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Evaluation of the Research Council of Norway

Background Report No 9. - Returns to publicly funded R&D and the contribution of RCN to higher R&D spending in Norway

Ådne Cappeln

Arvid Raknerud

Marina Rybalka

technopolis |group|

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Returns to R&D in Norway. The role of public grants and subsidies.

Ådne Cappelen, Arvid Raknerud* and Marina Rybalka

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1 Introduction

Both economic theory as well as empirical evidence support the view that R&D plays a vital role in raising productivity on a sustainable basis. The social return to R&D investment is often higher than the private return to the investing firm. Thus in the presence of market failure, policy intervention may be justified if a well-designed intervention scheme can be implemented.

R&D incentives are designed in many different ways. Many countries offer tax credit schemes for R&D expenses and all countries in the OECD offer fiscal incentives in the form of grants to R&D. Although more countries have introduced tax incentives over time there is no consensus on what is best practise. Evaluations of the incentives in various countries may provide some evidence on which policies or policy mix that work well.

The present study is part of an evaluation of the Research Council of Norway (RCN) and deals with the returns to R&D, with a particular focus on the role of grants given by RCN. RCN finances R&D activities at the firm level in order to stimulate firms to increase their R&D. Since Norwegian firms on average do not spend much on R&D compared to other European countries[1], the role of RCN in stimulating R&D spending in the business sector is particularly important. A recent study (Henningsen et al., 2011) show that RCN

*Corresponding author: Arvid Raknerud, Statistics Norway, PO Box 8131 Dept, 0033 Oslo, Norway. E-mail: arvid.raknerud@ssb.no; tel.: +4721094445

[1] The official R&D statistics for 2009 (published in 2011), show that total R&D expenditure in Norway was equal to 42 billion Norwegian kroner (NOK) (4.8 billion EURO). 43 per cent of the R&D activity took place in the private sector, while the Higher Education Sector contributed with 32 per cent and the Institute sector with 25 per cent. R&D expenditure as a share of GDP was 1.8 per cent, which is below the OECD average of 2.3 per cent. Norway is among the 1/3 countries in the OECD with the lowest R&D expenditure relative to GDP.

is quite successful in achieving a high input additionality of their funding compared to what is often found for other countries. An important issue is therefore to investigate to what extent RCN funded R&D projects create value added for the business sector and society as a whole.

In our study we address productivity and profitability effects of R&D using a comprehensive panel of Norwegian firms in all industries over the period 2001-2009. All firms in Norway with more than 50 employees are included. The main data source is the R&D survey, which contains information on total amount of firm's R&D spending as well as information on the financing of the R&D projects. We are therefore able to construct data for accumulated R&D investments by source of financing. In order to evaluate the value added of RCN funded R&D projects, we estimate the total R&D capital stock for each firm in our panel, and the share of this capital stock that has been financed by RCN. Then we address the question of whether the return to R&D is different for RCN funded R&D compared to R&D in general.

In the existing economic literature, the most common way of estimating returns to R&D is to add all R&D spending for each firm or industry (or even country) without distinguishing between source of financing. Thus it is implicitly assumed that projects are perfect substitutes with the same economic returns. A more flexible approach is to *allow* various projects to be perfect substitutes in terms of economic returns, but without imposing this as a restriction a priori. Aggregating various R&D projects according to their source of finance using a constant elasticity of substitution (CES) aggregation function, provides a framework for testing whether the economic returns to different projects depend on financing.

When studying the value added of R&D for firms and society we must allow for the possibility of running a viable firm without ever undertaking R&D. This seems to be a fairly obvious statement since most firms state in R&D surveys that they do not undertake any R&D.[2] Our reason for drawing attention to this issue is to emphasize that it has important implications for how we should specify the underlying production structure when analyzing firm behavior. Not allowing for the possibility of running a viable firm

[2] The shares of firms reporting positive R&D in the survey vary from 25 % to 37 % during 2001-2009 with about 72 % of firms never undertaking R&D. For the firms with more than 50 employess the corresponding shares vary from 37 % to 48 % with about 49 % of these firms never undertaking R&D in 2001-2009.

with zero R&D capital may bias our estimate of the returns to R&D.

We focus on labour productivity, measured as net value added per man-hour, as a measure of firm performance. When analyzing the effects of R&D expenditures, and the RCN incentives in particular, we use a standard approach in the literature where log-productivity is regressed on firm specific characteristics including various R&D related variables. Our results suggest that the productivity effects of RCN subsidies to R&D projects are not significantly different from R&D spending in general. To be more precise, we cannot reject the hypothesis that the productivity effect of RCN funded projects is similar to that of ordinary R&D. Our estimate of the average rate of return to R&D spending by Norwegian firms is 10 per cent. This estimate is in line with what is common in the international literature, cf. Hall et al. (2010).

The structure of the paper is as follows. In Section 2 we present some studies relevant for our investigation. In Section 3 we present our theoretical framework for analyzing the effect of R&D on productivity. Section 4 shows how the variables are constructed from various data sources, Section 5 presents the results and Section 6 offers some concluding comments.

2 Previous studies of R&D effects on productivity and firm performance

There are several models for the relationship between R&D activities and productivity at the firm or industry level in the economic literature. One quite general model structure is developed in Pakes and Griliches (1984) and used in Crepon et al. (1998). See also the recent survey by Hall, Mairesse and Mohnen (2010). In these studies output is a function of input services and total factor productivity. If we take the standard neoclassical production function with constant returns to scale as a starting point, we can express labour productivity (say net value added per man-hour) as a function of capital intensity (capital per man-hour), K/L, and total factor productivity, A^*,

$$Y/L = A^* f(K/L). \tag{1}$$

The productivity level, A^*, is assumed to depend on several variables relating to market factors, industry, knowledge capital, research and development and so forth. In several studies, see Parisi et al. (2006) for an example, R&D capital and investment are not necessarily treated as the driving forces of productivity directly, but are instead assumed to influence the productivity level (A^* in the equation above) through product and process innovations. There is also a separate strand of literature that looks at the impact of R&D expenditures on innovation separately, cf. Mairesse and Mohnen (2004), and Cappelen et al. (2012) for a recent study.

A common approach when specifying the effects of R&D on productivity is to link the productivity factor A^* in equation (1) to the R&D knowledge stock, RK. The standard approach is to assume that

$$A^* = A(RK)^{\eta}, \tag{2}$$

where η is the elasticity of Y with respect to RK, A is total factor productivity and the knowledge capital stock accumulates according to

$$RK_t = (1 - \delta)RK_{t-1} + R_{t-1}, \tag{3}$$

where δ is the depreciation rate of the knowledge stock and R is R&D investment. If we assume the depreciation rate to be small, we can write

$$\Delta \ln(A_t^*) = \varrho(R_{t-1}/Y_{t-1}) + \Delta a_t, \tag{4}$$

where ϱ is the rate of return to R&D, cf. Griffith et al. (2004), and $a_t = \ln A_t$. Equation (4) says that the growth rate of productivity depends linearly on the R&D investment divided by net value added, lagged one year. On the other hand, if an estimate (or qualified guess) of the depreciation rate is available, one can calculate the R&D capital stock, RK, according to standard PIM-procedures. In this case a direct estimation of (1)-(2) is possible. However, if one is uncertain about the depreciation rate of R&D, but is willing to assume that it is "small", model (4) is an alternative. Since little is known about the depreciation rate of R&D, both approaches are well worth pursuing in empirical work.

Parisi et al. (2006), using Italian data, estimate the rate of return to knowledge capital to 4 per cent. This is rather low and is an interesting result for a country with relatively low R&D intensity in the business sector. Their results show that when both R&D intensity and an indicator for process innovation are included in the model, the

R&D variable becomes insignificant. However, this result could be due to a simultaneity problem. Crepon et al. (1998) estimate a model with labour productivity as the dependent variable, as in (1) above. They estimate the η-parameter in equation (2) to lie in the interval 0.12-0.15 when they use OLS and GLS, but obtain rather implausible figures using two-stage least squares. In their sample of French manufacturing firms, they estimate that the mean rate of return to R&D is 14 to 18 percent[3]. Similar results are found in a panel of OECD-countries, cf. Guellec and van Pottelsberghe de la Potterie (2001). This result is also within the typical range reported by Griliches (1995), which found that the median private gross return is 25 percent. Assuming a depreciation rate of 15 per cent, the net return becomes around 10 per cent.

There are few econometric studies using Norwegian firm data to estimate the rate of return to R&D at the micro level. A well known study is that of Klette and Johansen (1998) using data on manufacturing firms. They estimate a modified version of the model presented earlier. In their model the knowledge stock does not accumulate according to a linear function but according to a log-linear one. This assumption is based on the idea that old capital and investment in new knowledge capital are complementary so that the more you have of existing knowledge, the higher is the marginal return to investment. In this way, you may have increasing returns in the production of knowledge. They do not assume a rate of depreciation a priori but instead estimate it, imposing some identifying restrictions (no increasing returns to knowledge production), to be around 0.15 which is a quite common value used in the literature, cf. also Parisi et al. (2006). The model in Klette and Johansen (1998) is not very different from equation (4) above. However, in their model lagged growth in total factor productivity is included on the right hand side. Moreover, their R&D variable is not specified as in equation (4), but includes the growth rate of R&D in addition to industry dummies, the age of the firm, plant type dummies etc. Their "best-practice" estimate of the mean net rate of return to R&D at the firm level is 9 per cent. However, the rate of return varies considerably between industries.

Griffith et al. (2004) develop a generalization of the model discussed so far. Based on theories of endogenous innovation and growth, technology transfer is seen as a source of productivity growth for countries or industries behind the technological frontier. Further-

[3] Note that $\eta = \frac{\partial Y_t}{\partial RK_{t-1}} \frac{RK_{t-1}}{Y_t}$, where $\frac{\partial Y_t}{\partial RK_{t-1}}$ is the rate of return on R&D.

more, R&D activities are seen as an important factor in creating an absorptive capacity for new knowledge and technology in line with the seminal paper by Cohen and Levinthal (1989). The specification chosen by Griffith et al.(2004) is

$$\Delta \ln (A_t^*) = \varrho \frac{R_{t-1}}{Y_{t-1}} + \beta X_t + \mu \ln(\frac{A_{F,t-1}}{A_{t-1}}) + \kappa \frac{R_{t-1}}{Y_{t-1}} \ln(\frac{A_{F,t-1}}{A_{t-1}}), \tag{5}$$

where A_F is the productivity level at the frontier (country or industry). The term A_F/A measures the difference from the technology frontier for each firm and can be seen as a way of capturing "catch-up" effects, a concept well-known from the literature on economic convergence of income. The last term on the right hand side captures the interaction between distance from the frontier and own R&D effort. This variable is an indicator of absorptive capacity. The idea is that the further a firm/industry/country lags behind the frontier, the more it will benefit from investing in capacity to learn from or imitate others. In their estimated equations, they also include a measure of human capital separately in addition to R&D. This variable also interacts with the technology gap variable. They find that the technology gap variable, or "catch-up" variable is not significant when entered alone ($\mu = 0$), whereas all the other terms enter significantly. Their conclusion is that disregarding interaction terms may lead to a potential mis-specification, and hence producing a bias when estimating the effects of R&D investment on productivity growth.

A limitation of the (standard) approach presented above is that the production function framework cannot be valid for a whole industry, as it predicts zero output for firms with zero R&D, which is obviously false. The problem is usually treated as a technical one, the remedy being to add a small constant, say λ, to RK in equation (4). However, this solution may lead to biased inference. We propose instead a more flexible and general approach.

We base our study on conventional regression analyses using a specification of the production function of firms, or what Hall et. al (2010) call the "primal approach". We do not focus on how R&D subsidies and grants may increase R&D, but rather whether the productivity effect of R&D capital financed by the Research Council of Norway (RCN) differs from the effects of R&D capital in general. Because the implicit price of RCN-financed R&D is lower than the market price of R&D one might expect that the economic return of RCN-funded R&D is lower than the average return. However, this applies only to the firms whose marginal price of R&D is affected by RCN financing. Thus the effect of RCN financing may depend on the size of the R&D activity.

3 Theoretical framework

Our starting point is a production function which is homogeneous of degree one in number of man-hours (L), real capital (K) and a measure of aggregate R&D capital (F). We assume

$$Y = AL^{\beta_0}K^{\beta_1}(\lambda L + F)^{\beta_2}, \tag{6}$$

with $\beta_0 + \beta_1 + \beta_2 = 1$ (constant returns to scale), where Y is production, measured as net value added, i.e. net of depreciation, in constant prices, A is total factor productivity (unexplained "efficiency") and F is an aggregate of two types of R&D capital, N and O;

$$F = (\alpha N^{\rho} + O^{\rho})^{\frac{1}{\rho}}, \tag{7}$$

where we distinguish between RCN funded R&D capital, N, and other R&D capital, O.

A recent study of input additionality of grants from RCN indicates that the additionality factor in Norway is 1.2 which implies that a grant from the RCN is matched by 20 per cent additionality from internal funds by the firm, cf. Henningsen et al. (2011). An R&D-project financed by the RCN is therefore almost completely separate from an R&D project financed only by the firm. When we suggest to aggregate R&D capital financed by the RCN versus the firm using a CES-function, we are close to aggregating separate R&D-projects.

The elasticity of substitution between the two "types" of R&D capital equals $s = 1/(1-\rho)$. If the distribution parameter $\alpha \neq 1$, N and O enter the aggregate *asymmetrically* with N being less productive (for given N and O) the lower is α. In particular, the marginal product of N is higher than that of O when $N/O < \alpha^s$. The special case $s = \infty$ ($\rho = 1$), is particularly important. Then $\alpha = 1$ implies that the two types of R&D capital have the same marginal productivity, whereas $\alpha < 1$ implies that for a given level of $RK = N + O$, the marginal product of R&D will be higher the *lower* is the share of RCN financing. Note that in general F differs from RK, unless $s = \infty$ *and* $\alpha = 1$.

Our conjecture is that we should not expect the decomposition of RK into N and O, i.e., the ratio N/O to matter much for the marginal productivity of R&D. Hence our hypothesis is that $s = \infty$ and $\alpha = 1$. However, there are at least two arguments that might lead to different results. Usually RCN finances projects that are of the matching grant type where RCN decides to provide a firm with additional funds if the firm also commits to spend its own resources on R&D. If the firm wants to improve the probability for receiving additional funds from the RCN it may propose R&D projects that are particularly well prepared or have a high chance of being selected. In this case there may be a form of self-selection of projects with high probability of being successful. These projects might then have a more positive effect on productivity than an average R&D project. In this case we might find that the estimated effect of RCN subsidized R&D is positive ($\alpha > 1$). The alternative is to think that since there is an element of subsidy in RCN funded projects, the marginal cost of the project for the firm is lower and therefore also the return ($\alpha < 1$).

The specification (6), unlike (2), allows the (aggregate) R&D variable, F, to be zero without implying $Y = 0$. Note that this model is invariant with respect to choice of scale[4]. Two limiting cases are of particular interest: (i) $\lambda \to 0$, in which case (6) approaches a Cobb Douglas production function in L, K and F (the traditional approach), and (ii) $\lambda \to \infty$, which we will analyse in more detail below.

In the general model, assuming $\beta_0 + \beta_1 + \beta_2 = 1$, it follows that

$$\begin{aligned} \frac{Y}{L} &= A\left(\frac{K}{L}\right)^{\beta_1}\left(\lambda + \frac{F}{L}\right)^{\beta_2} \\ &= A\left(\frac{K}{L}\right)^{\beta_1}\left(\lambda + (\alpha n^{\rho} + o^{\rho})^{\frac{1}{\rho}}\right)^{\beta_2}, \end{aligned} \tag{8}$$

where $n = N/L$ and $o = O/L$. Note that labor productivity is homogenous of degree zero in (K, L, N, O). Taking logarithms of both sides of (8) and reformulating, we obtain:

$$y = a + \beta_1 k + \beta_2 \ln(\lambda + f), \tag{9}$$

where

$$y = \ln(Y/L), \;\; a = \ln A \; k = \ln(K/L), \; f = F/L.$$

[4]For example, replacing F by $F^* = kF$, gives

$$Y = AL^{\beta_0}K^{\beta_1}(\lambda L + \frac{F^*}{k})^{\beta_2} = kAL^{\beta_0}K^{\beta_1}(\frac{\lambda}{k}L + F^*)^{\beta_2} = A^*L^{\beta_0}K^{\beta_1}(\lambda^* L + F^*)^{\beta_2}$$

which has the same form as (6).

It follows that

$$\begin{aligned} \mathrm{El}_F Y &= F\frac{\partial y}{\partial F} = \beta_2 (\lambda + f)^{-1} f \\ \mathrm{El}_L Y &= 1 - \beta_1 - \mathrm{El}_F Y \\ \mathrm{El}_K Y &= \beta_1. \end{aligned} \tag{10}$$

To study the case where λ is large, we can rewrite (9) as

$$y = a + \beta_1 k + \beta_2 \ln\left(1 + \frac{f}{\lambda}\right) \tag{11}$$

(where a is redefined to include the term $\beta_2 \ln \lambda$). When λ is large, $\ln(1 + f/\lambda) \simeq f/\lambda$. Hence we can reformulate (11) as

$$y = a + \beta_1 k + \beta_2^* f, \tag{12}$$

where $\beta_2^* = \beta_2/\lambda$. Then

$$\begin{aligned} \mathrm{El}_F Y &= \beta_2^* f \\ \mathrm{El}_L Y &= 1 - \beta_1 - \beta_2^* f. \end{aligned} \tag{13}$$

The parameter β_2^* in (12) has a different interpretation than β_2 in (9).

The limiting case (12) is particularly interesting because it allows an approximation when and the depreciation rate of R&D capital, δ, is small, similar to Griffith et al. (2004): Then, as we show in Appendix B,

$$\Delta y_t \simeq \Delta a_t + \beta_1 \Delta k_t + \varrho\left(\frac{R_{t-1}}{Y_{t-1}}\right) - \eta \Delta \ln L_t, \tag{14}$$

where ϱ can be interpreted as the expected return to R&D: $\varrho \equiv E(\partial Y/\partial F)$. In (14) it is assumed both that $s = \infty$ and $\alpha = 1$, so that $F = RK$, whereas η is the expected (mean) value of $\mathrm{El}_F Y$: $\eta \equiv E(\mathrm{El}_F Y)$.

4 Data and variables construction

We have constructed a panel of annual firm-level data for Norwegian firms, with at least three consecutive observations during 2001–2009. The base for the sample is the R&D

statistics which are survey data collected by Statistics Norway. These data comprise detailed information about firms' R&D activities, such as total R&D expenses (divided into own-performed R&D and purchased R&D), grants from the RCN, the number of employees engaged in R&D activities and the number of man-hours worked in R&D. Each survey contains about 5000 firms. Only firms with more than 50 employees are automatically included in the survey. For smaller firms (with 5-49 employees) a stratified sampling scheme is employed. The strata are based on industry classification (NACE codes) and firm size. However, these smaller firms are not representative for firms of their size and industry, since they have a higher probability of doing R&D. Hence, to reduce the problem of endogenous sample selection, we include only firms with more than 50 employees in our analysis. Currently, data are available for 1993, 1995, 1997, 1999, and *annually* from 2001-2009. The information from all available surveys is used for the construction of the R&D capital stocks. However, only data from 2001 are useful for estimation of our empirical models, because the surveys conducted before 2001 are not annual but biannual.

Table 1: Overview of variables and data sources.

Variable	Definition	Data sources
Y	Output (net value added)	accounts statistics
R	R&D investment	R&D statistics
RK	Total R&D capital stock	R&D statistics
RCN	Grants from the RCN	R&D statistics
N	RCN capital stock	R&D statistics
K	Total capital stock	accounts statistics
L	Man-hours	REE
h	Share of man-hours worked by high-skilled workers	REE, NED
Derived variables:		
O	$RK - N$	
y	Log of labour productivity: $\ln(Y/L)$	
k	Log of capital intensity: $\ln(K/L)$	
o	O/L	
n	N/L	
F	$(\alpha N^{\rho} + O^{\rho})^{\frac{1}{\rho}}$	
f	F/L	

The data from the R&D statistics are supplemented with data from three different registers: The accounts statistics, The Register of Employers and Employees (REE), and The National Education Database (NED). Table 1 presents an overview of the main variables and data sources used in our study. The data sources are described in more detail in Appendix A.

Output, Y, is net value added at factor costs and computed as the sum of operating profits net of depreciation and labour costs and deflated by the consumer price index. R&D investment, R, is yearly R&D investment and RCN are the grants from RCN as they are reported in the questionnaire, deflated by a price index for R&D investment based on the price indices from the national accounts for the various components making up total R&D. According to Hall et. al. (2010) the choice of deflator for R&D expenditures usually does not matter much for the econometric results for the main parameters of interest.

The (real) R&D capital stock (RK) at the beginning of a given year t, is computed by the perpetual inventory method using (3) and a constant rate of depreciation ($\delta = 0.15$). Following Hall and Mairesse (1995), the benchmark for the R&D capital stock at the beginning of the observation period for a given firm, RK_0, is calculated as if it were the result of an infinite R&D investment series, R^*_{-t}, $t = 0, 1, 2, ...$, with a fixed pre-sample growth rate $g = 0.05$. See Cappelen et al. (2012) for details. A separate capital stock, N, is calculated in the same way, using RCN instead of R to accumulate the capital stock. Then $O = RK - N$ is R&D capital stock of R&D financed from other sources than RCN.

To construct the physical capital stock, K, we used information from accounts statistics. The accounts statistics distinguish between several groups of physical assets. To obtain consistent definitions of asset categories over the sample period, all assets have been divided into two types: equipment, denoted by e, which includes machinery, vehicles, tools, furniture, and transport equipment; and buildings and land, denoted by b. The expected lifetimes of the physical assets in group e (of about 3–10 years) are considerably lower than those of the assets in group b (about 40–60 years). Total capital, K, is then an aggregate of equipment capital, e, and building capital, b. We use the book value as a measure of the capital stock. This is justified on the grounds of the short time series for each firm and corresponds to the approach taken by Power (1998) and Baily et al. (1992). When aggregating the two capital types, we use a Törnqvist volume index with time-varying weights that are common across firms in the same industry (see OECD, 2001).

Man-hours, L, is the sum of all individual man-hours worked by employees in the given firm according to the contract. For each firm, we distinguish between two educational groups, high-skilled and low-skilled. High-skilled workers are those who have post-secondary education, i.e., persons who have studied for at least 13 years (for a description of the educational levels, see Table 5 in Appendix A). Man hours worked by high-skilled persons are aggregated to the firm level and divided by the total number of man-hours worked in the given firm defining h. That is, h is the share of man-hours worked by high-skilled workers.

As we mentioned above, to avoid the problem of endogenous sample selection, only firms with more than 50 employees are included in our analysis. We further exclude from the sample firms with incomplete information or with extreme values for the variables of interest. We need to use the panel structure of the data in order to address the endogeneity problem that arises with respect to input choices and to be able to conduct a dynamic analysis. Hence, only firms with observations in at least three consecutive years are kept. The final sample contains then about 1900 firms. Descriptive statistics for the main variables are presented in Appendix C.

5 Implementations and results

5.1 Estimation

In addition to the variables discussed above, our analysis includes dummies for firm's age, industry and location, whether the firm cooperate with other firms and whether the firm uses an external research institute for their R&D. The dummy variables are collected in the vector D_i. Then

$$y_{it} = \beta_1 k_{it} + \beta_2 \ln(\lambda + f_{it}) + \beta_3 h_{it} + \beta_4' D_i + \nu_i + \zeta_{it}, \qquad (15)$$

where the indices $i = 1, ..., N$ and $t = 1, ..., T$ denote firm and time, respectively, ν_i represents a random firm specific term and ζ_{it} is an error term. We allow the error term ζ_{it} in (15) to follow a first-order autoregressive process, i.e.,

$$\zeta_{it} = \phi \zeta_{i,t-1} + \varepsilon_{it},$$

where

$$|\phi| < 1, \; E[\varepsilon_{it}] = 0, \; E[\varepsilon_{it}^2] = \sigma_\varepsilon^2$$

and

$$Cov[\varepsilon_{it}, \varepsilon_{jt}] = 0 \text{ if } t \neq s \text{ or } i \neq j.$$

Then, multiplying (15) by ϕ and taking quasi-difference, we get a dynamic panel data equation

$$\begin{aligned} y_{it} &= \phi y_{i,t-1} + \beta_1 k_{it} + \varphi_1 k_{i,t-1} + \beta_2 \ln(\lambda + f_{it}) + \varphi_2 \ln(\lambda + f_{i,t-1}) \\ &\quad + \beta_3 h_{it} + \varphi_3 h_{i,t-1} + \varphi_4' D_i + \varpi_i + \varepsilon_{it} \end{aligned} \tag{16}$$

where

$$\begin{aligned} \varphi_1 &= -\phi\beta_1, \, \varphi_2 = -\phi\beta_2, \varphi_3 = -\phi\beta_3, \\ \varphi_4 &= (1-\phi)\beta_4, \, \varpi_i = (1-\phi)\nu_i. \end{aligned} \tag{17}$$

Equation (16) is a first order difference equation, which can be solved by repeated substitution of lagged values $y_{i,t-1}$, $y_{i,t-2}$, and so forth. If we do this, we will see that every value of y_{it} depends on ω_i and all $\varepsilon_{i,t-s}$ for $s \geq 0$. Thus, $y_{i,t-1}$, is correlated with the firm specific effect, ω_i, but not with ε_{it}. Moreover, we assume that k_{it}, f_{it} and h_{it} are predetermined variables, i.e., determined at the beginning of t, and hence correlated with ω_i and $\varepsilon_{i,t-s}$ for $s > 0$.

The estimation of equation (16) using least squares will give inconsistent estimators. The common idea of the methods for addressing the endogeneity problem is to estimate equation (16) in first-differenced form in order to exclude ω_i from the equation and then use instruments for the endogenous variables. We use the version of the generalised method of moments (GMM) proposed by Arellano and Bond (1991) which is implemented in STATA. Their framework identifies which lags of the endogenous variables that are valid instruments and how to combine these lagged levels with first differences into a potentially large instrument matrix. This procedure can be very useful in our case, since we have relatively short time-series, which requires effective instruments.

To estimate the non-linear parameters (λ, ρ, α), we performed a grid search in the (λ, ρ, α)-space, where for each λ, ρ and α value, we estimate (16) using the GMM-estimator described above. This is equivalent to non-linear GMM with the same orthogonality conditions used as in the linear GMM method. The final (λ, ρ, α)-estimates are chosen such that the GMM-criterion function is minimized [5]. It turned out that $\widehat{\rho} = 1$ and $\widehat{\lambda} \approx 130$ for all $\alpha \in [0, 2]$ (and hence for all reasonable values of α). Therefore, for all practical purposes we can assume that $\widehat{\lambda} = \infty$. Then we can write

$$\begin{aligned} f &= \alpha N/L + O/L \\ &= RK/L + (\alpha - 1)N/L. \end{aligned} \tag{18}$$

Moreover, using (11) and (15), $\ln(\lambda + f_{it})$ in (15) can be replaced by f_{it}. We then obtain

$$y_{it} = \beta_1 k_{it} + \beta_2^* \frac{RK_t}{L_t} + \beta_2^*(\alpha - 1)\frac{N_t}{L_t} + \beta_3 h_{it} + \beta_4' D_i + \nu_i + \zeta_{it}, \tag{19}$$

The corresponding dynamic regression equation can be expressed as

$$\begin{aligned} y_{it} &= \phi y_{i,t-1} + \beta_1 k_{it} + \varphi_1 k_{i,t-1} + \beta_2^* \frac{RK_t}{L_t} + \beta_2^*(\alpha - 1)\frac{N_t}{L_t} + \\ & \varphi_2^* \frac{RK_{t-1}}{L_{t-1}} + \varphi_2^*(\alpha - 1)\frac{N_{t-1}}{L_{t-1}} + \beta_3 h_{it} + \varphi_3 h_{i,t-1} + \varphi_4' D_i + \varpi_i + \varepsilon_{it}, \end{aligned} \tag{20}$$

where $\varphi_2^* = -\phi\beta_2^*$ and ε_{it} is white noise.

Note that the parameters β_1, β_2^* and β_3, can be interpreted both as short-run and long-run coefficients under the restrictions (17). For example, from (20) the long-run effect on y_{it} of a *permanent* unit change in k_{it} equals $(\beta_1 + \varphi_1)/(1 - \phi)$, which is equal to β_1 under the restrictions (17). Similarly, the long-run coefficient of RK/L, is $(\beta_2^* + \varphi_2^*)/(1 - \phi)$ which is equal to β_2^*. There are several possible estimators of the long-run coefficients. One is the estimated coefficient of k_{it} in (20), $\widehat{\beta}_1$. However, this estimator is not robust towards specification errors in (17). A more robust estimator is the long-term coefficient of k_{it} derived from (20): $\widehat{\beta}_1^{LR} = (\widehat{\beta}_1 + \widehat{\varphi}_1)/(1 - \widehat{\phi})$. If the model is correctly specified, $\widehat{\beta}_1$ should be close to $\widehat{\beta}_1^{LR}$. A third method is to impose (17) a priori when estimating (20). We will pursue the first and second approach here and test whether the restrictions are valid or not.

The final estimates are presented in Table 2. As a benchmark we also present fixed effects (FE) estimators of (19). The FE estimator is a conventional within-estimator applied to equation (19). However, this method yields biased estimates due to endogeneity of explanatory variables, as explained above.

[5] This is asymptotically equivalent to maximzing the Wald-statistic provided by STATA as a goodness of fit-test of the model against an alternative with only a constant term. We refer to Appendix C for some results from the grid search.

Both the FE and GMM estimators of the coefficient of the aggregate R&D capital stock variable, RK_t/L_t, are positive and significant. However, the estimated (long-run) coefficient is notably smaller using FE (0.10) than GMM (0.29). Note that the estimated short-run coefficient of RK_t/L_t (0.23) is close to the long-run coefficient (0.29). This gives support to the parameter restrictions (17). The estimates of $\beta_2(\alpha - 1)$ (the coefficient of N_t/L_t) are not significantly different from zero using any of the methods. These results indicate that R&D capital subsidized by RCN adds no more or less to a firm's productivity than other R&D projects and that this is a robust finding.

As expected, we find a significant positive relation between capital intensity, k, and labor productivity: the estimated elasticity of tangible capital is around 0.1 using GMM. The FE-estimate is much smaller. Seen together, these results indicate that the FE-estimator of the coefficients of both the physical capital stock (k) and the R&D capital stock (RK/L) are biased downwards. With regard to the variable h (share of man-hours by high skilled workers), the results are ambiguous. GMM yields no significant coefficient estimates, whereas the FE estimator is positive, but significant only at the 10% level. The reason may be that both the FE and GMM estimator eliminates regressors that are constant over time, and poorly identify effects of variables that exhibit little variation over time, which is the case for h.

The estimate of ϕ – the coefficient $y_{i,t-1}$ – in Table 2 is equal to 0.38 and is highly significant. Thus the error term in (16) exhibits strong serial correlation. Note that from (16) and (17) the coefficient, φ_2, of RK_{t-1}/L_{t-1} should satisfy the constraint $\varphi_2 = -\phi\beta_2$. This constraint, and the other parameter restrictions in (17), are tested in Table 3. Neither of the restrictions are rejected by the statistical tests. As also seen form Table 3, the Arellano-Bond test of zero autocorrelation in the error term ε_{it} in (19) is not rejected. The test reported in the table is that of second order autocorrelation in the *differenced* errors, $\Delta\varepsilon_{it}$. We applied a Sargan test to test the validity of the instrumental variables. The hypothesis being tested is that the overidentifying restrictions are valid. With a χ^2-test statistic of 125.55 and 121 d.f. we cannot reject this hypothesis. All these tests taken together give support to our econometric specification.

Table 2: GMM-estimates of productivity equation. Robust standard errors in brackets

Explanatory variables,[a)]	GMM-estimates		FE (Within)
	short run coefficients[b)]	long run coefficients[c)]	estimates[d)]
y_{t-1}	0.38 [0.03]***	–	–
k_t	0.09 [0.02]***	0.10 [0.03]***	0.03 [6.18]***
k_{t-1}	-0.03 [0.02]*	–	–
RK_t/L_t	0.23 [0.03]***	0.29 [0.06]***	0.10 [2.46]**
RK_{t-1}/L_{t-1}	-0.05 [0.03]*	–	–
N_t/L_t	-0.59 [0.38]	-1.00 [1.44]	-0.60 [0.48]
N_{t-1}/L_{t-1}	-0.02 [0.77]	–	–
h_t	-0.09 [0.16]	0.14 [0.24]	0.16 [1.98]**
h_{t-1}	0.18 [0.14]		
Number of observations	7124		7124
Number of firms	1886		1886
R^2			0.17

[a)]Dummies for firm age, region, industry, cooperation and time dummies are included in the analysis but not reported here

[b)]Estimates of coefficients of dynamic equation (20): $\widehat{\phi}, \widehat{\beta}_k, \widehat{\varphi}_k$, etc.

[c)] Derived long-run coefficients from (20): $(\widehat{\beta}_k + \widehat{\varphi}_k)/(1 - \widehat{\phi})$, etc.

[d)]Fixed effects estimator of (19)

* significant at 10 per cent ** significant at 5 per cent ***significant at 1 per cent

5.2 Returns to R&D

GMM is the most appropriate method to handle the problem of endogeneity and autocorrelation in the residuals. From the GMM-estimates in Table 2, we can calculate the elasticity of labour productivity with respect to R&D for any firm from (13). Moreover, the marginal return to R&D capital, $\partial Y/\partial F$, equals

$$\frac{\partial Y}{\partial F} = \beta_2^* \frac{Y}{L}.$$

Using our long-run estimate of β_2^* (= 0.29), we find that the estimated mean elasticity of net value added with respect to R&D (for firms with positive R&D) is 2.6 per cent, whereas the derived marginal returns has a mean value of 10.0 per cent and median of 7.9 per cent. These figures are within the range of estimates obtained in the international literature and also in line with the result obtained by Klette and Johansen (1998) on Norwegian manufacturing firms for the period 1980-1992.

An alternative approach to estimating the average returns to R&D, is provided by the model described in equations (14), which assumed a small depreciation rate δ, $s = \infty$ ($\rho = 1$) and $\alpha = 1$. Under the same assumptions regarding the error term ε_{it} and

Table 3: Test of parameter restrictions and significance of derived long-run coefficients

Test of:	Test statistic (Z) z	Level of significance $\Pr(Z > z)$
parameter restrictions (17)*		
$\varphi_1 = -\phi\beta_1$	0.32	0.75
$\varphi_2^* = -\phi\beta_2^*$	1.38	0.17
$\varphi_3 = -\phi\beta_3$	1.21	0.23
$(\alpha-1)\varphi_2^* = -\phi\varphi_2^*(\alpha-1)$	-0.32	0.75
Arelano-Bond test of zero autocorrelation in errors*	0.28	0.77
Sargan test of overidentifying restrictions**	125.55	0.10

*t-test **test statistics is $\chi^2(107)$

explanatory variables as above, we can re-write (14) as

$$\Delta y_{it} = \beta_1 \Delta k_{it} - \eta \Delta \ln L_{it} + \varrho \left(\frac{R_{i,t-1}}{Y_{i,t-1}} \right) + \beta_3 \Delta h_{it} + \Delta \varepsilon_{it}, \tag{21}$$

where ϱ is the expected return to R&D.

The estimation results for (21) are presented in Table 4, together with an extended version of the model which is similar to Griffith et al. (2004); the productivity gap variable (A_f/A) is included as an explanatory variable as in (5). The dependent variable is the first-differenced log net value added per man-hour, Δy_t. The main variable of interest is R&D intensity, i.e., R&D expenditures (R) divided by net value added (Y). In this model the assumed rate of depreciation of R&D capital is small so that R&D intensity is the relevant variable to include as discussed earlier. The advantage of this approach is that we do not need to assume any specific number for the depreciation rate (only that it is small) nor do we have to impute the initial R&D capital stock. Looking at the instrumental variable estimates in the first column of Table 4 we obtain an estimate of the real rate of return to R&D (ϱ) of about 5 percent, whereas the estimate for the extended model (second column) is 10.4 per cent. This latter estimate is significant at the one per cent level, and almost exactly equal to the mean return derived from the model estimated above (of 10 per cent). However, the estimate of the elasticity of tangible capital is implausible, and even negative, although insignificant. The growth in share of employees with high education is estimated to have an unexpected negative effect. More importantly we have included a dummy variable (d_RCN) to capture the productivity effect of having R&D financing from RCN. This dummy is virtually zero and insignificant implying that firms that receive financing from RCN have the same returns on their R&D activities as firms

Table 4: GMM estimates of productivity growth equation. Standard errors i brackets

Dependent variable: $\triangle y_t$	Instrumental variable estimates			
Explanatory variables[a)]	Basic model (21)		Extended model as in (5)	
Δk_t	-0.006	[0.006]	-0.005	[0.005]
$\Delta \ln(L_t)$	-0.244	[0.029]***	-0.215	[0.028]***
R_{t-1}/Y_{t-1}	0.048	[0.024]**	0.104	[0.036]***
$\ln(A_f/A)_{t-1}$	–		-0.053	[0.021]**
$R_{t-1}/Y_{t-1} * \ln(A_f/A)_{t-1}$	–		0.105	[0.008]***
Δh_t	-0.380	[0.183]**	-0.339	[0.181]*
d_RCN_t	0.009	[0.011]	0.016	[0.016]
Number of observations	7124		7124	
Number of firms	1886		1886	
R^2	0.047		0.086	

* significant at 10 per cent ** significant at 5 per cent *** significant at 1 per cent
[a)]Dummies for firm age, region, industry, cooperation and time dummies are included in the analysis but not reported here.

that do not receive any funding from the RCN. Thus, also in this case the results support the view that we can add both kinds of R&D investments into a common aggregate, $RK = N + O$, and that the returns to R&D is independent of the source of financing.

The second column of Table 4 shows the result from estimating equation (21) when we include the productivity gap variable (A_f/A) as in (5). The main term that enters with a significant influence is the absorptive capacity term interacting R&D intensity and productivity gap variable (A_f/A). This result is similar to what Griffith et al. (2004) found. However, contrary to their results, we find the pure "catch-up" variable to be significant, and negative. A dummy variable d_RCN is again virtually zero and insignificant. Hence, we conclude that the productivity effects of RCN funded projects are not different from the productivity effect of R&D in general.

6 Conclusions

Norway is not a “big spender” when it comes to R&D expenditures. In particular, business spending on R&D is rather low by OECD standards. In this paper, which is part of a comprehensive evaluation of the Research Council of Norway (RCN), we analyse the effects of R&D and in particular RCN financed R&D spending on firm performance using data mainly for 2001-2009. We base our study on econometric models of productivity effects of R&D spending. Some of these models are well known in the economic literature. The most standard model relates R&D spending to some measure of productivity, either labour productivity or total factor productivity. A number of specific assumptions need to be made in order to estimate the effects of R&D on productivity. In particular one must address whether or not to try to calculate the stock of R&D capital or simply to use R&D investments. We specify several model versions as an attempt to study the robustness of our results.

The estimates of reduced form productivity equations give results that are generally in line with the results in the literature. R&D spending stimulates productivity growth at the firm level even after controlling for a number possible effects relating to industries, common shocks etc. The effect of RCN financed R&D spending is generally not significant in these models. The interpretation is that to the extent that RCN subsidies and grants increase R&D, its effect is captured by our R&D variables just like R&D spending in general (this is our null hypothesis). RCN offers subsidies or grants for many marginal R&D projects and thus our alternative hypothesis was that the return to a RCN financed project should on average be less than an ordinary R&D project. We find that the null hypothesis cannot be rejected in any of our models. Based on our preferred model we estimate that the returns to R&D is roughly 10 per cent and that the rate of return applies both to RCN financed and firm financed R&D.

References

[1] Arellano, M. and S. Bond (1991): Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations, *Review of economic studies,* 58, 277-297.

[2] Baily, M., C. Hulten and D. Campbell (1992): Productivity Dynamics in Manufacturing Plants. *Brookings Papers on Economic Activity, Microeconomics*, 187-249

[3] Cappelen, Å, E. Fjærli, F. Foyn, T. Hægeland, J. Møen, A. Raknerud and M. Rybalka (2011): Evaluation of the Norwegian R&D Tax Credit Scheme. *Journal of Technology Management and Innovation*, 5, 97-109.

[4] Cappelen, Å. A. Raknerud and M. Rybalka (2012): The effects of R&D tax credits on patenting and innovations. *Research Policy,* 41, 334-345..

[5] Cohen, W. and D. Levinthal (1989): Innovation and Learning: Two Faces of R&D, *Economic Journal*, 99, 569-596.

[6] Crepon, B. E. Duguet and J. Mairesse (1998): Research, Innovation and Productivity: An Econometric Analysis at the Firm Level, *Economics of Innovation and New Technology*, 7, 115-158.

[7] Griffith, R., S. Redding and J. Van Reenen (2004): Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Countries, *Review of Economics and Statistics*, 86, 883-895.

[8] Griliches, Z. (1995): R&D and Productivity: Econometric Results and Measurement Issues, in P. Stoneman (ed.): *Handbook of the Economics of Innovation and Technical Change*, NBER and University of Chicago Press.

[9] Guellec, D. and B. van Pottelsberghe de la Potterie (2001): R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries, STI Working Paper, DSTI/DOC(2001)3, OECD.

[10] Hall, B.H. and J. Mairesse (1995): Exploring the relationship between R&D and productivity in French manufacturing firms, *Journal of Econometrics*, 65, 263–293.

[11] Hall, B.H. and J. Mairesse and P. Mohnen (2010): Measuring the Returns to R&D, Chapter 24 in Handbook of the Economics of Innovation, vol. 2. North-Holland Publ. Comp., Amsterdam.

[12] Henningsen, M., T. Hægeland and J. Møen (2011): Estimating the additionality of R&D subsidies using proposal evaluation data to control for firms' R&D intentions, mimeo. NHH, Bergen.

[13] Klette, T.J. and F. Johansen (1998): Accumulation of R&D capital and dynamic firm performance: A not-so-fixed effect model, Annales, de Economie et de Statistique, 49/50, 389-419.

[14] Mairesse, J. and P. Mohnen (2004): The Importance of R&D for Innovation: A Reassessment using French Survey Data, NBER Working Paper 10897, National Bureau of Economic Research, Cambridge, US.

[15] Norges forskningsråd (2010): Det norske forsknings- og innovasjonssystemet - statistikk og indikatorer, 2010.

[16] OECD (2001): *Measurement of capital stocks, consumption of fixed capital and capital services.* OECD manual 131 (Paris and Washington).

[17] Pakes, A. and Z. Griliches (1984): Patents and R&D at the Firm Level in French Manufacturing: A First Look. In Z. Griliches (ed.): *Research and Development, Patents and Productivity*, The University Press of Chicago, Chicago, 55-72.

[18] Parisi, M.L., Schiantarelli, F. and Sembenelli, J. (2006): Productivity, Innovation and R&D: Micro Evidence for Italy, *European Economic Review,* 50, 2037-2061.

[19] Power, L. (1998): The Missing Link: Technology, Investment, and Productivity. *Review of Economics and Statistics*, 80(2), 300–313.

Appendix A. Data sources

Accounts statistics: All joint-stock companies in Norway are obliged to publish company accounts every year. The accounts statistics contain information obtained from the income statements and balance sheets of joint-stock companies, in particular, the information about operating revenues, operating costs and operating result, labour costs, the book values of a firm's tangible fixed assets at the end of a year, their depreciation and write-downs.

The structural statistics: The term "structural statistics" is a general name for the different industrial activities statistics, such as Manufacturing statistics, Building and construction statistics, Wholesale and retail trade statistics, etc. They all have the same structure and include information about production, input factors and investments at the firm level. The structural statistic are organized according to the NACE standard and are based on General Trading Statements, which are given in an appendix to the tax return. In addition to some variables, which are common to those in the accounts statistics, the structural statistics contain data about purchases of tangible fixed assets and operational leasing. These data were matched with the data from the accounts statistics. As the firm identification number here and further we use the number given to the firm under registration in the Register of Enterprises, one of the Brønnøysund registers, which is operative from 1995.

R&D statistics: R&D statistics are the survey data collected by Statistics Norway every second year up to 2001 and annually later on. These data comprise detailed information about firm's R&D activities, in particular, about total R&D expenses with division into own-performed R&D and purchased R&D services, the number of employees engaged in R&D activities and the number of man-years worked in R&D. In each wave the sample is selected with a stratified method for firms with 10-50 employees, whereas the firms with more than 50 employees are all included. Strata are based on industry and firm size. Each survey contains about 5000 firms, although many of them do not provide complete information.

The Register of Employers and Employees (REE): The REE contains information obtained from employers. All employers are obliged to send information to the REE about each individual employee's contract start and end, working hours, overtime and occupation. An exception is made only if a person works less than four hours per week in a given firm and/or was employed for less than six days. In addition, this register contains identification numbers for the firm and the employee, hence, the data can easily be aggregated to the firm level.

The National Education Database (NED): The NED gathers all individually based statistics on education from primary to tertiary education and has been provided by Statistics Norway since 1970. We use this data set to identify the length of education. For this purpose, we utilize the first digit of the NUS variable. This variable is constructed on the basis of the Norwegian Standard Classification of Education and is a six-digit number, the leading digit of which is the code of the educational level of the person. According to the Norwegian standard classification of education (NUS89), there are nine educational levels in addition to the major group for "unspecified length of education". The educational levels are given in Table 5.

Table 5: Educational levels

Tripartition of levels	Level	Class level
	0	Under school age
Primary education	1	1st – 7th
	2	8th – 10th
Secondary education	3	11-12th
	4	12th – 13th
	5	14th – 17th
Post-secondary education	6	14th – 18th
	7	18th – 19th
	8	20th+
	9	Unspecified

Appendix B: Derivation of (14)

By differencing (11), we obtain

$$\Delta y_t = \Delta a_t + \beta_1 \Delta k_t + \beta_2 \Delta f_t. \tag{22}$$

If δ is small, $\alpha = 1$ and $s = \infty$, then $F_t = RK_t$ and $\Delta F_t / F_{t-1} \simeq R_{t-1}/F_{t-1}$. Now

$$\Delta f_t \simeq \frac{L_{t-1}\Delta F_t - F_{t-1}\Delta L_t}{L_{t-1}^2} = \frac{\Delta F_t}{F_{t-1}} f_{t-1} - \frac{\Delta L_t}{L_{t-1}} f_{t-1} \simeq f_{t-1}(\frac{R_{t-1}}{F_{t-1}} - \Delta \ln L). \tag{23}$$

Thus

$$\Delta y_t \simeq \Delta a_t + \beta_1 \Delta k_t + \beta_2 f_{t-1} \left(\frac{R_{t-1}}{F_{t-1}} \right) - \beta_2 f_{t-1} \Delta \ln L_t.$$

Defining $\eta = \mathrm{El}_F Y$ and $\varrho = \partial Y / \partial F$, then by definition $\eta = \varrho F/Y$ and from (13), $\eta = \beta_2 f$. Finally, from (22) and (23)

$$\begin{aligned}
\Delta y_t &\simeq \Delta a_t + \beta_1 \Delta k_t + \eta \left(\frac{R_{t-1}}{F_{t-1}} \right) - \eta \Delta \ln L_t \\
&= \Delta a_t + \beta_1 \Delta k_t + \varrho \frac{F_{t-1}}{Y_{t-1}} \left(\frac{R_{t-1}}{F_{t-1}} \right) - \eta \Delta \ln L_t \\
&= \Delta a_t + \beta_1 \Delta k_t + \varrho \left(\frac{R_{t-1}}{Y_{t-1}} \right) - \eta \Delta \ln L_t
\end{aligned}$$

Appendix C: Tables with descriptive statistics

Table 6: Descriptive statistics on main variables for the final sample

Variable	Obs	Mean	Std.	Min	Max
Y	10976	234071	2518593	3953	1.48E+08
R	10976	6444	41758	0	1551539
RK	10976	38182	231021	0	6982151
RCN	10976	70	667	0	32311
N	10976	371	2285	0	51769
K	10976	47449	642380	1.5	2.88e+07
L	10976	475042	1033602	42862	3.40E+07
h	10976	0.262	0.218	0	0.937
y	10976	-1.233	0.509	-3.644	1.766
k	10976	-4.313	1.623	-11.566	2.198
rk	10976	0.133	0.379	0	6.94
R/Y	10976	0.045	0.146	0	0.937

Table 7: Firms' description in the final sample, 1886 firms

Firm characteristics	Share of firms (in %)	R/Y	RK/L	N/L	h (in %)
All firms	100	0.049	0.079	0.0011	25.8
50-99 employees	41.6	0.066	0.108	0.0018	26.3
100-249 employees	36.9	0.037	0.071	0.0008	26.0
250+ employees	21.5	0.028	0.065	0.0005	26.2
age 0-2	13.8	0.057	0.088	0.0018	27.1
age 3-5	13.2	0.055	0.089	0.0013	28.4
age 6-9	13.4	0.049	0.087	0.0012	30.4
age 10-14	15.9	0.046	0.092	0.0013	27.4
age 15+	40.6	0.042	0.078	0.0009	23.9
Sentral region	29.8	0.051	0.114	0.0014	37.1
Eastcoast	15.8	0.045	0.077	0.0005	20.2
Eastinn	6.5	0.039	0.071	0.0014	16.0
South	17.4	0.051	0.090	0.0015	24.8
West	16.9	0.035	0.045	0.0006	20.9
Trøndelag	7.2	0.047	0.078	0.0010	22.5
North	6.4	0.029	0.041	0.0010	21.2
Manufacturing	50.0	0.049	0.082	0.0009	18.8
Construction	6.9	0.003	0.005	0.0001	14.3
Retail trade	8.1	0.029	0.063	0.0001	27.0
Transport	14.1	0.009	0.029	0.0003	21.2
Services	10.8	0.126	0.225	0.0048	65.6
Other industries	10.0	0.041	0.094	0.0013	40.6

Note: Based on the first firm-year observations

Table 8: Description of main variables by time period

	2001-2003	2004-2006	2007-2009
Number of firms	1351	1652	1416
R/Y	0.052	0.044	0.039
RK/L	0.070	0.085	0.086
N/L	0.001	0.001	0.001
h	24.8 %	26.2 %	26.8 %
Share of firms (R&D_$av > 0$)	54.4 %	54.7 %	49.6 %
R/Y | R&D_$av > 0$	0.095	0.080	0.078
RK/L | R&D_$av > 0$	0.123	0.145	0.156
N/L | R&D_$av > 0$	0.002	0.002	0.002
h | R&D_$av > 0$	26.8 %	29.4 %	31.4 %
Share of firms (*all* R&D > 0)	37.2 %	38.9 %	36.0 %
R/Y | *all* R&D > 0	0.128	0.104	0.104
RK/L | *all* R&D > 0	0.166	0.192	0.204
N/L | *all* R&D > 0	0.003	0.003	0.003
h | *all* R&D > 0	28.6 %	31.4 %	32.7 %
Share of firms (RCN_$av > 0$)	7.8 %	5.9 %	6.4 %
N/L | RCN_$av > 0$	0.008	0.011	0.014
Share of firms (*all* RCN > 0)	1.5 %	2.0 %	2.5 %
N/L | *all* RCN > 0	0.027	0.023	0.023

Note: R&D_$av > 0$ when $R > 0$ at least in one year in the given period, *all* R&D > 0 when $R > 0$ in all years in the given period (the same for RCN).

Table 9: Example of the grid search for different s and lambda when alpha=1

$s \setminus \lambda$	0.1	0.2	0.3	0.4	0.5	...	10	...	50	60	70	80	90	100	110	120	130	140	150
1.05	850.0	854.4	855.9	856.6	856.8	...	851.4	...	850.9	851.4	851.9	852.4	853.0	853.5	854.0	854.6	855.1	855.6	856.1
1.1	859.5	860.8	860.3	859.5	858.6	...	861.9	...	929.4	938.0	944.7	950.1	954.6	958.2	961.2	963.7	965.9	967.7	969.3
1.15	857.3	855.3	852.6	850.4	848.7	...	913.8	...	973.9	975.5	976.5	977.1	977.5	977.8	978.0	978.2	978.4	978.5	978.6
1.2	849.2	848.5	846.5	844.8	843.5	...	950.5	...	978.5	979.1	979.5	979.8	980.0	980.2	980.4	980.5	980.6	980.7	980.7
1.25	841.3	843.3	842.7	841.7	840.9	...	965.6	...	981.6	982.0	982.3	982.4	982.6	982.7	982.7	982.8	982.8	982.9	982.9
1.3	834.2	839.2	839.8	839.5	838.9	...	972.8	...	984.3	984.5	984.7	984.8	984.9	984.9	985.0	985.0	985.0	985.0	985.1
1.35	828.1	835.9	837.7	837.9	837.6	...	977.3	...	986.5	986.7	986.8	986.9	987.0	987.0	987.0	987.1	987.1	987.1	987.1
1.4	822.9	833.2	836.1	836.8	836.6	...	980.5	...	988.4	988.6	988.7	988.7	988.8	988.8	988.9	988.9	988.9	988.9	990.9
1.45	818.5	831.1	834.8	835.9	835.8	...	982.9	...	990.0	990.1	990.2	990.3	990.3	990.4	990.4	990.4	990.4	992.4	992.4
1.5	814.8	829.3	833.8	835.3	835.3	...	984.8	...	991.2	991.4	991.5	991.5	991.6	991.6	991.6	991.7	993.6	993.6	993.6
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5	785.3	815.2	825.5	829.6	831.2	...	995.4	...	999.9	1000.0	1000.2	1000.3	1000.4	1002.6	1002.7	1002.7	1002.7	987.1	987.1
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
10	783.5	814.2	824.9	829.2	830.8	...	995.8	...	1000.3	1000.5	1000.7	1000.8	1000.9	1003.1	1003.2	1003.2	1003.2	987.3	987.3
20	782.8	813.9	824.6	829.0	830.7	...	996.0	...	1000.5	1000.7	1000.9	1001.0	1001.1	1003.3	1003.4	1003.4	1003.4	987.4	987.4
30	782.6	813.8	824.5	828.9	830.6	...	996.1	...	1000.6	1000.8	1000.9	1001.0	1003.4	1003.4	1003.4	1003.4	1003.5	987.4	987.4
40	782.5	813.7	824.5	828.9	830.6	...	996.1	...	1000.6	1000.8	1000.9	1001.1	1003.4	1003.4	1003.4	1003.5	1003.5	987.5	987.4
50	782.5	813.7	824.5	828.9	830.6	...	996.1	...	1000.6	1000.8	1001.0	1001.1	1003.4	1003.4	1003.5	1003.5	1003.5	987.5	987.4
60	782.5	813.7	824.4	828.8	830.6	...	996.1	...	1000.6	1000.8	1001.0	1001.1	1003.4	1003.4	1003.5	1003.5	1003.5	987.5	987.4
70	782.4	813.6	824.4	828.8	830.6	...	996.1	...	1000.6	1000.8	1001.0	1001.1	1003.4	1003.4	1003.5	1003.5	1003.5	987.5	987.4
80	782.4	813.6	824.4	828.8	830.6	...	996.1	...	1000.6	1000.8	1001.0	1001.1	1003.4	1003.4	1003.5	1003.5	1003.5	987.5	987.4
90	782.4	813.6	824.4	828.8	830.6	...	996.1	...	1000.6	1000.8	1001.0	1001.1	1003.4	1003.5	1003.5	1003.5	1003.5	987.5	987.4
100	782.4	813.6	824.4	828.8	830.6	...	996.1	...	1000.6	1000.8	1001.0	1001.1	1003.4	1003.5	1003.5	1003.5	1003.5	987.5	987.4
$\rho = 1$	782.3	813.6	824.4	828.8	830.5	...	996.2	...	1000.7	1000.9	1001.0	1001.1	1003.5	1003.5	1003.5	1003.5	1003.6	987.5	987.5

Ådne Cappelen, 2012-06-29, (input.add.doc)

To what extent does the Research Council of Norway contribute to higher R&D spending in Norway?

Summary

The private sector in Norway spends less on R&D as share of value added than in many other OECD-countries. This is largely due to industry composition as Norwegian industry is concentrated in sectors that spend relatively little on R&D. It is a major goal of government R&D policy to increase private R&D spending and the Research Council of Norway (RCN) has an important role to play in achieving this goal. The introduction of the tax credit scheme SkatteFUNN in 2002 is indicative of the importance of this policy target. We ask to what extent RCN is able to allocate funds to businesses so that private R&D spending is increased. Usually this issue is discussed using the concept of input additionality. We may therefore rephrase our question. To what extent does RCN achieve input additionality of the funds it allocates? We address the issue by referring in some detail to two existing and recent Norwegian studies and also refer to findings in the international literature on the subject. The study by Hægeland and Møen (2007a) concerns the input additionality of the tax credit scheme SkatteFUNN where RCN has a major role to play in the administration of the system. The second study is on the input additionality of grants or subsidies by RCN by Henningsen et al. (2011).

The input additionality of the tax credit system is complicated to assess because access to the scheme is universal. Hægeland and Møen (2007a) find that the additionality factor is roughly 2 (between 1.3 and 2.9) so that each krone in lost tax revenue triggers two krones of R&D expenditures. By international standards this is a high estimate indicating that the scheme is successful in stimulating R&D. The scheme is also administered fairly cost efficiently and this may partly explain the attractiveness of the scheme cf. Cappelen et al. (2010) for a summary of the evaluation of the scheme.

The study by Henningsen et al. (2011) on the grants or subsidies to industry provided by RCN faces a somewhat different set of challenges compared to the analysis of a universal tax credit. First of all there are budget constraints related to various programmes in RCN. Also there are panels evaluating the quality of the proposals and grade the proposals. In addition those firms that receive subsidies are selected and far from being a random selection. Henningsen et al. (2011) explore the value of proposal quality data, gathered by RCN in estimating the effect of support to industry-led R&D. RCN has for several years emphasised program evaluation, and proposal quality data is available in the PROVIS database. They match the PROVIS evaluation data to the Norwegian Business Enterprise R&D

statistics and discuss different ways of using the available data to identify the causal effect of R&D subsidies on firms' R&D investments. The effect they attempt to identify is the average effect on firms, conditional on the existence and scale of the entire subsidy program of RCN and alternative public sources. In this way the study represents an attempt to use data on proposal quality to obtain better estimates of input additionality in commercial R&D projects. Their preferred estimates suggest that the short term additionality of subsidies from the RCN is positive and 1.15, i.e. one unit in subsidy increases total R&D expenditure in the recipient firm by somewhat more than one unit. They find that the elasticity of total R&D with respect to subsidies is 0.2, suggesting that a one percent increase in subsidies gives rise to a moderate increase in total R&D. Hence, there is no evidence that subsidies to commercial R&D crowd out private investments, but additionality appears to fall with firm size. Their estimates are well in line with the previous literature, but given the many difficulties presented above, the results should obviously be interpreted with caution. Given the extent of measurement errors that they document, they believe that the estimates are more likely to be too low than too high.

Both studies referred to conclude that RCN is reasonably successful in allocating government support to firms in order to stimulate their R&D spending. If anything input additionality seems to be on the high side when compared with international experience. There are potentially three reasons for this result. First, the systems administered by RCN may stimulate a many quality proposals. Secondly, the systems may be good at selecting proposal with high potential for input additionality. Finally, the comparative success may be due to the fact that R&D spending is relatively low in the Norwegian business sector compared to many OECD economies so that government incentives are quite effective. We are not able to distinguish clearly between these possible explanations.

We do not address the issue of input additionality of allocations to government controlled research institutions. The main reason for assuming that input additionality is much smaller in this part of the research sector is that these institutions are mainly funded by the government with little room for reallocating funds between activities. If the government reduced funding for research at the universities but left the funding of education unchanged, research might perhaps not be reduced krone by krone, but the difference would not be large simply because budget constraints are fairly binding over time. In the private sector budget constraints are more flexible and a cut in government financed R&D may or may not be compensated using internal funds.

2. Additionality of R&D subsidies (grants) administered by the Research Council of Norway

2.1. Introduction

The economic justification for subsidies to commercial R&D is the public good nature of innovation. Large amounts of public resources are devoted to R&D subsidies in all OECD economies. There are many policy interventions but little is known about some important policy impacts. Do subsidies to commercial R&D crowd out or stimulate private R&D investments? In a survey of 32 studies David, Hall and Toole (2000) conclude that “the findings overall are ambivalent”. Garcia-Quevedo (2004) has undertaken a meta-analysis of 74 results from 39 studies, and concludes similarly that “the econometric evidence … is ambiguous”. Does this result also apply to the Norwegian case and more specifically to public funding of private R&D through the Research Council of Norway? We answer this question using a recent study for Norway, cf. Henningsen et al. (2011). As this study has not been published yet, we report the results in some details and draw heavily on an unpublished draft.

A possible explanation for the lack of clear evidence on the effect of public R&D subsidies is econometric problems related to selectivity. Typically, subsidised firms are more R&D intensive than average firms, hence regressing R&D subsidies on private R&D investments will lead to a severe positive bias in the effect of the subsidies. The standard remedy for this selection problem is to include a firm fixed effect or, equivalently, to analyse the effect of a *change* in subsidies on the *change* in private R&D investments. Firm fixed effects will pick up aspects such as R&D experience, networks and experience with the application process and technological opportunities in the firm’s product group. However, as pointed out by Klette and Møen (2011), there may be unobserved transitory effects that invalidate fixed effects estimation. Firms are more likely to apply for subsidies when they have particularly good projects and a particularly good chance of receiving subsidies. At the same time, when firms have particularly good projects one would expect them to undertake more R&D than usual even without subsidies.

Reflecting on these difficulties, Jaffe (2002) notes that in a “canonical research program” the agency that disburses money for research typically solicits evaluation reports from outside experts and then organise a committee to rank or group the proposals in terms of priority for funding. The agency decides which proposals to fund, given the available budget, the recommendations of the committee and possibly other criteria not related to proposal quality such as gender, geography and balancing of the grant portfolio e.g. by scientific field. Data generated by such a process can potentially solve the selection problem. Jaffe’s idea is to compare projects right above and below the quality cut-off line used by the agency, and to utilise the randomisation that the criteria not related to project quality creates in the data. He suggests using an estimator based on the regression discontinuity design.

Typically, the qualitative data suggested by Jaffe is produced, but not recorded systematically and made available to researchers by grant awarding agencies. The Research Council of Norway (hereafter RCN) has for several years emphasised program evaluation, and proposal quality data is available in the PROVIS database established in 1999. At the outset, these unique data should be well suited for an analysis of the type proposed by Jaffe. Henningsen et al. (2011) (hereafter HHM) explore the value of these proposal quality data, gathered by RCN, when estimating the effect of support to industry-led R&D. HHM match the PROVIS evaluation data to the Norwegian Business Enterprise R&D statistics that is part of the joint OECD/Eurostat R&D survey, and discuss different ways of using the available data to identify the causal effect of R&D subsidies on firms' R&D investments. The effect they attempt to identify is the average effect on firms, conditional on the existence and scale of the entire subsidy program of RCN and alternative public sources.

In the course of their analysis HHM present a series of estimates obtained under alternative assumptions and model specifications. Their best estimate suggests that the short term additionality of subsidies from the RCN is positive and 1.15, i.e. one unit increase in subsidy increases total R&D expenditure in the recipient firm by somewhat more than one unit. Using a log-log specification, they find that the elasticity of total R&D with respect to subsidies is about 0.2 suggesting that a one percent increase in subsidies gives rise to a moderate increase in total R&D. Hence, there is no evidence that subsidies to commercial R&D crowd out private investments, although additionality appears to fall with firm size. Their estimates are well in line with the previous literature, but given the many difficulties presented above, the results should obviously be interpreted with caution. Taking into account the extent of measurement errors that HHM document, they suggests that the estimates are more likely to be too low than too high.

2.2. Selection and proposal evaluation data as a potential remedy

The challenge of establishing the counterfactual in the case of governmental support for R&D comes from the fact that recipients of support typically are not a random sample of all possible recipients. Jaffe (2002) discusses this selection issue and considers the following version of the standard model: [1]

(1) $$Y_{it} = \beta_i D_i + \lambda X_{it} + \alpha_i + \mu_t + \omega_{it} + \varepsilon_{it}$$

Y_{it} is is total R&D expenditure of (a potential) applicant *i* in year *t*, and D_i is a dummy variable that is one if the applicant has received a grant. X_{it} is a set of observed covariates, and there are four unobservable determinants of research output. First, there is an unobserved firm-specific effect, α_i,

[1] On page 25, Jaffe sets up the equation and discusses the effect of public support on R&D *output*. However, on page 31, he makes it clear that the same selection problems apply when the dependent variable is total R&D expenditure, i.e. when estimating input additionality as we aim to do in this paper. See also his equation (2b) on page 32.

and a common unobserved time effect, μ_t . Next, there is a time- and firm specific effect, ω_{it} , which is unobservable by the econometrician, but partly observable by the granting agency. Finally, there is a standard error term, ε_{it} , that is assumed to be uncorrelated with X_{it} and D_i. The key challenge is that D_i is correlated with ω_{it} and α_i due to selection on β_i .[2] The fixed firm effects can be eliminated by using panel data methods, whereas the time-varying unobserved effect, ω_{it} , cannot.

The regression discontinuity design, see e.g. Imbens and Lemieux (2008), requires that the granting agency constructs one single variable that sums up the quality of the proposal that can be transformed into a unique value for each firm and year. The rate of acceptance should increase in the ranking, jump clearly at one threshold and not jump at other points. The ranking, if incomplete, should have a sufficient range and there must be a sufficient number of data points on either side of the threshold. Furthermore, the method requires that the relationship between the quality ranking and outcome is smooth around the threshold. The regression discontinuity design uses a dummy variable for a ranking above the threshold as an instrument for D_i, while conditioning on the quality ranking itself. This will identify the effect of receiving a grant on *Y* in a "small" region around the threshold.

The necessary data requirements are not always fulfilled, however. The proposal quality data from RCN – which are typical for similar support programs in other countries – do not seem fully compatible with the regression discontinuity design.[3] Instead it is possible to use the quality ranking as a conditioning proxy variable and to control for unobserved firm specific effects using a standard fixed effects estimator. However, while the regression discontinuity design only requires conditioning on what the granting agency knows, and uses IV estimation to solve any remaining endogeneity problems, the proxy solution requires that the evaluation data capture all factors that affect both the probability of receiving a subsidy and the R&D investment decisions. It is not obvious that external experts can evaluate the private or social returns to commercial R&D projects with any precision, and this caveat should be kept in mind when interpreting the results.

2.3. Data

The core data source used in the study by HHM is the project databases PROVIS and FORISS of RCN. These databases contain detailed information on how reviewers and RCN itself have evaluated proposals according to scientific quality and other characteristics. Information on projects that did not

[2] An agency trying to maximize the impact of its funding will order the projects according to the β_I *'s* and choose as many of the high β_I projects as possible. This translates into a selection problem because β_I is likely to be correlated with ω_{it} and α_{it}.

[3] If more detailed data are made available in the future, this might change. Presumably, there is a clear cut-off applied in each subprogram and budget year. If the proposals can be grouped at this level, it might be possible to apply the regression discontinuity design.

receive support is also recorded. By matching these unique data to administrative registers and censuses for firms, such as the R&D survey and structural statistics of Statistics Norway, results in a dataset that provides detailed information on firms and research support proposals.

The PROVIS database contains information on every application to RCN for R&D subsidies. Data on annual amount received in subsidy have been added by the RCN from their FORISS database. The evaluation scheme was introduced gradually from 1999 and contains all applications from private sector firms until 2008.[4] Firms apply for funding from specific thematic programs within RCN, and each program is administered by a program board. The programs analysed seek to promote R&D initiatives in industrial circles and constitute RCN's main instrument for achieving its industry-oriented R&D objectives. The programs are of the matching grants type, and funding requires at least 50 per cent co-financing from private enterprise.

The R&D survey conducted by Statistics Norway is usually the source of information on R&D investments. The survey is conducted at the firm level annually since 2001 (every second year before that) and includes all private sector firms with at least 50 employees. Among firms with 10-49 employees, all firms that reported R&D activity in the previous survey are included. Among the remaining firms with 10-49 employees a stratified sample (by industry and size) is used. The 2006 survey also included a sample of firms with 5-9 employees. The survey includes approximately 4500 firms each year. The R&D statistics include, among other things, information on intramural R&D and R&D subsidies received from various sources. Data on sales are obtained from firm statistics collected separately by Statistics Norway. The use of unique firm identifiers throughout enables us to link data from different sources. The sample is restricted to firms that are represented in the R&D statistics in at least one of the years 2001-2007. These data is merged with the firms' project proposals from the PROVIS database from the same time period.

The PROVIS database is organized with project proposals as the unit of observation, whereas the remaining data, and hence the analyses, are at the firm level. This makes it necessary to aggregate from the proposal level to the firm level. This aggregation concerns two sets of variables, proposal evaluations and the associated project subsidies.

In addition to subsidies from the RCN (S^R), firms can receive R&D subsidies from EU bodies (S^{EU}) and from Norwegian ministries and Innovation Norway (S^G). It is impossible to distinguish between subsidies from the latter two sources. Innovation Norway is a government office for the promotion of

[4] This is industry led R&D or "user directed innovation programs" (BIP) in the terminology of the Research Council of Norway. See http://www.rcn.no/en/Research_programmes/1184159006970.

nationwide industrial development. It is important to account for subsidies from other sources than RCN, because subsidies may be correlated. Omitting alternative subsidies may then lead to bias in the estimated additionality associated with the subsidies from RCN. The presence of measurement error in the subsidy variables imply that the estimates of additionality will be biased towards zero. However, one may exploit the fact that there are two measures of the subsidy to obtain better estimates of the true additionality using an instrumental variables model.

Project proposals are evaluated on 11 aspects. Five of these are evaluated by external scientific experts, the remaining by RCN. The eleventh aspect, Total evaluation, is evaluated by RCN taking into consideration the external experts' evaluations. All aspects except 'Risk' and 'Other conditions', are evaluated on a scale from 1 to 7. When deciding on the amount of subsidies, the program board in charge may decide to grant subsidies to many or few of the applicants, subsidise only parts of a given project proposal, or only a shorter period than applied for. This varies across programs, and may be endogenous to the number and quality of proposals. In most cases, however, the granted subsidy is close to the amount applied for if the proposal receives a subsidy.

Table 1 shows the number of proposals and the acceptance rate by grades of Aspect 11: Total evaluation, before aggregation to the firm level. Grades are concentrated in the range 3-6, and it is difficult to identify one jump point. Without a clear threshold, and observing that there are *de facto* only 4 grade levels assigned, it is difficult to apply the approach advocated by Jaffe (2002) on these data. However, the original endogeneity problem arises from an omitted variable. The omitted variable is the potential returns to R&D investments to the firm, and the evaluation data may provide good proxies for this variable.

HHM focus on Aspect 5: Commercial benefits. This variable measures the evaluation panel's expectation of the contribution to profits from the proposed project. If the panel on average makes correct judgments, this variable should be a useful proxy for the quality of current project ideas in the firm that also affects the decision to invest in R&D. Table 1 shows that the acceptance rate increases with MG5, but of course less strongly than with MG11, because Aspect 5 is only one of several aspects behind Aspect 11.

Table 1. Number of proposals and acceptance rate by grades. Before aggregation

	Aspect 11: Total evaluation		Aspect 5: Commercial benefits	
Grade	Number of proposals	Acceptance rate	Number of proposals	Acceptance rate
1	9	0.00 %	3	33.33 %
2	41	0.00 %	16	31.25 %
3	102	1.96 %	96	33.33 %
4	257	35.02 %	431	49.42 %
5	510	72.75%	426	71.13 %
6	362	91.99%	152	71.05 %
7	16	100.00%	8	100.00 %
Missing	743	35.40 %	908	44.60 %

Table 2 shows how R&D investment, subsidies and sales vary by whether the firm has applied for support from the RCN this year, and by the average evaluation of commercial benefits for proposals. Firms that did not apply are less likely to invest in R&D, and invest less than applicants if they do invest. Among applicants, there is also a clear positive relationship between grade and R&D investment as we would expect: When firms have particularly good research ideas, they invest more in developing them. However, some of this positive correlation may be due to size, as grades increase with average sales. The relationship between grade and whether or not the applicant invests is less strong, suggesting that the decision to invest or not is mainly governed by factors less closely related to proposal quality, i.e. grades seem to matter more for the intensive margin than for the extensive margin. Finally, grades are closely related to whether or not RCN grants support.

Table 2. Variables by grade for Aspect No. 5: Commercial benefits (MG5)

MG5 (rounded up to nearest integer)	N	Share with Intramural R&D >0	Mean Intramural R&D, given >0	Share with S^R>0	Share with S^C>0	Mean sales
1	2	0.500	135.2	0.000	0.500	15.8
2	6	1.000	9996.4	0.000	0.333	149.6
3	52	0.788	6665.8	0.192	0.327	262.4
4	289	0.907	21762.5	0.394	0.581	1002.9
5	514	0.918	41397.6	0.444	0.784	3452.5
6	165	0.897	43435.7	0.412	0.758	1193.4
7	10	1.000	36746.9	0.600	1.000	1231.8
Missing	252	0.893	12126.4	0.254	0.508	743.6
Did not apply	10078	0.685	3795.1	0.024	0.000	361.2
Total	11368					

All firm year observations. S^C is subsidies from the Research Council as reported by the Research Council. S^R is subsidies from the Research Council as reported by the firms in the R&D surveys.

The fixed effects analyses rely on variation in grades over time within firms. Using only firm-year observations where the firm has applied for support and where MG5 is non-missing, 122 firms have at least two different values of this variable in two different years, and account for 779 valid observations, of which 559 have non-zero MG5. Among the 559 observations, the variance of MG5 cleansed of within-firm means is 0.24, ranging from -1.5 to 2. It is essentially this variation that is utilized for estimating the effect of grade 5 on R&D investment when accounting for firm fixed effects. Because the fixed effects approach with grades as proxies for research intentions relies on a limited number of firms and limited variation in grades, a dynamic model is used where firm fixed effects are replaced by a lagged dependent variable.

Table 3 gives summary statistics for key variables. Sales are measured in NOK million, R&D investment and subsidies are measured in NOK 1000, all deflated by the consumer price index to base year 2000. Note that the distributions of sales and intramural R&D are highly skewed, with the means exceeding the medians by a factor of 8 and 4.5, respectively. Outliers in intramural R&D are dealt with by truncating intramural R&D from above at the level of sales.

Table 3. Distribution of selected variables

	N	Median	Mean	Std. Dev.
Intramural R&D	8072	2150.4	9515.8	36273.1
Sales	11368	69.255	537.948	5207.761
Subsidies from the Research Council in the R&D surveys (S^R)	727	679.6	1456.2	2207.4
Subsidies from the Research Council in the FORISS database (S^C)	854	947.8	1753.1	2485.9
Subsidies from Ministries and Innovation Norway (S^G)	728	442.8	3872.3	29355.4
Subsidies from EU bodies (S^{EU})	280	568.7	1654.5	2814.8
Evaluation of commercial benefit (MG5)	1038	5	4.647	0.818
Share of S^R in Intramural R&D	727	0.081	0.144	0.175

Distribution of variables conditional on positive entries. Sales are measured in million real NOK, subsidies and R&D investment are measured in 1000 real NOK.

2.4. Econometric analysis

HHM apply two alternative approaches that utilize the available proposal evaluation data to try to estimate the causal effect of subsidies from the Research Council of Norway on intramural R&D in private firms. They begin with a specification similar to equation (1), but with a continuous rather than a dichotomous subsidy variable:

(2) $$Y_{it} = \beta S_{it} + \lambda X_{it} + \alpha_i + \mu_t + u_{it}$$

The dependent variable, Y_{it} is intramural R&D of firm *i* in year *t* and S_{it} is the amount of R&D subsidies received from the Research Council of Norway by firm *i* in year *t*. HHM chose to use the subsidy that is self-reported by the firms (S^R) as this matches the intramural R&D variable and the other subsidy variables in the sense that they all come out of the R&D surveys conducted by Statistics Norway. Other observed variables that affect R&D are contained in X_{it}. These are sales, subsidies from Norwegian ministries and from Innovation Norway (S^G), and subsidies from EU bodies (S^{EU}). Time effects μ_t capture macroeconomic variations that affect all firms, and firm specific fixed effects α_i capture constant differences in R&D investment between firms over time. Other unobserved factors that influence Y_{it} are captured by the error term u_{it}. The parameter of main interest is β, which measures the average effect of subsidies to intramural R&D from RCN. If β exceeds unity, there is positive additionality, i.e. one unit extra in subsidy causes firms to invest more than one unit extra in R&D. If β is smaller than one, subsidies partly crowd out private capital, i.e. firms use the subsidy to finance some of the R&D activity that would also have been carried out without the subsidy. A zero coefficient implies full crowding out. RCN runs a matching grants subsidy scheme. The additionality associated with these subsidies should therefore be above unity if the program works as intended.

The data description showed substantial variation in sales and intramural R&D within the sample. In particular, many firms do not invest in R&D at all. This translates into a heteroskedasticity problem. It is common that R&D subsidy programs include firms that vary considerably in scale, but the literature is remarkably silent as to whether and how this is handled. In order to reduce heteroskedasticity, HHM weight the data using a simple method suggested by Park (1966). Table 4, columns (1) and (2), show the results of estimating equation (2) in levels with and without firm fixed effects. A matching grants subsidy regime implies a linear relationship between R&D investments and subsidies in accordance with Lach (2002). The specification without fixed effects includes industry dummies at the 2-digit NACE level. In column (1) Park's (1966) procedure implies dividing the equation through by $sales^{0.24}$. In the fixed effects regression in column (2), Park's weight is $sales^{0.21}$.

It is somewhat surprising that pooled OLS yields an additionality estimate close to zero, as one would expect a positive bias. Comparing the OLS results i column (1) with the corresponding log-log specification in column (3) suggests that this is due to an outlier problem. The fixed effects estimate of 1.37 in column (2) is probably closer to the true causal effect. As an alternative to the linear specification, HHM apply a log-log model.[5] The survey by David et al. (2000) shows that log-log is also a fairly common functional form in the previous literature. Taking logs has the benefit of reducing problems with outliers and heteroskedasticity such that weighting has little effect on the estimates. But this specification alters the interpretation of the relationship between the variables as the coefficient on log subsidy is now an elasticity.

[5] The large number of zeros in intramural R&D and subsidies present a specification problem. HHM use the approximation that ln(z) = 0 if z = 0, where z is a variable measured in 1,000 real NOK.

Table 4. Additionality estimates.

	Levels form		Log-log form	
	Pooled OLS (1)	Within (FE) (2)	Pooled OLS (3)	Within (FE) (4)
S^R	4.323***	1.368***	.4163***	.217***
	(1.349)	(.4123)	(.0168)	(.02102)
S^{EU}	7.761***	2.774*	.1431***	.06038**
	(1.726)	(1.681)	(.03104)	(.02961)
S^G	1.508***	.3387***	.3604***	.3036***
	(.0261)	(.07477)	(.01622)	(.02216)
Sales	4.173***	.5442	.372***	.2964***
	(.9501)	(.7073)	(.03661)	(.07121)
Sales squared	-.00722*	.00238		
	(.00376)	(.00213)		
N	11368	11368	30341	30341
Number of firms	2570	2570	13187	13187
R-squared	.3479	.03764	.2120	.06196

The dependent variable is intramural R&D. S^R is R&D subsidies from the Research Council of Norway. S^{EU} is subsidies from EU bodies. S^G is R&D subsidies from Norwegian ministries and Innovation Norway. All specifications include year dummies. Pooled OLS also includes dummies for 2-digit NACE group. We correct for heterskedasticity using using Park's (1966) procedure in the levels regression. Standard errors allowing for clustering of residuals by firm are reported in parentheses.

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 4 columns (3) and (4) show estimates of equation (2) in log-log form with and without fixed effects. The estimated elasticities on subsidies from RCN are 0.42 using OLS and 0.22 when introducing firm fixed effects. The fixed effects estimates are now substantially smaller than the pooled OLS estimates. This is consistent with the former being spuriously high due to omitted firm specific effects. The fixed effect estimate implies that a 1% increase in the subsidy raises intramural R&D by 0.22%. For a firm with initial intramural R&D and subsidy equal to the means presented in Table 3, a marginal increase in the subsidy of 1 percent is about NOK 14 600, and the implied increase in intramural R&D is about NOK 21 900. Hence, each unit in subsidy increases intramural R&D by about 1.5 units. This is a relatively high degree of additionality at the margin for a subsidised firm at the mean and the result is also close to the fixed effects levels estimate of 1.37 in column (2).

A major concern when interpreting additionality estimates obtained from the models presented above, is that subsidies may be endogenous due to correlation with contemporaneous errors, even after eliminating fixed firm effects. In section 2 this was formalized by having two time-varying error-components ω_{it} and ε_{it} in equation (1). The first component, ω_{it}, represents the quality of current research ideas, or the intention to do R&D in absence of subsidies. This intention may be correlated with the likelihood of applying for and receiving subsidies. To account for ω_{it} by a proxy variable solution, HHM use the mean grade for Aspect 5: Commercial benefits ($MG5_{it}$). Recall that $MG5_{it}$ is the average of grade 5 over all proposals that potentially spanned the current year for the given firm, as described in the data section. Aspect 5 is meant to measure the net financial gains from completing the project, although it is unclear whether or not this involves conditioning on taking the product to the market, or reaching some other threshold of success. The proxy solution requires that *MG5* is redundant in (2) and that (X_{it}, S_{it}, μ_t) are uncorrelated with ω_{it}, conditional on $MG5_{it}$.[6] Because $MG5_{it}$ is missing in some cases, a dummy variable $MG5MISS_{it}$ that equals one if the firm applied this year and MG5 is missing is also included. Note that 'applied this year' refers to years spanned by the projects applied for, not the years when proposals were submitted. In addition, a dummy $\text{REJECT}_{\text{it}}$ for 'applied and rejected' is included because those firms who applied have demonstrated that they have an intention to do R&D (although perhaps not in case of rejection). Hence, the reference category is 'did not apply for funding this year'. The estimated equation then becomes

$$Y_{it} = \beta S_{it} + \lambda X_{it} + \varphi_1 \text{MG5}_{\text{it}} + \varphi_2 \text{MG5MISS}_{\text{it}} + \varphi_3 \text{REJECT}_{\text{it}} + \alpha_i + \mu_t + \tilde{\varepsilon}_{it} \tag{3}$$

Table 5 shows results of estimating the levels model in equation (3). Column (1) shows the pooled OLS results. The coefficient for MG5 is positive and highly significant. The coefficient for MG5_{it} missing is large and significant, and corresponds to an average grade around 2.5.[7] The rejection dummy is large, negative and significant. This reflects that applicants with low-quality proposals also tend to invest less in R&D than other firms, including non-applicants. The additionality estimate associated with subsidies from RCN, however, is suspiciously high.

When including fixed effects in column (2), the explanatory power of the proposal data vanishes. This shows that it is the cross sectional variation that drives the significance in the model without fixed effects. The additionality estimate is also very close to the fixed effects estimate without using evaluation data. Because Aspect 5 may not pick up all relevant information about the firms' R&D intentions, HHM try in column (3) a specification where they include the mean of grades for Aspect 11, Total evaluation. However, this grade seems not to add any information about R&D investment. Experimenting with other grades leads to the same conclusion.

Many firms never apply, and these are on average small firms with no or low R&D investments. Because the parameters may be different for these firms, in Column (4) HHM limit the sample to firms that applied at least once during the data period and for which there are at least two observations in the R&D surveys. Despite the much smaller sample size, the additionality estimate is stable, increasing slightly to 1.46, and the grade and rejection variables are still insignificant. Finally, in column (5), HHM only use firms that have variation in MG5, because these are the firms that contribute directly to identifying the coefficients on grades. In this sample the coefficient on MG5_{it} is negative and still insignificant. Note the marked drop in estimated additionality for this last estimation.

[6] This is when the model is estimated with firm fixed effects. For pooled OLS the firm fixed effects α_i also need to be uncorrelated with ω_{it} conditional on the proxy.

[7] This is seen by dividing 3702 with 1514.

Table 5. Additionality estimates. Levels form. With proposal evaluations

	Pooled OLS	Within (FE) estimator			
	All firms (1)	All firms (2)	All firms (3)	Firms that applied at least one year (4)	Firms with variation in MG5 (5)
S^R	2.756**	1.275***	1.257***	1.458**	1.126
	(1.181)	(.4333)	(.4343)	(.6117)	(.8365)
S^{EU}	7.947***	2.727	2.722	3.396	1.769
	(1.78)	(1.692)	(1.693)	(2.173)	(1.775)
S^G	1.486***	.3397***	.3402***	.3263***	.3122***
	(.0277)	(.07525)	(.07498)	(.06909)	(.06574)
Sales	3.946***	.5387	.5417	.7568	.7883
	(.9196)	(.7039)	(.7043)	(1.698)	(2.073)
Sales squared	-.00628*	.0024	.00239	.00192	.00168
	(.00363)	(.00212)	(.00212)	(.00481)	(.00584)
MG5	2262***	192.8	634.1*	59.73	-64.05
	(440)	(179.7)	(343.4)	(176.2)	(304.5)
MG11			-434.4		
			(277.5)		
MG5MISS	3537*	293.5	1213	307.2	154.1
	(1812)	(873.3)	(947.7)	(776)	(2140)
REJECT	-2125	-701.2	-859	-370.4	650.4
	(1817)	(1165)	(1094)	(1132)	(2357)
N	11368	11368	11368	2208	729
Number of firms	2570	2570	2570	406	122
R-squared	.3676	.03666	.03718	.06126	.05805

The dependent variable is intramural R&D. S^R is R&D subsidies from the Research Council of Norway. S^{EU} is subsidies from EU bodies. S^G is R&D subsidies from Norwegian ministries and Innovation Norway. MG5 is the evaluation grade on aspect 5 'Commercial benefits'. MG11 is the evaluation grade on aspect 11 'Total evaluation'. REJECT implies that the firm applied for subsidies, but had the application rejected by the Research Council. All specifications include year dummies. Pooled OLS also includes dummies for 2-digit NACE group. We correct for heterskedasticity using using Park's (1966) procedure. Standard errors allowing for clustering of residuals by firms are reported in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 6 shows the same analyses as in Table 5 for the log-log specification. Introducing the proxy for R&D intensions in pooled OLS reduces the estimated elasticity of intramural R&D with respect to Research Council subsidies from 0.42 to 0.31. This suggests that evaluation data do reduce endogeneity in cross-sectional regressions. The coefficients on $MG5_{it}$ and $MG5MISS_{it}$ are positive and significant. $REJECT_{it}$ becomes positive and insignificant in this specification. Again, the evaluation data add nothing to the fixed effects analysis. The additionality estimates are virtually unaffected by the proxy variable approach, and the additional variables have insignificant coefficients. Dropping firms that never applied to RCN has little impact on the estimate, with only a slight decrease in precision. Dropping firms with no variation in MG5 cuts the estimated subsidy elasticity to half, but note that the retained firms are very large compared to the firms that are dropped. The coefficient of $MG5_{it}$ remains insignificant. HHM conclude that with the available data, and within a fixed effects framework, there is little to gain from adding grades from proposal evaluations.

Table 6. Additionality estimates, models in log-log form. With proposal evaluations

	Pooled OLS	Within (FE) estimator			
	All firms	All firms	All firms	Firms that applied at least one year	Firms with variation in MG5
	(1)	(2)	(3)	(4)	(5)
ln S^R	.3057***	.2203***	.2207***	.1899***	.09896***
	(.02168)	(.02151)	(.02149)	(.02522)	(.03228)
ln S^{EU}	.1349***	.06753**	.0666**	.07872**	.05438
	(.02939)	(.0294)	(.02942)	(.03422)	(.04231)
ln S^G	.3478***	.3054***	.3053***	.1395***	.05053
	(.01578)	(.022)	(.02201)	(.02659)	(.03184)
ln sales	.3287***	.3014***	.3012***	.5989***	.5897***
	(.0359)	(.07117)	(.07117)	(.1323)	(.2096)
MG5	.2887***	.00344	.03857	.0118	-.01474
	(.04178)	(.0431)	(.09242)	(.04365)	(.07506)
MG11			-.03436		
			(.0771)		
MG5MISS	1.098***	-.423	-.372	-.3823	.07043
	(.2741)	(.2852)	(.3052)	(.2838)	(.3971)
REJECT	.07405	.2714	.2569	.1878	-.09183
	(.2149)	(.2051)	(.2082)	(.2062)	(.2261)
N	11368	11368	11368	2208	729
Number of firms	2570	2570	2570	406	122
R-squared	.2212	.05891	.05893	.08741	.08185

The dependent variable is ln intramural R&D. S^R is R&D subsidies from the Research Council of Norway. S^{EU} is subsidies from EU bodies. S^G is R&D subsidies from Norwegian ministries and Innovation Norway. MG5 is the evaluation grade on aspect 5 'Commercial benefits'. MG11 is the evaluation grade on aspect 11 'Total evaluation'. REJECT implies that the firm applied for subsidies, but had the application rejected by the Research Council. All specifications include year dummies. Pooled OLS also includes dummies for 2-digit NACE group. Standard errors allowing for clustering of residuals by firm are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The models presented above ignore potential adjustment costs and that projects often span two or more calendar years. Adjustment costs imply that past R&D investment affect current investment conditional on current values of the control variables, see e.g. David et al. (2000, section 2.6) for a discussion. The problem can be handled by including lagged R&D investments as a regressor, and 12 out of 39 studies used in the meta-analysis by Garcia-Quevedo (2004) use a specification of this type. As pointed out by Angrist and Pischke (2009) it can be challenging to separate fixed effects and lagged dependent variables in applied work. They recommend trying out both specifications to check robustness. The interpretation of the coefficients on the subsidy differs, however, in an important way. With adjustment costs (represented by a lagged dependent variable), the long run effect of increasing the subsidy exceeds the short run effect, whereas if the persistence in R&D is attributed to a fixed effect, the impact of increasing the subsidy for one period only lasts one period.

It is plausible that there are both fixed effects and adjustment costs in R&D investment. With fixed effects, however, the lagged dependent variable becomes endogenous, and the best empirical approach would be to use the Arellano-Bond GMM estimator to account for the lagged dependent variable and eliminate the fixed effects. Since this technique makes use of at least two lags of data, and the within-firm variation in key variables is limited in their data set, HHM are forced to leave out fixed effects when including lagged intramural R&D. The latter variable will account for part of the fixed effects and allows one to exploit the cross sectional variation in the data, in particular in the proposal evaluations. Angrist and Pischke (2009) show that if a model erroneously is estimated with fixed effects instead of a lagged dependent variable, the estimated 'treatment effect' of an intervention will be overestimated. Opposite, if the model is estimated using a lagged dependent variable when one should have used a fixed effect, the treatment effect is underestimated. Hence, estimates from a model with a lagged dependent variable and a model with fixed effects may under certain assumptions be seen as lower and upper bounds of the true treatment effects. In this respect, a dynamic specification complements the fixed effects analysis.

HHM estimate the following model, where they apply the proxy variable approach combined with lagged R&D as a right hand side variable:

(4) $$Y_{it} = \theta Y_{it-1} + \beta S_{it} + \lambda X_{it} + \varphi_1 \mathrm{MG5}_{\mathrm{it}} + \varphi_2 \mathrm{MG5MISS}_{\mathrm{it}} + \varphi_3 \mathrm{REJECT}_{\mathrm{it}} + \alpha_i + \mu_t + \tilde{\varepsilon}_{it}$$

A corresponding model for the log-log form is also estimated. The long run effect of a marginal increase in the subsidy is $\beta/(1-\theta)$.

Table 7 displays the results from estimating equation (4) in levels and logs. Beginning with the levels regression in column (1)-(3), lagged intramural R&D has a large coefficient which means that adjustment costs and persistence in R&D investment are large. However, the omitted fixed effects may inflate the estimate. For the other variables, the results are quite similar to the fixed effects estimates in Table 5. The variables $\mathrm{MG5}_{\mathrm{it}}$, $\mathrm{MG5MISS}_{\mathrm{it}}$ and $\mathrm{REJECT}_{\mathrm{it}}$ are all insignificant, and the estimated additionality is in a plausible range, from 1.11 to 1.48. The implied long run effects are very large, from 5.7 to 7.7. Given that an omitted fixed effect that is correlated with the included lagged dependent variable is likely, however, we should not put much emphasis on the long run effects.

Following the reasoning of Angrist and Pischke (2009) and combining the estimated contemporaneous effect, β_2, from column (1) and the corresponding fixed effects estimates in Table 5, column (2), suggests that the true short run additionality effect is within the rather narrow interval 1.0 to 1.3 with a mid-point of 1.15.

With the log-log specification, the estimates in Table 7 column (3) and (4) also reveal substantial persistence in R&D investments. The contemporaneous elasticities are considerably lower than the pooled OLS estimates, and slightly smaller than the fixed effects estimates. For all firms, the interval suggested by Angrist and Pischke (2009) is 0.17 to 0.22. The estimated long run elasticities range from 0.19 to 0.37.

Table 7. Models with lagged dependent variable.				
	Levels form	Levels form	Log-log form	Log-log form
	Firms with positive intramural R&D at least one year	Firms with variation in MG5	Firms with positive intramural R&D at least one year	Firms with variation in MG5
	(1)	(2)	(3)	(4)
Intramural R&D$_{t-1}$	.8403***	.7372***	.5572***	.4257***
	(.0892)	(.143)	(.01115)	(.06644)
S^R	1.034**	1.562*	.1656***	.1073***
	(.425)	(.9329)	(.01682)	(.02778)
S^{EU}	.6043	1.148	.02739	-.01103
	(.746)	(1.515)	(.01942)	(.02096)
S^G	.5548***	.6367***	.2075***	.02354
	(.1081)	(.1484)	(.01392)	(.01957)
Sales	.3014	.5996	.2128***	.261***
	(.3447)	(1.114)	(.02546)	(.06237)
Sales squared	.00202**	.00156		
	(.00102)	(.00354)		
MG5	418.4**	340.5	.09496***	.0681
	(201.8)	(358.5)	(.02738)	(.05364)
MG5MISS	310	-1742	.1877	.4173
	(999.7)	(3480)	(.1855)	(.3278)
REJECT	-474.9	-427.5	-.0136	-.2767
	(885.8)	(2699)	(.1638)	(.182)
N	7793	591	7793	591
Number of firms	2319	120	2319	120
R-squared	.8536	.8943	.4626	.642

The dependent variable is intramural R&D. S^R is R&D subsidies from the Research Council of Norway. S^{EU} is subsidies from EU bodies. S^G is R&D subsidies from Norwegian ministries and Innovation Norway. MG5 is the evaluation grade on aspect 5 ´Commercial benefits'. MG11 is the evaluation grade on aspect 11 ´Total evaluation'. REJECT implies that the firm applied for subsidies, but had the application rejected by the Research Council. All specifications include year dummies. Pooled OLS also includes dummies for 2-digit NACE group. We correct for heterskedasticity using using Park's (1966) procedure in the levels regression. Standard errors allowing for clustering of residuals by firm are reported in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

HHM also attempt to use an instrument variables technique to correct for measurement errors but without much success probably because the assumptions behind the errors-in-variables model are not met. We refer to their study for a more detailed discussion.

2.5. Conclusion

Empirical examination of whether R&D subsidies to private firms crowd out private investments has been hampered by problems related to selection bias. In particular, subsidies may be endogenous even after eliminating firm fixed effects since the quality of current research ideas may be correlated with the likelihood of applying for and receiving subsidies. Access to proposal evaluation data has been suggested as a potential remedy. Using such data Henningsen et al. (2011) find no evidence suggesting that this type of selection problems creates a severe bias. Proposal evaluation grades from RCN strongly predict R&D investments in cross-sectional regressions, with one unit higher grade being associated with an increase in intramural R&D of between 20 and 30 %. There is, however, limited variation in the proposal evaluation grades within firms over time. Evaluation grades are by no means a perfect measure of project quality, but the findings suggests that unobserved project quality to a large extent is absorbed by firm fixed effects. This suggests that selection bias is not a major issue when panel data are available.

The study by Henningsen et al. (2011) also demonstrates that there is potentially severe measurement error in the subsidy variable if we take Norwegian data as an indication. Consequently, additionality may therefore be underestimated and they conclude that measurement errors may be a more important source of bias than selection.

The estimates of the short term additionality of R&D subsidies from RCN is 1.15, i.e. one unit increase in subsidy increases total R&D expenditure in the recipient firm by somewhat more than one unit. Using a log-log specification their best estimate for the elasticity of R&D with respect to subsidies is about 0.20.

3. Input additionality of the Norwegian tax credit scheme administered by RCN

3.1. Introduction

The introduction of an R&D tax credit in Norway was proposed by the Hervik Commission in a green paper for the Ministry of Trade and Industry in 2000 (NOU 2000:7). The commission suggested using an R&D tax credit as one of several policy tools to stimulate R&D investments. The argument was that the proposed R&D tax credit would be administratively simpler and more robust to informational problems than direct R&D grants. The tax credit was to become the main policy tool towards small and medium sized firms (SMEs). According to the commission's opinion, RCN should focus on R&D of strategic importance, and spend their resources initiating and evaluating large projects. Also an R&D tax credit scheme would provide more stable conditions for the business community than direct grants because the scheme would not be subject to annual budget deliberations if it was embedded in the general tax code. Of course, the specifics of the scheme, such as deduction rates and rules on eligibility etc. could change over time, but it was a widely held view that it would be less vulnerable to discretionary budget policy than direct R&D grants. The tax credit scheme was proposed in the National Budget for 2002, passed by the Parliament in December 2001 and brought into force for the fiscal year 2002. The scheme is codified in § 16-40 of the Norwegian Taxation Act.

3.2. Main features of the tax credit scheme

The Norwegian R&D tax credit scheme, "Skattefunn", implies that parts of a firm's R&D expenditures are deductible against taxes. A firm must meet the relevant terms and have its project plan approved by the Skattefunn secretariat which is part of the RCN. Another government agency, Innovation Norway, is helping firms through the application process and makes a first assessment of whether the projects qualify for support or not. The actual R&D expenditures have to be approved by the tax authorities, who mainly base their judgement on a statement from the applicant's auditor.

Originally, only SMEs were eligible. An SME was defined as a firm fulfilling two of the following three criteria: (i) Fewer than 100 employees (ii) an annual turnover of less than NOK 80 million – about EUR ten million (iii) an annual balance sheet total of less than NOK 40 million – about EUR five million. In 2003 large enterprises were included as well. Large enterprises may deduct 18 percent of expenses related to an approved R&D project from taxes owed. A 20 percent deduction is possible if the following conditions for being a "small enterprise" are fulfilled: (i) Fewer than 250 employees, (ii) an annual turnover not exceeding EUR40 million or an annual balance sheet total not exceeding EUR 27 million and (iii) less than 25 per cent of the company is owned by a large enterprise. This distinction between large and small enterprises follows EU/EEA state aid rules. The maximum basis for deduction was at the outset NOK 4 million per year (about EUR 500 000) for R&D projects conducted by the enterprise itself. Stimulating cooperation between academia and commerce is considered an important objective of the scheme. For this reason, a firm could purchase R&D services from universities and R&D institutes for another NOK 4 million under the scheme. If the firm did not conduct in-house R&D, it could purchase R&D services for a total of NOK 8 million. This cap was the maximum sum from which a tax deduction could be calculated. In 2009, the caps were increased to NOK 5.5 and 11 million, respectively.

In order to qualify for the tax credit, the R&D activity must come under the definition of R&D as stipulated in the scheme. This definition is very similar to that given in the Frascati manual. Standard product development with no research component is not covered by the scheme.

Enterprises that are not currently liable to taxation are also eligible. If the tax credit exceeds the tax payable by the firm, the difference is paid to the firm in the form of a negative tax or a grant. If the firm is not in a tax position at all, the whole amount of the tax credit is paid to the firm as a grant. In practice this has turned out to be a very important feature of the scheme. Around three-quarters of the total support given through the scheme are paid as grants. The payment is made when the tax authorities have completed their tax assessment, and takes place the year after the actual R&D expenses have occurred. The R&D tax credit is thus neutral with regard to qualifying projects, regions, industries and the tax position of the qualifying firms, but lowers the marginal cost of low R&D spenders and is slightly more generous to small firms than to large firms. For firms that would have spent more on R&D than the maximum amount in the scheme even without the presence of the tax credit, the scheme gives little or no incentive on the margin to increase R&D investments, although they have a clear incentive to qualify for the scheme and receive the tax deduction.[8]

The total maximum tax deduction for a small establishment was at the outset NOK 1.6 million per year (20 % of 8 million). For large establishments included in the scheme in 2003, it was NOK 1.44 million (18 % of 8 million).[9] However, the average tax deduction per tax credit project has been much lower than this. Table 8 below shows the development in the number of applications, budgeted and actual R&D expenses, as well tax deductions in the years 2002-2010. Figures for R&D are based on data from RCN and tax data from the Directorate of Taxes.

Table 8: Applications, R&D expenses and tax deductions	2002	2003	2004	2005	2006	2007	2008	2009	2010
Number of applications by year of submission									
Total number of applications	3287	4739	4225	3176	2624	2104	2071	2121	2057
Applications approved	2798	3532	2762	2177	1801	1530	1549	1596	1597
Applications rejected	397	974	1160	699	543	574	522	525	460
Percentage approved (incl. withdrawn applications)	85	75	65	69	70	73	75	75	78
Active projects, budgeted and actual R&D costs, NOK mill.									
Number of active projects	2798	5571	6079	5137	4055	3735	3527	3560	3579
Total budgeted R&D costs (approved projects, figures from RCN)	4526	9032	9643	9003	8457	8456	8403	9416	10392
Total actual R&D expenses approved by auditor (figures from SKD)	4104	7459	7758	7413	6965	5854	6366	6960	6844
Total tax reduction	690	1257	1301	1220	1147	994	1039	1185	1196
Of which paid out as a grant	568	978	978	909	841	741	782	937	929
Total corporate taxes payable for firm receiving tax deductions	164	2743	4960	4055	4648	*n.a*	*n.a*	*n.a*	*n.a.*
Actual R&D expenses in per cent of the budget	91	83	80	82	82	69	76	74	66
Paid deduction in per cent of total deductions	82	78	75	75	73	75	75	79	78
Deductions in per cent of corporate taxes payable	42	46	28	30	24	*n.a*	*n.a*	*n.a*	*n.a.*

For the years 2002-2009, the table corresponds to Table 1. in Cappelen et al. (2010). The table is updated with data for 2010 using numbers from the annual report (Årsrapport 2010) published by the Skattefunn secretariat (and RCN) at www.skattefunn.no. SKD is the Norwegian Directorate of Taxes. *n.a* means not available.

3.3. Does the tax credit scheme lead to more R&D?

Hægeland and Møen (2007a) evaluate the degree of input additionality, i.e. to what extent the scheme induces firms to invest more in R&D than they otherwise would have done. This is obviously a critical aspect when evaluating the overall efficiency of the scheme. Identifying this effect in a non-experimental setting, where access to the scheme is in principle universal, is difficult. They use a difference-in-difference regression approach in their main analysis. Many of the methodological issues

[8] In theory, the presence of liquidity constraints or internal political processes related to the investment budget could also give firms whose R&D expenditures exceed the maximum amount of the scheme an incentive to increase their R&D investments.

[9] The maximum deductions increased by 37.5 per cent in 2009.

discussed earlier are valid also in this study so we will not address them here. These issues are also discussed in the published report by Hægeland and Møen (2007a) and we refer to the report for details.

Their descriptive analyses clearly show that firms that have received support through the tax credit scheme have more growth in their R&D investments than other firms. The difference-in-difference regressions show that firms that previously invested less than the 4 million in-house R&D cap have increased their R&D investments more than those previously above the cap. The latter group is used as a control group because firms that invest more than the 4 million-cap are not subsidized at the margin and hence have little or no incentive to increase their R&D expenditure as a result of the R&D tax credit scheme.

The estimated input additionality is mainly driven by firms that did not invest very much in R&D before the tax credit scheme was introduced. Hægeland and Møen (2007a) also find that firms that previously did not invest in R&D were more likely to start doing so after the introduction of the tax credit scheme. The additionality appears to be strongest in small firms, firms in non-central areas of the country, firms in which the employees have a relatively low level of education, and firms in industries that are traditionally not research intensive.

The empirical results in Hægeland and Møen (2007a) are consistent with the tax credit scheme being effective in stimulating R&D investments. The main results are qualitatively the same across various data sources and model specifications. The estimates of how much extra R&D the tax credits trigger per NOK in lost tax revenue vary between 1.3 and 2.9, with 2 representing the best point estimate. This is high in comparison to other estimates in the international literature see e.g. Ientile and Mairesse (2009). The implication is that for every Norwegian krone received by the firms in tax deduction, two kroner are spent on R&D. However, it is worth noting that the strategy used to identify the effect of the tax credit scheme is not bullet proof. The main reason for this is that the tax credit scheme is available to all firms. A causal interpretation of the results rests among other things on the assumption that small and large R&D firms (below and above the 4 million-cap) are equally affected by changes in economic trends and macroeconomic framework conditions other than the tax credit scheme. In addition, the effects are estimated with considerable uncertainty.

To what extent does the tax credit scheme affect the utilisation of other innovation policy instruments? Hægeland and Møen (2007b) find no evidence suggesting that the R&D tax credit increases the probability of receiving direct R&D grants from RCN in the future, but they cannot exclude the possibility of an immediate positive effect. Firms with R&D tax credit projects have an increased likelihood of receiving direct R&D grants from RCN in the same year. At the individual firm level, therefore, direct subsidies and the tax credit seem to be complements. At the more aggregate level, however, the two instruments seem to be substitutes as the probability of receiving direct R&D grants fell after the introduction of the tax credit scheme.

In the years after the introduction of the tax credit scheme, firms that applied for support from RCN or received support from Innovation Norway in one year, were much more likely to reapply the year after as compared to the years prior to the scheme. It therefore seems that the R&D tax credit scheme has stimulated greater persistence in the use of other policy instruments. It is easy to demonstrate that firms receiving the R&D tax credit are in contact with the innovation policy system to a greater extent than other firms, but this cannot be interpreted as a causal effect. Both RCN and Innovation Norway require firms to apply for the R&D tax credit before other additional support is provided. However, firms that have not previously been in contact with the innovation policy system are more likely to have such contact after the R&D tax credit scheme was introduced. This suggests that the tax credit scheme has made the innovation policy system available to a new group of firms.

Hægeland and Møen (2007b) also analyse how the input additionality varies between different R&D policy instruments. They find that the additionality is high for both R&D tax credits and for direct R&D grants from RCN, while project support from ministries and the EU has lower additionality.

3.5. Conclusions

The two studies by Hægeland and Møen referred to in this section indicate that the input additionality of the tax credit scheme is quite high both by international standards and in absolute terms. That a firm receiving a tax credit of one krone adds another krone in R&D expenditures so that total spending is twice the revenue loss is a positive feature of the system. The partial contribution of RCN to this result is hard to identify because we cannot tell for sure if the result is due to the scheme per se or due to competent management of the scheme by RCN. The management cost of the scheme is not excessive which shows that high input additionality is at least not due to large administrative costs.

References

Angrist, J. D. and J-S. Pischke (2009). *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton University Press.

Ashenfelter, O. and A. Krueger (1994). Estimates of the Economic Return of Schooling from a New Sample of Twins, *American Economic Review*, **84**(5), 1157-1173.

Bergem, B.G., A. Hervik and H. Bremnes (2009). Ex ante evaluation in public policy programs for commercial R&D. Mimeo, Møreforsking Molde

Bound, J., C. Brown, and N. Mathiowetz (2001). Measurement Error in Survey Data, Ch. 59 in J. Heckman and E. Leamer (eds.) *Handbook of Econometrics*, **5**(5), , chap. 59, 3705-3843, Elsevier Science.

Cappelen, Å., E. Fjærli, F. Foyn, T. Hægeland, J. Møen, A. Raknerud, and M. Rybalka (2010), Evaluation of the Norwegian R&D Tax Credit Scheme, *Journal of Technology Management & Innovation,***5** (3), 96-109.

David, P. A., B. H. Hall, and A. A. Toole (2000). Is public R&D a complement or a substitute for private R&D? A review of econometric evidence. *Research Policy*, **29**(4-5), 497-529.

Garcia-Quevedo, J. (2004). Do Public Subsidies Complement Business R&D? A Meta-analysis of the Econometric Evidence, *Kyklos*, **57**, 87-102

Griliches, Z., and J. Hausman (1986). Errors in Variables in Panel Data. *Journal of Econometrics,* **31**(1), 93-118.

Henningsen, M., T. Hægeland and J. Møen (2011), Estimating the additionality of R&D subsidies using proposal evaluation data to control for firms' R&D intentions, mimeo. October 27th, 2011, NHH, Bergen.

Hægeland, T. and J. Møen (2007a), Input additionality in the Norwegian R&D tax credit scheme, Reports 2007/47, Statistics Norway, Oslo.

Hægeland, T. and J. Møen (2007b): The relationship between the Norwegian R&D tax credit scheme and other innovation policy instruments Reports 2007/45, Statistics Norway.

Ientile, D. and J. Mairesse (2009), A policy to boost R&D: Does the R&D tax credit work? *EIB papers* 6/2009, European Investment Bank.

Imbens, G. W. and T. Lemieux (2008). Regression discontinuity designs: A guide to practice, *Journal of Econometrics*. **142**(2), 615-635.

Jaffe, A. B. (2002). Building programme evaluation into the design of public research-support programmes. *Oxford Review of Economic Policy*, **18**(1), 22-34.

Klette, T. J. and J. Møen (2011). R&D investment responses to R&D subsidies: A theoretical analysis and a microeconometric study. NHH Discussion paper, FOR 11 2011. ISSN:1599-4066.

Klette, T. J., J. Møen and Z. Griliches (2000). Do subsidies to commercial R&D reduce market failures? Microeconometric evaluation studies. *Research Policy* 29(4-5), 471-495.

Lach, S. (2002). Do R&D subsidies Stimulate or Displace Private R&D? Evidence from Israel, *Journal of Industrial Economics*, **50**(4), 369-390.

Park, R. E. (1966). Estimation with Heteroscedastic Error Terms, *Econometrica,* **34**(4), 888.