Mixed R&D Incentives

The effects of R&D subsides on patented inventions

Schneider, Cédric

Document Version
Final published version

Publication date:
2008

Copenhagen Business School
HANDELSHØJSKOLEN

Department of Economics

Copenhagen Business School

Working paper 6-2008

MIXED R&D INCENTIVES: the effect of R&D subsidies on patented inventions

Cédric Schneider

Department of Economics -Porcelænshaven 16A, 1.fl. - DK-2000 Frederiksberg

Mixed R&D incentives: the effect of R&D subsidies on patented inventions*

Cédric Schneider†
KU Leuven
and
Copenhagen Business School

May 26, 2008

Abstract

This paper analyzes the effects of mixed public-private R&D incentives and empirically tests whether patents that were publicly sponsored are more "important" than non-subsidized ones. Blending patents and public subsidies will allow the funding agency to subsidize inventions that would otherwise not elicit investment because the private incentive will not fully cover the cost of the invention. Thus, the policy maker will only subsidize inventions that have a high social value. The empirical analysis shows that subsidized inventions result in more "important" patents, as measured by the number of forward citations.

Keywords: patents, R&D, subsidies.

JEL: O31, O32, L10

*__Acknowledgments__: I would like to thank Dirk Czarnitzki for his useful inputs throughout the completition of this paper. In addition, I would like to thank Alan Marco and Andy Toole for useful comments and Ulrich Kaiser for sharing the PatVal data with me.

†**Address**: KU Leuven, department of Managerial Economics, Strategy and Innovation, Naamsestraat 69, 3000 Leuven, Belgium; email: `csc@cebr.dk`

1 Introduction

Technological change and innovation have long been understood to be a key driver of economic growth. It is an explicit policy in most of the OECD countries to promote innovation in order to achieve sustainable economic growth. There is a vast literature that relates Research and Development (R&D) to market failures, coming from the fact that "ideas" or "knowledge" underlying the R&D process are by nature "non-excludable" and "non-rival". Thus, under competitive pricing, an innovator will not invest in his/her idea if the market price does not cover the cost of innovating. The main challenge, from a policy point of view, is then to strike a balance between giving the right incentive to innovate and allowing subsequent diffusion of the innovation

Two possibilities to overcome the public good propriety of innovation are intellectual property rights (for example patents) and government/public subsidies. A patent creates a temporary monopoly for the innovator, by preventing any other entity to use or sell the innovation whereas the governmental subsidy covers part of the cost of the innovation. However, both policies have defects: a patent creates a monopoly distortion which implies a "deadweight loss" for society and public funding of R&D implies financing the subsidy with tax revenues. There is a vast literature on the optimal design of the patent system, starting with Nordhaus (1969) or on patent races initiated by Reinganum (1983, 1985). There is also a burgeoning literature that tries to assess the impact of public subsidies on private R&D, see for example the surveys by David et al. (2000) and Klette et al. (2000). The traditional way to evaluate the effectiveness of public subsidies in the economic literature is to relate the receipt of a public R&D grant on private R&D spendings at the firm level. A majority of studies finds a complementary relationship between these two measures, that is, they usually reject full "crowding-out". For example, Almus and Czarnitzki (2003) find a significant effect of publicly supported R&D on private R&D incurred by German firms, while Lach (2002) finds a positive effect for small firms and an insignificant one in his full sample. However, some studies find the opposite effect. For example, Wallsten (2000) finds a substitutive effect of R&D subsidies from the SBIR program in the US and Gonzàlez et al. (2005) using Spanish data conclude that publicly sponsored R&D projects would be carried out even without the subsidy, although this would reduce their scope.

However, patent and subsidy policies are generally treated separately in the economic literature and the literature analyzing the effects of blending public and private R&D incentives is meager. From a theoretical point of view, Scotchmer (2004, Chapter 5) shows that a public-private R&D partnership with mandatory matching funds will allow a public sponsor to subsidize project that would not be carried out otherwise. Romano (1989, 1991) shows the optimal patent design and R&D policy in a model in which both patents and public funding coexist.

The 1980 Stevenson-Wydler and Bayh-Dole acts in the US encouraged universities and private entities to patent the outcome of publicly funded research which created a debate among economists on the "quality" of university patents after this policy change (see for example Henderson et al. 1998 and Sampat et al., 2003). However, the blending of patents and public funding goes beyond universities (see Scotchmer, 2004 and Eisenberg, 1996) and even large businesses can apply for patents on inventions partly financed with public funds. As pointed out by Scotchmer (2004) and Eisenberg (1996), blending patents and public funds is a counterintuitive policy, since it requires the users to pay twice for the same innovation, first through taxes to finance the subsidy and then through higher monopoly prices.

The aim of this paper is to conduct an empirical test showing whether patents that were publicly sponsored are more "important" than non-subsidized ones. In other words, instead of testing the crowding-out effect, I analyze whether public subsidies create additional social value. At this end, I use the result of a recent survey of inventors in Denmark that I merged with patent citations data. It is to my knowledge the first attempt to assess the effectiveness of R&D subsidies on the outcome for which the project was initially funded.

The main results of the paper is that subsidized inventions result in more "important" patents, as measured by the number of forward citations.

The paper is organized as follows: Section 2 introduces the theoretical background. Section 3 describes the data and provides the empirical results, and Section 4 concludes.

2 Theoretical background

Scotchmer (2004) and Romano (1989, 1991) have both developed models in which patent policy and subsidies can be blended. They show that the interplay between both policies will allow the funding agency to subsidize inventions that would otherwise not elicit investment because the private incentive (i.e. the patent) will not fully cover the cost of the invention. Since the empirical test relies on patented inventions only, it is worth sketching the underlying incentive mechanism and how this affects the empirical results.

Suppose a firm has an "idea" which requires R&D expenditures amounting to x and therefore maximizes an objective function over the lifetime T of the patent. Now suppose that private R&D x is not sufficient to cover the cost of the invention. If the cost of the invention is $x+S$,We will assume that the firm has the possibility to apply for a subsidy amounting to $S>0$ from a policy maker.

In this model, public funding of R&D can be combined with patents. However, combining these policies comes at a cost for society. First, the patent creates a deadweight loss through proprietary pricing, by excluding consumers from buying the good, even though their willingness to pay exceeds the marginal cost. Second, there are likely to be excess social costs associated with the public funding of R&D resulting from raising tax revenues to finance the subsidy. Following Romano (1989, 1991), I assume that each monetary unit of subsidy has a social cost of $1+\Omega$, with $0 \leq \Omega < +\infty$.

The policy-maker seeks to maximize the following social welfare function:

$$V_s = \frac{1-e^{-rT}}{r}\pi_s^m + \frac{e^{-rT}}{r}\pi_s - x - (1+\Omega)S \tag{1}$$

where π_s^m denotes the social return flow from the discovery over the duration of the patent. π_s^m is composed of the increase in producer surplus and of the consumer surplus. Finally assuming free entry after the patent has expired, π_s denotes the social return flow of the invention after the date T. Thus $\Delta \equiv \pi_s - \pi_s^m$ is the deadweight loss associated to proprietary pricing. Let $\beta(T) \equiv \frac{1-e^{-rT}}{r}$ for notational convenience, then (2) can be rewritten as:

$$V_s = \frac{\pi_s}{r} - \beta(T)\Delta - x - (1+\Omega)S \tag{2}$$

Assuming that social value lasts forever, the objective of the policy-maker will be to invest in those ideas for which the discounted social value (π_s/r) is greater than the social cost comprising the deadweight loss over the discounted length of patent protection ($\beta(T)\Delta$), the public and private R&D expenses (x) and the social cost of the subsidy $(1+\Omega)S$. As pointed out by Scotchmer (2004), the policy maker especially wants to avoid subsidizing low value inventions

The equilibrium discussed above requires that there is no asymmetric information, i.e. that the private and social value of the invention are known to both the firm and the sponsor ex-ante. In most of the cases, however, the firm is repository of the best information about the private value of the invention. If the social cost exceeds the sum of private and public spendings (which is likely to be the case in the model outlined above), Scotchmer (2004) suggests the firm commits to pay the difference, whereas Romano's (1989, 1991) analysis implies that the policy-maker can increase monitoring of R&D outlays, which would result in an increase of the social cost through Ω. In both cases this implies that the social value of the invention is known to both parties at least ex-post. The aim of the next section is to test whether subsidized inventions that were patented are indeed more "important" than non-subsidized patented inventions. The focus is therefore on specific type of research project, that received a subsidy and were subsequently patented. However, the aim in this paper is not to test whether there is a crowding-out effect, i.e., whether firm substitute their own R&D with the subsidy or whether public agencies fund projects that would have been carried out even without the subsidy because the private incentive (i.e. the patent) would have covered the cost of R&D. Instead, the goal is to undertake the more modest task of estimating the impact of public subsidies on social welfare at the patent level.

The remainder of the paper focuses on the implementation of an empirical test for the effectiveness of public support to patented inventions. Before describing the results, I first present the dataset employed in the empirical analysis and then outline the methodology and the identification strategy.

3 Data and variables

The data was compiled from two sources. First, I used the results of the so-called "PatVal" survey for Denmark, that contains information on 495 patents granted by the European Patent Office (EPO), with priority dates between 1993 and 1997. The PatVal project is a European-wide survey of inventors, which primary aim was to assess the economic value of European patents, by asking questions related to the personal characteristics of one of the inventors listed in the selected patents. However, the survey also asked questions related to the invention process more generally, including questions on the financing of the research that lead to the patent. This enables to distinguish between patents that received a R&D subsidy from those that did not. A summary of the key findings of the Danish PatVal survey can be found in Kaiser (2006). Giuri et al. (2007) provide a summary of the PatVal survey for six other European countries.[1]

The second source of data is the EPO/OECD patent citations database, that comprises all citations made to EPO patents in the period 1978-2006 (see Harhoff et al., 2005 and Webb et al, 2005).

I use the number of forward citations to the focal patent as the relevant output measure since this indicator can effectively play the role of proxy for the "importance" or "quality" of a patent (see Trajtenberg, 1990, Henderson et al., 1998, Harhoff et al.,1999, Trajtenberg, 2001 or Hall et al., 2004). Trajtenberg (1990) shows that forward patent citations are indeed highly correlated with the social value of the underlying inventions in the computed tomography industry, while Albert et al. (1991) find a strong association

[1] France, Germany, Italy, the Netherlands, Spain and the United Kingdom.

between citation counts and knowledgeable peer opinion as to the technical importance of the patents. Jaffe et al. (2000) further validate this indicator by finding a significant correlation between the number of forward citations to a given patent and the economic and technological "importance" of the invention (as perceived by the inventors). Since a policy maker should be interested in supporting "important" inventions as shown in the previous Section, one can expect publicly supported patents to receive more citations. Contrary to the well-known "NBER Patent Database", the "EPO/OECD patent citations database" does not contain any information on "self-citations" (i.e. the cited and citing patents are owned by the same entity). However, I would not expect any significant changes in the results from excluding self-citations for two reasons. First, Sapsalis and Van Pottelsberghe de la Potterie (2007) found that removing self-citations in their sample of Belgian universities does neither affect the magnitude, nor the significance of the variables[2]. Second, unlike at the USPTO, applicants at the EPO do not have the "duty of candor", which means that there is no legal requirement to disclose prior art. The so-called "search report" that contains all citations made in a patent application is carried out by the examiner at the EPO. Simple descriptive statistics show that more than 95% of the citations in EPO patents are added by the examiner. In contrast, USPTO applicants have to provide a full list of prior art, including their own work which they know best. This suggests that the "self-bias" in EPO patent applications is presumably very low and would carry a weak informational content. Moreover, the fact that the allocation of citations follows a standardized procedure at the EPO is likely to reduce the noise contained in the forward citations as a measure of the "importance" of patents.

The main explanatory variable is a dummy indicating whether the applicant received any sort of public support to undertake the invention. Unfortunately, I am not able to distinguish between the different potential sources of public subsidy. However, as shown by Jespersen and Olsen (2007), almost all R&D subsidies in Denmark stem from the Danish Ministry of Science,

[2] This is, to my knowledge, the only analysis that controls for self-citations in EPO data.

Technology and Innovation.

Following the literature on patent "quality" using forward citations as a dependent variable, intrisic attributes of the patent and the underlying technology need to be controlled for. Citation measures might be influenced by variations in citation practices across time and technology areas. In addition, citations counts are usually also influenced by the truncation effect, since later patents have less time to garner citations than earlier ones. Therefore it is important to control for both time and technology effects (see for example Henderson et al., 1998). For these reasons, I include dummies for different application years and six technology dummies using the so called OST-INPI-FISI classification, provided by the “Office des Sciences et Techniques” (OST), the French Patent Office (INPI) and the Fraunhofer ISI Institute, which is based on a concordance with the International Patent Classification (IPC) assignments.

Forward citations are subject to unobserved heterogeneity (Marco, 2007). Building on the baseline specification outlined above, I also whish to control for potential heterogeneity arising from the identity of the patent owner, the competitive environment and the invention process. This aspect has been largely neglected in the prior literature (see Cassiman et al., 2008 for an exception). Given that the analysis is confined at the patent level, including applicant and inventor specific variables is not straightforward, notably in the case of multiple ownership of the patent. However, the PatVal survey contains two interesting candidates to be included in the analysis.

In order to capture a patent’s science linkage, I will include a dummy indicating whether the surveyed inventors claimed that they used universities, public research institutes or scientific publications to carry out the research leading to the patent (*science linkage*). For example, Nagaoka (2008) shows that firms that cite scientific literature in their (U.S.) patents also receive, on average, more citations. Taking the question from the survey enables to have a more direct measure of an invention’s science linkage.

The second additional variable included in the analysis (*small firm*) is a dummy indicating whether (one of) the applicant(s) is a firm with less than 100 employees. First, public R&D policies tend to offer a favorable treatment to "small firms"[3]. Second, firm size might affect the "quality" of the invention, but the sign of this effect is not obvious. On the one hand, small firms might suffer from deficiencies in economies of scope and/or scale compared to larger corporations and on the other hand they may produce innovations of higher "quality" because they have a reduced bureaucratic burden in comparison to large companies (Acs and Audretsch, 1987; Cassiman and Veugelers, 2006).

Finally, to control for regional-specific sources of heterogeneity, I also include a set of ten dummies that indicate in which Danish region the invention took place. The literature shows that knowledge spillovers tend to be localized (Henderson et al., 1998). These dummies will control for the presence of innovation clusters and any regional-specific characteristics more generally.

In addition, the data was cleaned for missing observations and inconsistencies. Table 1 shows that 11% of the firms received a public subsidy to carry out the research leading to the patented invention.

4 R&D subsidies and innovative performance: the selection issue

Regressing forward citations or more generally any measure of research output on the receipt of a public grant is not unproblematic. The selection problem that arises in attempting to assess the impact of a public program is well known in the economic literature (Heckman et al., 1998; Klette et al., 2000; Hall et al., 2000 or Jaffe, 2002). In fact, variables that are unobservable by the econometrician might be correlated with the receipt of a public subsidy. These variables could be the budget submitted to the agency, the agency's personal knowledge of the applicants or the quality of the research project proposed (Jaffe, 2002). In addition all the components of the social cost of a patented invention, as described in the theory background in Section 2, are also unobservable That is why I use an instrumental variable

[3]For example the "Small Business Act" or the "Small Business Innovation Research" (SBIR) program in the U.S. and the "Young Innovative Companies" status in some European countries.

(IV) approach in this paper. Technically, there is no special consideration in estimating a model by IVs when the endogenous explanatory variable is a dummy (Wooldridge, 2002). Actually, estimating the first stage equation with a linear probability model will yield consistent estimates (if the instruments are valid), whether or not the first stage equation is linear (Angrist, 2001).

The candidate source of exogenous variation in the R&D subsidy equation is a dummy indicating whether at least one of the inventors listed in the application was employed at a university or a public research institute at the time of the invention (*academic inventor*). There is considerable evidence that European universities do not claim ownership of the intellectual property right even when one of their researchers took part in the invention process (see for example Guena and Nesta., 2006). In fact, the owners of those patents are most of the time firms.[4] It is an explicit policy of the Danish government (and most of the other European governments) to strengthen public-private collaborations,[5] thus, applications involving academic inventors are systematically favored by the funding agencies. However, "academic consulting" might have an effect on the quality of the patented invention, but the sign of this effect is uncertain. On the one hand, academic involvement in patents owned by corporations may lower their incentives to provide a high quality contribution (Aghion and Tirole, 1994) and on the other hand, a firm can benefit from a researcher's expertise in science intensive areas (Lacetera, 2007). However, as mentioned above, the dummy indicating whether the surveyed inventors claimed that they used scientific source of knowledge to carry out the research leading to the patent is included in both stages of the model. Once this scientific linkage is controlled for, there is no obvious reason to think that the academic inventor dummy still affects the unobservables in the equation of interest.

[4] There was actually no observation with a university-owned patent in the survey used in this paper. In Schneider (2007), I show that there were only eight patents applied for by Danish universities or public institutions at the EPO in the period 1978-1998.

[5] The Danish Ministry of Science, Technology and Innovation (that funds almost all R&D subsidies in Denmark) states that "Collaboration between public-sector research institutions and private-sector companies" is one important criteria for allocating R&D subsidies. See `http://fi.dk`

Table 1: Descriptive statistics

Variables	*N*	Mean	S.D.	Min.	Max.
Number of Forward citations	495	2.159	2.913	0	23
Subsidy	494	10.93%	0.312	0	1
Science linkage	410	69.02%	0.463	0	1
Small firm (< 100 employees)	495	18.18%	0.386	0	1
Academic inventor	486	4.94%	0.216	0	1
City with less than 10,000 inhabitants	478	16.52%	0.371	0	1
Rural area	478	10.66%	0.309	0	1
Application years					
1993	495	2.02%	0.143	0	1
1994	495	25.65%	0.435	0	1
1995	495	19.79%	0.401	0	1
1996	495	18.98%	0.396	0	1
1997	495	22.83%	0.418	0	1
1998	495	10.70%	0.306	0	1
Technology classes					
Electricity-electronics	495	8.08%	0.274	0	1
Instruments	495	11.31%	0.311	0	1
Chemicals, pharmaceuticals	495	24.64%	0.432	0	1
Process engeneering	495	18.99%	0.394	0	1
Mechanical engeneering	495	26.66%	0.442	0	1
Others	495	10.30%	0.303	0	1

5 Results

The regression results are presented in Table 2. The specification follows closely a well established literature that analyzes the structure of patent citations, see for example Henderson et al., (1998) or Harhoff et al., (1999). The reported standard errors are robust to heteroskedastisity and corrected for potential dependence of observations by respondent. Table 2 reports the baseline results of OLS regressions using the log of (one plus) the number of forward citations as the dependent variable. The subsidy dummy has a positive and significant effect (at the 5% level) on the number of forward citations. According to these estimates, patents that received a public subsidy are more important than others by about 20%. Columns (2) and (3) repeat the regression by sequentially introducing two additional controls. The results show that there is a slight negative effect of small firms, and that the science linkage of the invention tends to improve the quality of patents.

Table 2: Estimation results

	(1) OLS		(2) OLS		(3) OLS	
	Coef.	s.d.	Coef.	s.d.	Coef.	s.d.
Subsidy	0.192*	0.102	0.199**	0.102	0.219*	0.119
Small firm			-0.164*	0.089	-0.091	0.099
Science linkage					0.172**	0.081
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Constant	0.435	0.281	0.635***	0.245	0.635***	0.239
Number of observations	486		486		477	
R squared	0.107		0.114		0.120	

As argued in the previous Section, OLS can only establish a correlation between the grant dummy and the outcome variable, but in this case it cannot determine a causal effect of R&D grants on the "quality" of patents.

This is why Table 3 repeats the regressions instrumenting for the subsidy dummy with the academic inventor variable presented above. The first stage regressions are reported at the bottom of the Table. The instrument is highly significant and explains about 15% of the variation of the subsidy dummy. The instrumented subsidy dummy gains in significance compared to OLS and the measured coefficients and standard errors are of higher magnitude than in the OLS regressions resulting in wider confidence intervals.

Regarding the statistical validity of the instrument, the Kleibergen-Paap underidentification LM and Wald tests reject their null hypotheses, suggesting that the instrument is adequate to identify the equation. In addition, the academic dummy passes a standard F-test of identifying restriction.

With respect to the control variables, the results show that patents that involve a small firm receive on average less citations once the endogenous nature of the subsidy dummy is controlled for. This result goes in the direction of the Schumpeterian argument that large firms might be more capable of producing high quality technologies due to scale economies and advantages in accessing up-front knowledge in the market. However, no significant effect is found for small firms on the propensity to be granted a R&D subsidy.

The science linkage of the invention still appears to be relevant to explain patent quality once the subsidy dummy is instrumented for, which confirms the presumption that breakthrough innovations have a higher technological impact.

Table 3: Regression results (2)

	(1) IV		(2) IV		(3) IV	
	Coef.	s.d.	Coef.	s.d.	Coef.	s.d.
Subsidy	0.843***	0.287	0.837***	0.302	0.865***	0.318
Small firm			-0.193**	0.090	-0.096	0.100
Science linkage					0.137*	0.084
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Constant	0.659***	0.245	0.697***	0.244	0.719***	0.275
First stage:						
Small firm			0.037	0.044	0.002	0.046
Science linkage					0.026	0.031
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Excluded Instruments for *subsidy:*						
Academic inventor	0.542***	0.095	0.543***	0.096	0.564***	0.110
Constant	0.036	0.061	0.029	0.059	-0.030	0.061
Number of observations	477		477		394	
Diagnostic tests and statistics						
R-squared (first stage)	0.302		0.303		0.306	
Partial R-squared of excluded instruments	0.150		0.151		0.165	
F-test of excluded instrument	32.40***		31.88***		26.18***	
Underidentification tests:						
Kleibergen-Paap rk LM statistic	16.47***		16.34***		13.03***	
Kleibergen-Paap rk Wald statistic	31.46***		30.82***		25.45***	

As a robustness check, Table 4 repeats the regression using the dummy endogenous variable IV regression model following Wooldridge (2002). This estimator is more efficient than the traditional 2SLS model and has several robustness properties, but requires to make stronger assumptions. The estimation of this model consists of two steps: (i) estimate a binary response model (probit or logit) of the dummy endogenous subsidy variable on all exogenous variables (including the instruments) and obtain the fitted probabilities, say $\overset{\curlywedge}{g}$. (ii) Estimate the outcome equation by IVs using $\overset{\curlywedge}{g}$ as an instrument. The subsidy coefficient estimate from this procedure using fitted values from a probit estimation as an IV as well as the standard errors are almost identical to the traditional IV estimates.

Table 4: Estimation results (3)

	(1) IV (wooldridge)		(2) IV (wooldridge)		(3) IV (wooldridge)	
	Coef.	s.d.	Coef.	s.d.	Coef.	s.d.
Subsidy	0.840***	0.280	0.881***	0.313	0.897***	0.320
Small firm			-0.188**	0.093	-0.087	0.103
Science linkage					0.132	0.087
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Constant	0.659***	0.246	0.694***	0.245	0.723***	0.276
First stage:						
Small firm			-0.009	0.046	-0.008	0.047
Science linkage					-0.005	0.033
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Excluded Instruments for *subsidy:*						
g hat	1.001***	0.156	0.970***	0.161	0.947***	0.195
Constant	0.000	0.061	0.007	0.058	0.012	0.061
First Stage Probit:						
Academic inventor	1.800***	0.289	1.820***	0.297	1.951***	0.346
Small firm			0.307	0.225	0.081	0.271
Science linkage					0.221	0.254
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Constant	-4.834***	0.553	-4.843***	0.483	-5.936***	0.738
Number of observations	477		477		394	
Diagnostic tests and statistics						
R-squared (first stage)	0.308		0.301		0.275	
Partial R-squared of excluded instruments	0.157		0.149		0.156	
F-test of excluded instrument	41.14***		36.11***		23.71***	
Underidentification tests:						
Kleibergen-Paap rk LM statistic	16.45***		15.87***		12.75***	
Kleibergen-Paap rk Wald statistic	39.44***		33.96***		23.61***	

Thus, the conclusion for all three models is that publicly subsidized inventions lead to patents of higher "importance" as measured by the number of forward citations. The literature on the evaluation of public funding generally analysis how public subsidies relate to private R&D. The results of this paper show that public subsidies have a positive impact on the outcome for which the project was initially funded. Using patent data solely enables to improve our understanding of the role of governement-sponsored research at the project level.

6 Conclusion

Innovation is widely recognized as being a major determinant of economic growth. Therefore, public initiatives aim at increasing the current level of innovative activity. In this context, the evaluation of these public policy is crucial in order to determine which policy tools are the most effective.

Most of the existing empirical literature shows that public subsidies to R&D are effective in stimulating private R&D (David et al., 2000; Aerts and Czarnitzki, 2008). However, little is known about the effect of these subsidies on innovative output. The aim of this paper was to assess whether R&D subsidies create additional social value by testing the effectiveness of public support to patented inventions. The results show that subsidized inventions result in more "important" patents, as measured by the number of forward citations.

Two important limitations of this analysis (and opportunities for future work) should be noted. The empirical analysis is confined to inventions that were successfully patented. The data did not enable me to track inventions that were subsidized but not patented either because of a contractual agreement between the sponsor and the applicant or because the research was unsuccessful. At the same time, the data does not allow me to test the "crowding-out" hypothesis, in other words, this specification does not answer the question as to whether the research would have been carried out even without the subsidy. However, most of the recent empirical work in this area concludes that this would not be the case.

References

[1] Acs, Z. and Audretsch, D. (1987), "Innovation, Market Structure and Firm Size", *Review of Economics and Statistics*, 71(), 567-574.

[2] Aghion, P. and Tirole, J. (1994), "The Management of Innovation" *Quarterly Journal of Economics*, 109(), 1185-1209.

[3] Almus, M. and Czarnitzki, D. (2001), "The Effects of Public R&D Subsidies on Firms' Innovation Activities: The Case of Eastern Germany", *Journal of Business and Economic Statistics,* 21 (2), 226–236.

[4] Angrist, J. (2001), "Estimation of Limited-Dependent Variable Models with Binary Endogenous Regressors: Simple Strategies for Empirical Practice", *Journal of Business and Economic Statistics.*

[5] Card, D. E. (1995), "Earnings, Schooling and Ability Revisited", in *Research in Labor Economics,* vol. 14. Polachek, S. W. (ed.), 23-48

[6] Cassiman, B., Veugelers, R. and Zuniga, M. (2008), "In Search of Performance Effects of (In)direct Industry Science links", *Industry and Corporate Change*, forthcoming.

[7] Cassiman, B. and Veugelers, R. (2006), "In Search of Complementarity in the Innovation Strategy: Internal R&D and External Knowledge Acquisition", *Management Science*, 52 (1), 68-82.

[8] David, P. A., Hall, B. H. and Toole, A.A. (2000), "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence", *Research Policy,* 29, 497–529.

[9] Eisenberg, R. (1996), "Public Research and Private development: Patents and Technology Transfer in Government-Sponsored research", *Virginia Law Review*, 82 (8), 1663-1727.

[10] Gonzalez, X., Jaumandreu, J. and Pazo, C. (2005), "Barriers to innovation and subsidy effectiveness", *Rand Journal of Economics,* 36 (4), 930-950.

[11] Giuri, P., Mariani, M., Brusoni, S., Crespi, G., Francoz, D. , Gambardella, A., Garcia-Fontes, W., Geuna, A., Gonzales, R., Harhoff, D., Hoisl, K., Le Bas, C, Luzzi, A., Magazzini, L., Nesta, L., Nomaler, Ö., Palomeras, N., Patel, P., Romanelli, M. and Verspagen, B. (2007), "Inventors and invention processes in Europe: Results from the PatVal-EU survey", *Research Policy*, 36 (8), 1107-1127.

[12] Hall, B., Jaffe, A. and Trajtenberg, M. (2005) "Market value and patent citations", *Rand Journal of Economics*, 36.

[13] Harhoff, D., Narin, F., Scherer, F. & Vopel, K. (1999), "Citation Frequency and the Value of Patented Innovation", *Review of Economics and Statistics* 81(3), 511–515.

[14] Harhoff, D., Hoisl, K. & Webb, C. (2005), "European Patent Citations – How to count and how to interpret them", Discussion paper, *University of Munich.*

[15] Henderson, R., Jaffe, A. and Trajtenberg, M. (1998) "Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting 1965-1988", *Review of Economics and Statistics*, Vol LXXX (1), 119-127.

[16] Jaffe, A. (2002), "Building Program Evaluation into the Design of Public Research-Support Programs" *Oxford Review of Economic Policy,* 18 (1), 22-34.

[17] Kaiser, U. (2005) "The Value of Danish Patents - Evidence from a Survey of Inventors", CEBR Discussion Paper No 2006-01.

[18] Klette, T. J., Møen, J. and Griliches, Z. (2000), "Do Subsidies to Commercial R&D Reduce Market Failures? Microeconometric Evaluation Studies", *Research Policy* 29, 471–495.

[19] Lach, S. (2002), "Do R&D Subsidies Stimulate or Displace Private R&D? Evidence from Israel", *Journal of Industrial Economics,* 50(4), 369–390.

[20] Marco, A. C. (2007), "The Dynamics of Patent Citations", *Economics Letters*, 94 (2), 290-296

[21] Moffitt, R. A., (1996), "Identification of Causal Effects Using Instrumental Variables: Comment.", *Journal of the American Statistical Association,* 91, 462-465.

[22] McClellan, M., McNeil, B. J. and Newhouse, J. P., (1994), "Does More Intensive Treatment of Acute Myocardial Infraction in the Elderly Reduce Mortality?" *Journal of the American Medical Association,* 272 (11), 859-866.

[23] Nordhaus, W. (1969), "Inventions Growth and Welfare: a Theoretical Treatment of Technological Change", MIT Press: Cambridge.

[24] Reinganum, J. F. (1983), "Uncertain Innovation and the Persistance of Monopoly", *American Economic Review*, 73, 741-748.

[25] Reinganum, J. F. (1985), "Innovation and Industry Evolution", *Quarterly Journal of Economics,* 100, 81-99.

[26] Romano, R. E. (1989), "Aspects of R&D Subsidization", *Quarterly Journal of Economics*, 104 (4), 863-873.

[27] Romano, R. E. (1991), "The Optimal R&D Policy: Patents, Public Funding, or Both?", *Southern Economic Journal*, 57 (3), 703-718.

[28] Sampat, B. N., Mowery, D. C. and Ziedonis, A. A.,(2003). “Changes in the University Patent Quality After Bayh–Dole: A Re–Examination” *International Journal of Industrial Organization,* 21, 1371–1390.

[29] Scotchmer, S. (2004) "Innovations and Incentives", MIT Press: Cambridge.

[30] Wallsten, S. J. (2000), The Effects of Government–Industry R&D Programs on Private R&D: the Case of the Small Business Innovation Research Programm, *RAND Journal of Economics* 31(1), 82–100.

[31] Webb, C., Dernis, H., Harhoff, D. and Hoisl, K. (2005), "Analyzing European and International Patent Citations: A Set of EPO Patent Database Building Blocks", *OECD Science, Technology and Industry Working Papers*, 2005/9, OECD Publishing.

[32] Wooldridge, J. M., (2002), "Econometric Analysis of Cross Section and Panel Data", MIT Press Cambridge.

Appendix

In this Appendix I check the robustness of the results with alternative instruments: two geographical dummies. The first one equals one if the invention was carried out in a city with less than 10,000 inhabitants and the second instrument takes the value one if the invention took place in a rural area. The choice of these instruments is motivated by the labour and health literature, in which geographical instruments are typical instruments used to assess the effect of a treatment on some outcome (see for example Card, 1995, Moffitt, 1996 or McClellan et al., 1994). In the present case, being an inventor in a small city or a rural area is assumed to have a negative impact on the probability to get a R&D subsidy and to be uncorrelated with unobserved quality of the invention. Governmental agencies delivering R&D subsidies are usually located in large cities (national or regional capitals), thus the physical distance between inventors located outside these urban areas and the relevant governmental agency is supposedly high. Another motivation for the choice of these instruments is that it is probably more difficult to simply get access to information on the different types of fundings when located in a small city or a rural area. The fact that regional dummies are included in both stages of the analysis avoids confounding large cities with innovation clusters that may attract more endowed human capital.

The instruments pass two standard tests, i.e. the test of overidentification, indicated by the p-value of the Sargan-Hansen test, and the test of excluded instruments, indicated by the p-value of the F-test. The results show that the instrumented subsidy dummy and the associated standard errors are very large in magnitude, which reveals that this identification strategy leads to less precise results, but confirms the causal effect found in Section 4. Moreover, the results show that once the subsidy dummy is instrumented for, the academic dummy is no longer significant which argues in favor of using it as an instrument.

Table 5: Estimation results (4)

	(3) 2SLS		(1) 2SLS		(2) 2SLS	
	Coef.	s.d.	Coef.	s.d.	Coef.	s.d.
Subsidy	1.716**	0.789	1.934**	0.927	1.82**	0.880
academic inventor			-0.543	0.538	-0.488	0.513
Small firm					-0.230*	0.125
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Constant	0.526**	0.268	0.587**	0.270	0.640**	0.262
First stage:						
academic inventor			0.513***	0.096	0.514***	0.097
Small firm					0.044	0.046
Technology classes	included		included		included	
Application years	included		included		included	
Regional dummies	included		included		included	
Excluded Instruments for *subsidy:*						
City with less than 10,000 inhabitants	-0.128***	0.037	-0.102***	0.032	-0.105***	0.032
Rural area	-0.099**	0.049	-0.109***	0.042	-0.112***	0.042
Constant	0.083	0.071	0.051	0.063	0.042	0.060
Number of observations	469		460		460	
F-test of excl. Instruments (p-value)	0.002		0.002		0.002	
Sargan-Hansen J test (p-value)	0.223		0.371		0.343	