized (See the approach of Arnold and Javorcik 2009).

[43]As mentioned above, the standard errors of the OLS DID equations are clustered by firm in order to account for potential autocorrelation.

Table 5: Characteristics of firms getting R&D subsidies - Eureka firms versus firms in termination case‡

	1	2	3	4
Age_{t-1}	0.001	-0.001	0.001	-0.002
	(0.002)	(0.002)	(0.002)	(0.002)
$ln(Employment)_{t-1}$	-0.023	-0.064	-0.010	-0.064
	(0.034)	(0.051)	(0.045)	(0.064)
TFP_{t-1}	-0.011	0.071	-0.039	0.104
	(0.061)	(0.150)	(0.075)	(0.176)
Δ TFP	0.151**	0.170**	0.151**	0.191**
	(0.064)	(0.076)	(0.071)	(0.082)
$ln(Exports/Sales)_{t-1}$	0.539**	0.743	0.558	0.901*
	(0.318)	(0.386)	(0.446)	(0.551)
$ln(Loans/Sales)_{t-1}$	2.564	2.207	2.487	1.993
	(1.666)	(1.730)	(1.649)	(1.742)
$\Delta Capital$	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Year FE	YES	YES	YES	YES
Region FE	NO	YES	NO	YES
Industry FE	NO	NO	YES	YES
Intercept	-4.731***	-3.930	-5.242***	-5.796***
	(1.055)	(1.073)	(1.402)	(1.520)
R^2	0.084	0.092	0.103	0.111
Observations	751	746	718	715

‡ The table reports the regression results of the logit models where the control group comprises the firms that applied for R&D subsidies but did not obtain them. FE stands for fixed effects. Standard errors are reported in brackets. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

The DID equation is the following:

$$Outcome_{it} = \alpha + \beta_1 SUBS_{it} + \beta_2 POSTSUBS_{it} + \phi_t + \delta_i + \epsilon_{it} \quad (1)$$

The $SUBS$ variable identifies the period of subsidization. The dummy variable takes the value 1 in this period and 0 in the pre- and post-subsidy periods for the Eureka firm. The dummy always takes the value 0 for the firm in the control group. In the specifications on TFP, the $SUBS$ dummy was created as a placebo variable. Since R&D expenditures are sunk costs that need time to bear fruit, it is not expected that any effect of R&D subsidies on productivity will be registered during the period of subsidization. It is more likely that a delay will be found between the formation of RJV and the effect on productivity. The $POSTSUBS$ variable captures this delayed effect. $POSTSUBS$ variable takes the value 1 in the post-subsidy period and it takes 0 in the pre-subsidy period and period of subsidization for the

Eureka firm. It is always 0 for the firm in the control group. $SUBS$ and $POSTSUBS$ are key variables in the DID specifications. We believe that they can estimate the causal relationship between the R&D subsidies and productivity.[44]

The quality of the propensity score matching depends on how well the matching technique can balance the distribution of the firm characteristics affecting the treatment between the Eureka firms and the matched firms. To assess the matching quality, we perform two types of balancing tests. First, we run univariate t-tests on the difference in means for each firm characteristic. Next, we perform the multivariate Hotelling T^2 test, comparing the means of all characteristics simultaneously.

Table $A1$ in the Appendix reports that matching technique performs well. The univariate t-tests reveal that the means of each variable were similar in the treated and matched groups during the pre-treatment period. The Hotelling T^2 test does not suggest any imbalance neither. The assumption that the two vectors of seven means are simultaneously equal is not rejected.[45]

In addition, we adopt an alternative to the identification strategy based on the matching approach. This other strategy employs the different timing of the Eureka intervention (Einiö & Overman 2012). More specifically, we perform a DID evaluation in which the future Eureka applicants are the counterfactuals. In this respect, the Eureka firms entering the program in 1999 and 2000 are compared with those entering in 2001, 2002 and 2003. Considering the latter firms also fill in the Eureka application form and get the subsidies, they seem to have the same unobserved characteristics as the former ones (Busso et al 2013).

5 Results

5.1 Effect of R&D subsidies on productivity

We start reporting the results on the relationship between R&D subsidies and TFP and labor productivity, the first outcomes of interest (table 6). In the following subsection, we investigate the potential differential effect of R&D subsidies according to firm productivity. Next, we show the results for employment, physical capital, R&D expenditures and average wage. These second outcomes of interest are used to test the crowding out effect and

[44] ϕ_t and δ_i capture year and firm fixed effects, respectively.

[45] We perform two types of tests since the balancing tests can yield different conclusions about the balancing ability of matching evaluation (Smith & Todd, 2005).

to assess whether R&D subsidies cause firm restructuring (table 7). We also perform some robustness checks and show further results to deepen our understanding of the relationship between public R&D intervention and firm performance (tables 8 and 10).

Table 6 reports the results of the DID specifications on TFP and labor productivity. Column 1 shows a positive and significant coefficient for the $POSTSUBS$ variable. This suggests that the subsidized firm experiences on average a gain in TFP of 18.2% compared with its matched firm in the post-subsidy period, i.e. towards the end of the four-year period of subsidization. Little evidence is found on an overall subsidy effect during the period of subsidization. As expected, the $SUBS$ variable capturing this effect and introduced as a placebo variable is not significant.[46]

The coefficient of the $POSTSUBS$ variable in column 2 for the variation in TFP is not significant. This suggests that the TFP improvement occurs in jumps rather than continuously. The results provide little evidence of an overall subsidy effect on labor productivity (columns 4 and 5).

Table 6: Effect of R&D subsidies on productivity - Eureka firms versus matched firms‡

	1	2	3	4	5	6
	tfp	$\Delta\ tfp$	tfp PTF	ln(Labor prod.)	Δln(Labor prod.)	ln(Labor prod.) PTF
$SUBS$	0.044	0.176	0.088	0.023	0.062	0.033
	(0.054)	(0.107)	(0.089)	(0.054)	(0.092)	(0.089)
$SUBS * PTF$			-0.118			-0.021
			(0.187)			(0.187)
$POSTSUBS$	0.182*	0.215	0.350**	0.151	0.143	0.280**
	(0.103)	(0.133)	(0.142)	(0.096)	(0.110)	(0.133)
$POSTSUBS * PTF$			-0.612**			-0.479*
			(0.296)			(0.287)
$Capital$				-0.034	-0.074	-0.036
				(0.046)	(0.051)	(0.045)
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
$Intercept$	4.548***	-0.147	4.547***	4.477***	0.728	4.501***
	(0.513)	(0.139)	(0.051)	(0.567)	(0.636)	(0.556)
Observations	1158	1137	1158	1158	1138	1158

‡ FE stands for fixed effects. PTF is the initial "proximity-to-frontier-firm" index. Standard errors are reported in brackets. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

5.2 Differential effect of R&D subsidies on productivity

It might be expected that the effect of subsidies for RJVs is larger for less productive firms than for more productive ones. The potential differential

[46] It is not expected that a subsidy effect emerges during the period of subsidization.

effect can be driven by negative selection characterizing this type of subsidy. Negative selection can appear since less productive firms self-select in applying for the subsidies to share the benefits and the cost of RJVs. In so doing, they may attract positive R&D spillovers from their partners (Cassiman & Veugelers, 2002). Change in market power can also explain negative selection. It is possible that less productive firms experience a gain in market share as they collaborate with more productive firms (See Roller et al, 2007).

To test whether the effect of R&D subsidies differs across firms according to productivity, we compute the initial "proximity-to-the-frontier" (PTF) index in the pre-subsidy period T (Konings & Vandenbussche, 2008). The index is defined as the TFP of the firm i divided by the TFP of the firm at the technology frontier of the NACE four-digit industry j.[47]

$$PTF_{ijT} = \frac{TFP_{ijT}}{Max_j TFP_{jT}} \tag{2}$$

The normalized index therefore lies within $[0; 1]$. An initial proximity of 1 indicates that the firm i is at the technological frontier of the industry. The closer to zero the index is, the less productive the firm is compared to the frontier firm. The "proximity-to-the-frontier" index is estimated using all the firms in the Amadeus database belonging to the Eureka industries and regions, i.e. out of the matched sample.

The average initial proximity of the Eureka firms was 0.32 and the median was 0.26. This means that the frontier firm (the most efficient firm, subsidized or not) in a Eureka industry was three times and four times more productive than the average subsidized firm and the median subsidized firm, respectively. Among the 87 Eureka firms considered after matching, 48 firms registered an initial proximity below 0.32, 72 registered a proximity index below 0.57 and 5 had a proximity index of 1. The large fraction of less productive Eureka firms is consistent with Cassiman and Veugelers (2002). These authors document that less productive firms have a higher propensity to enter RJVs.

Controlling for the initial "proximity-to-the-frontier" reveals a differential effect of R&D subsidies (columns 3 and 6 in table 6). More precisely, less productive firms seem to register a larger TFP gain than more productive firms. The positive $POSTSUBS$ variable in column 1 becomes more significant in column 3 and the interaction term between the $POSTSUBS$

[47] The firm i is the Eureka firm or the matched firm. The frontier firm of the industry j is the firm with the highest TFP. TFP_{ij} is the exponential of tfp_{ij} used in the DID models.

variable and the PTF variable is negative (-0.61) and significant. This suggests that the closer to the technology frontier the firm locates, the lower the subsidy effect is.

Consequently, although there is an overall gain in TFP of 18.2% in the post-subsidy period, only the 72 Eureka firms with an initial proximity below 0.57 experience a TFP gain. The least efficient firm in a Eureka industry (zero initial proximity) registers a 35% TFP gain compared with its matched firm. The most productive one has a disadvantage of 26% compared with its matched firm. A similar pattern emerges for labor productivity in column 6. These results on the differential effect of R&D subsidies prove to be similar to the ones of Damijan et al. (2012). These authors report a larger effect of innovation on the productivity of less productive firms in Slovenia. Inquiring the nexus between the Canadian trade liberalization, exports and productivity growth, Lileeva and Trefler (2010) outline also the same findings.

5.3 R&D subsidies and restructuring

We turn to the DID specifications on the second outcomes of interest. Table 7 reports a positive and significant $SUBS$ variable for employment and R&D expenditures (columns 1 and 3) and an insignificant $SUBS$ variable for physical capital and average wage[48] (columns 2 and 4). R&D subsidies appear to create an increase in the two former outcomes of 14.2% and 89.3%, respectively. Hence, R&D subsidies do not appear to crowd out private R&D expenditures. Little restructuring evidence is found in the post-subsidy period. This suggests that R&D subsidies do not produce a lasting effect on firm size and R&D expenditures.

5.4 Robustness checks and further results

5.4.1 Robustness checks

Earlier empirical literature on R&D subsidies and firm performance provide evidence that subsidies induce R&D expenditures to increase only for smaller firms (See for instance Lach 2002). This finding motivates the first robustness check where initial firm size is interacted with the two treatment variables $SUBS$ and $POSTSUBS$ (column 1 in table 8). The results do not support that the effect of subsidies for RJVs can differ according to firm size. The coefficients of the interaction terms are small and insignificant.

[48] The average wage is defined as total wage over employment.

Table 7: R&D subsidies and evidence of restructuring - Employment, physical capital, R&D expenditures and average wage - Eureka firms versus matched firms‡

	1	2	3	4
	ln(*employment*)	ln(physical capital)	*ln*(R&D expenditures)	*ln*(average wage)
SUBS	0.142**	0.004	0.893***	-0.076
	(0.060)	(0.085)	(0.333)	(0.059)
POSTSUBS	0.168	-0.102	0.495	-0.008
	(0.116)	(0.160)	(0.476)	(0.049)
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Intercept	5.118***	7.349***	8.432	8.314***
	(0.057)	(0.050)	(0.285)	(0.025)
Observations	1185	1185	1166	1182

‡ FE stands for fixed effects. Standard errors are reported in brackets. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

The second robustness check examines the effect of PTF and size simultaneously. It is possible that the differential effect related to initial PTF (table 6) is directly caused by size as the two variables are positively correlated.[49] The treatment variables are then interacted with initial PTF as well as with initial size (column 2). The results show a significant coefficient of the interaction between the $POSTSUBS$ variable and PTF as well as insignificant coefficients of the interactions between the treatment variables and firm size. These two robustness checks provide further confidence that the differential effect of subsidies for RJVs is driven to a larger extent by productivity than by size.

In the third robustness check, we account for spatial autocorrelation, i.e. we control for the firm TFP shocks affecting the other firms located in the same region. To this end, the standard errors of the DID OLS model are clustered by region (column 3). The results prove to be similar to the previous results on the differential effect in table 6. This suggests that spatial spillovers do not play a role in explaining the gain in productivity of the subsidized firms.

Finally, an alternative identification strategy using the different timing of the Eureka intervention is considered (Busso et al 2013). In particular, a DID evaluation is performed where the Eureka firms that start getting the subsidies in 1999 and 2000 are compared with the ones that start getting them in 2001, 2002 et 2003. Although the adoption of this strategy reduces drastically the number of observations,[50] the results in column 4 are close to

[49] The correlation between initial PTF and size is equal to 0.28.

[50] The decrease of the number of observations is linked to the fact that only the Eureka

those based on the matching approach. This provides also additional support to the subsidy effect reported.

Table 8: Robustness checks - Firm size effect, spatial spillovers and alternative identification strategy‡

	1	2	3	4
tfp	Initial size	Initial PTF and size	Spatial autocorrelation	Alternative strategy
$SUBS$	0.079	0.086	0.087	0.129
	(0.055)	(0.089)	(0.770)	(0.134)
$SUBS * PTF$		-0.010	-0.118	-0.101
		(0.232)	(0.190)	(0.145)
$SUBS *$ INITIAL SIZE	-2.1e-05	-2.1e-05		
	(2.0e-05)	(2.2e-05)		
$POSTSUBS$	0.189*	0.336**	0.350***	0.358**
	(0.104)	(0.140)	(0.119)	(0.173)
$POSTSUBS * PTF$		-0.575*	-0.612*	-0.459*
		(0.314)	(0.323)	(0.266)
$POSTSUBS *$ INITIAL SIZE	-2.7e-07	6.3e-06		
	(4.8e-05)	(4.3e-05)		
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Intercept	4.547***	4.546***	4.547***	4.549***
	(0.051)	(0.051)	(0.043)	(0.046)
Observations	1158	1158	1158	546

‡ The Eureka firms entering the program between 1999 and 2004 pertain to the treated group and the matched firms are in the control group in columns 1, 2 and 3. In column 4, the Eureka firms entering the program in 1999 and 2000 pertain to the treated group and those entering in 2001, 2002 and 2003 are in the control group. PTF is the initial "proximity-to-frontier-firm" index. Standard errors are reported in brackets. FE stands for fixed effects. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

5.4.2 Further results

As further results, we show the overall subsidy effect over time. We also assess whether the effect can be affected by collaborations with research institutes and by past participation in the program. We first report the subsidy effect one, two, three and four years after the period of subsidization. The results in table 9 indicate a gain in TFP of 20.0% one year after Eureka subsidies, a gain of 18.7% after two years and a gain of 17.8% after three years. The gain of 18.2% obtained in column 1 of table 6 emerges after 4 years.

Next, we focus on the collaborations with research institutes, i.e. universities and research centers. As mentioned in section 3, some Eureka firms collaborate with them. More precisely, 49 firms in our sample collaborate with universities and research centers.[51]

firms are taken into account in the DID evaluation.

[51]These 49 firms mainly conduct R&D with research centers rather than with univer-

Table 9: Further results - R&D subsidy effect over time - Eureka firms versus matched firms‡

	1	2	3	4
tfp	1 year after subsidies	2 years after subsidies	3 years after subsidies	4 years after subsidies
SUBS	0.047	0.046	0.046	0.044
	(0.054)	(0.054)	(0.054)	(0.054)
POSTSUBS	0.200**	0.187*	0.178*	0.182*
	(0.091)	(0.098)	(0.103)	(0.103)
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Intercept	4.555***	4.551***	4.549***	4.548***
	(0.051)	(0.051)	(0.051)	(0.051)
Observations	1108	1138	1152	1158

‡ Standard errors are reported in brackets. FE stands for fixed effects. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

Research institutes contribute to many industrial innovations.[52] For example, by creating more generic technologies, they may support firms to improve R&D skills through institutional spillovers (Poyago-Theotoki et al 2002 and Belderbos et al 2004).[53] Addressing specific technical or design problems, collaborations with research institutes may also result in new patentable innovation and university spin-offs (Lee 2000 and Segarra-Blasco & Arauzo-Carod 2008).[54]

To test the potential effect of such collaborations on TFP, we interact the treatment variables with the *RESEARCH INSTITUTES* variable (table 10). The latter variable measures the number of universities and/or research centers conducting R&D with the treated firm. The results provide little

sities. More precisely, two thirds of their collaborations with research institutes are with private centers.

[52]See for instance Mansfield (1995).

[53]Institutional spillovers are knowledge flowing from research institutes to firms and other agents in the economy. Belderbos et al (2004) also show that institutional spillovers foster collaborations between competitors, customers, suppliers and research institutes.

[54]Although several empirical papers focus on the incentives for collaborations between firms and research institutes, this topic is little studied theoretically. Exceptions are Zikos (2010) and Marinucci (2012) who propose network game theory models mixing private and public sectors. Zikos (2010) presents a model with R&D subsidies and three players (two private firms and one state-owned firm). The results show that the complete R&D network, i.e. the network with the highest number of pairwise collaborations, is stable. The results also suggest that the government could use the state-owned firm to shrink the conflict between individual and collective incentives to collaborate in R&D. Marinucci (2012) derives a model with an undefined numbers of players (firms and research institutes) where R&D effort is endogenous. He shows that the complete R&D network can be less stable since the incentive of firms to form collaborative links decreases with the magnitude of spillovers.

evidence that working with research institutes in the Eureka RJVs affects TFP. The coefficients of the interaction terms are not significant, as shown in columns 1, 2 and 3.

Finally, we interact the treatment variables with the *PAST EUREKA SUBS* variable to evaluate the effect of previous participation in Eureka.[55] The *PAST EUREKA SUBS* variable represents the number of RJVs in which the firm is involved from the inception of Eureka in 1985 to the first year of treatment.[56] Interestingly, the results show a positive and significant coefficient for the interaction term between the *SUBS* and *PAST EUREKA SUBS* variables (column 4). The subsidy periods generally overlap for the firms getting several Eureka subsidies over time. It might then be expected that the positive effect on TFP emerging during the observed subsidy period is related to the delayed effect of the previous subsidies.

5.5 Discussion: Subsidy effect and initial firm productivity

The differential effect of R&D subsidies according to firm productivity can have several explanations. First, it can be driven by a change in market power and R&D spillovers (see Cassiman & Veugelers 2002 and Roller et al 2007). As presented in section 2 on theoretical motivation, it might be that less productive firms working with more productive firms experience a higher gain in market power. It might also be that the further the Eureka firms are from the technology frontier, the larger the spillovers they attract from the RJV partners. This is possible since it is not likely that there is a strong "assortative matching" such that the "very laggard firms" only collaborate with other "very laggard firms" and the frontier firms only collaborate with frontier firms.

Second, the differential effect might be linked to the fact that more productive firms, which are large firms, do not obtain R&D subsidies large enough to innovate while smaller firms having the same initial productivity could innovate with the same level of subsidy. The possibility that more productive Eureka firms do not get enough subsidies compared with their size cannot be tested and therefore excluded since the database does not register small or medium-sized Eureka firms close to the technology frontier.

The differential effect can also come from the fact that more productive firms take more time to innovate. It might be that research conducted by a

[55] Fifteen percent of the Eureka firms in our sample had participated in Eureka in the past.

[56] The first year of treatment is the first year of the RJV in the sample. It pertains to the $1999 - 2004$ period.

Table 10: Further results - Effects of Eureka collaborations with research institutes and past Eureka subsidies - Eureka firms versus matched firms‡

tfp	1 Research institutes	2 Universities	3 Research centers	4 Past Eureka subs.
SUBS	0.077	0.068	0.072	
	(0.062)	(0.059)	(0.062)	
$SUBS*$RESEARCH INSTITUTES	-0.016	-0.039	-0.020	
	(0.010)	(0.029)	(0.014)	
POSTSUBS	0.187*	0.214*	0.176*	
	(0.109)	(0.116)	(0.104)	
$POSTSUBS*$RESEARCH INSTITUTES	0.003	-0.065	0.021	
	(0.026)	(0.062)	(0.041)	
SUBS				0.210
				(0.057)
$SUBS*$PAST EUREKA SUBS				0.070*
				(0.037)
POSTSUBS				0.190*
				(0.108)
$POSTSUBS*$PAST EUREKA SUBS.				-0.023
				(0.095)
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Intercept	4.549***	4.549***	4.548***	4.550***
	(0.015)	(0.051)	(0.051)	(0.052)
Observations	1158	1158	1158	1158

‡ A research institute can be an university or a research center. Standard errors are reported in brackets. FE stands for fixed effects. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

frontier firm in a Eureka RJV is part of a long-run R&D project whose effect on productivity will appear later on. For strategic reasons, more productive firms can decide that only a part of this project is shared with the Eureka partners.

6 Conclusion

In this paper, we endeavor to deepen our understanding of the relationship between R&D subsidies and firm performance by studying the differential subsidy effect according to initial firm productivity. We use a unique database on the French firms involved in Eureka, a European program of public subsidies for the formation of research joint ventures. Other firm data such as added value, exports and R&D expenditures were obtained using the Amadeus accounting database. Matching combined with difference-in-differences evaluation is performed to assess the effect of R&D subsidies on productivity and other firm performance measures like employment and physical capital. The potential crowding out of private R&D expenditures is also investigated. This effect is crucial to assess the causal relationship between subsidies and productivity. The results suggest that, on average, the total factor productivity of the subsidized firms is 18% higher towards the end of the four-year period of subsidization. The results also suggest that the subsidized firms register higher employment and R&D expenditures during the period of subsidization. Little evidence is found about an effect of R&D subsidies on physical capital and wages.

The results bring a new insight into the effect of R&D subsidies for research joint ventures. Such subsidies seem to create a higher productivity gain for less productive firms involved in research joint ventures. As Lach (2002), Gonzalez et al (2005), Bronzini and Iachini (2011) and Criscuolo et al (2012) providing evidence that firm size matters, our results on subsidized ventures show that studying the overall subsidy effect is not sufficient. Assessing the differential effect according to firm characteristics seems to bring a better understanding of the channels through which R&D subsidy policy can prove to be efficient in increasing firm performance. It is likely that the study of such a differential effect will attract more attention in future research on public intervention.

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APPENDIX

A1. Eureka spatial concentration

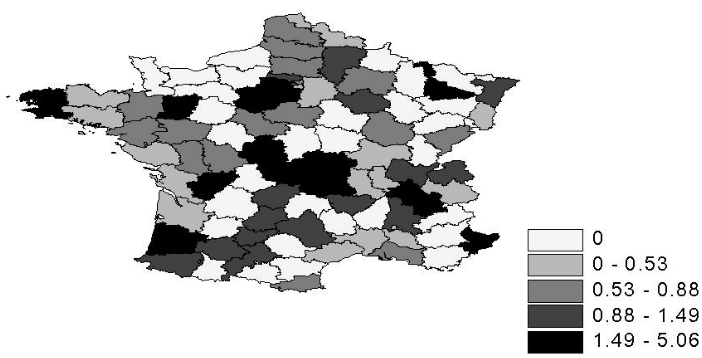
To study the geographic pattern of Eureka, we compute location quotients for the French Eureka NUTS three regions. The location quotient $Q_{e,l}$ is defined as follows:

$$Q_{e,l} = \frac{n_{e,l}/n_e}{n_l/N}$$

where $n_{e,l}$ is the number of Eureka firms located in region l; n_e is the total number of Eureka firms in France; n_l is the number of firms in region l; and N is the total number of French firms.

The map based on the location quotients shows that the Eureka firms are concentrated in heterogeneous NUTS three regions in terms of economic activity.[57] More precisely, the Eureka firms are located in high-density areas (Ile-de-France and Alpes-Maritimes) and in backward areas (mainly in Indre, Puy-de-Dôme and Landes).[58] This suggests as expected that the location of Eureka firms and then their selection are not random.[59]

Figure A1. Concentration of Eureka firms in 2006



[57]For the regional density, we use the regional GDP per capita, which is available on the Eurostat website: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.

[58]Eureka firms are mainly found in Puy-de-Dôme, Hauts-de-Seine, Yvelines, Charente and Creuse. The location quotient for each of these regions is above 3.

[59]The assumption that the location of Eureka firms is random - as far as the location of firms can be random (see Ellison and Glaeser 1997) - is rejected.

A2. Assessing one-to-one matching quality

To test the balancing assumption, we first perform univariate t-tests of difference in means between the Eureka firms sample and the matched firms sample. These tests show whether the mean of each variable used in matching evaluation is the same in both samples. Next, we use the multivariate Hotelling T^2 test. This test is more efficient than the former tests. The Hotelling T^2 test compares simultaneously the equality in the mean of the variables. In particular, the Hotelling T^2 test we implement is a F-test of joint equality of the two vectors of means. The vector of means $\in \mathbb{R}^{7\times 1}$. Each row of the vector corresponds to a firm characteristic included in matching evaluation.

Table A1: Matching balancing quality

	Matched firms	Eureka firms		
Test in mean difference	**Mean**	**Mean**	**T-test**	**P-value**
Age_{t-1}	34.07	30.40	0.8963	0.3714
$ln(Employment)_{t-1}$	5.16	5.08	0.2525	0.8010
TFP_{t-1}	4.64	4.56	0.4915	0.6237
ΔTFP	0.02	0.03	-0.1353	0.8925
$ln(Exports/Sales)_{t-1}$	0.23	0.23	-0.1718	0.8638
$ln(Loans/Sales)_{t-1}$	0.01	0.01	-0.1416	0.8876
$\Delta Capital$	0.14	1.16	-1.005	0.3177
Number of firms	87	87		
	T^2	**F-stat**	**P-value**	
Hotelling test	2.3080	0.3182	0.9450	

A3. Total factor productivity estimates based on Levinsohn and Petrin

Simultaneity is inherent to the estimation of firm production function since it is likely that input levels are correlated with the unobserved firm-specific productivity process. To correct the simultaneity problem, Levinsohn and Petrin (2003) use intermediate input as a proxy for the unobserved productivity shocks. An advantage of their approach based on the one of Olley and Pakes (1996) is the data availability.[60] Firms generally report intermediate input like material input.

In the empirical evaluation on R&D subsidies, we apply the approach of Levinsohn and Petrin (2003) to compute the total factor productivity (TFP) estimates. In this approach, the production function is assumed to

[60] Olley and Pakes (1996) take investment instead of intermediate input.

be a Cobb-Douglas function as follows:[61]

$$Y_{it} = A_{it} K_{it}^{\beta_k} L_{it}^{\beta_l} \quad (3)$$

where Y_{it} is the value added[62] of firm i at time t, A_{it} is the Hicksian neutral efficiency level, K_{it} is physical capital input and L_{it} represents labor input. Y_{it}, K_{it} and L_{it} are observed. It is not the case for the A_{it} efficiency.

The following linear production function is derived taking the log of equation (3):

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \epsilon_{it} \quad (4)$$

with $ln(A_{it}) = \beta_0 + \epsilon_{it}$. β_0 is the mean efficiency level and ϵ_{it} is the deviation from the mean efficiency level for firm i at time t. In particular, ϵ_{it} is the addition of the predictable component v_{it} with the unobservable i.i.d. component u_{it}^q. This latter component has no effect on the decisions of the firm. u_{it}^q can be measurement errors or unexpected productivity shocks (Van Beveren, 2007). On the other hand, v_{it} is considered a state variable as it affects the decisions of the firm.

In turn, the linear production function in equation (5) can be written as:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + v_{it} + u_{it}^q \quad (5)$$

where $\beta_0 + v_{it}$ is the tfp of firm i at time t denoted by w_{it}.

In Levinsohn and Petrin's approach, productivity depends on material input. In this respect, $w_{it} = s_t(m_{it})$. This allows rewriting equation (5):

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + s_t(m_{it}) + u_{it}^q \quad (6)$$

Next, the Levinsohn and Petrin tfp estimate $\hat{w_{it}}$ is derived for the latter equation:

$$\hat{w_{it}} = \hat{\beta_0} + \hat{v_{it}} = y_{it} - \hat{\beta_k} k_{it} - \hat{\beta_l} l_{it} - u_{it}^q \quad (7)$$

where $\hat{\beta_k}$ and $\hat{\beta_l}$ representing the elasticity estimates of K_{it} and L_{it} are not constant. They are specifically computed for each four-digit industry.

[61] Two types of Cobb-Douglas production function can be used: the value added production function presented above and the revenue production function. This latter production function is defined as: $Y_{it} = A_{it} K_{it}^{\beta_k} L_{it}^{\beta_l} M_{it}^{\beta_M}$ where Y_{it} and M_{it} are respectively the revenue and the material input of firm i at time t.

[62] Value added is defined as the revenue of the firm where the intermediate input are subtracted out.

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