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## Discussion paper

# Corporate returns to subsidized R&D projects: Direct grants vs tax credit financing

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# Corporate returns to subsidized R&D projects: Direct grants vs tax credit financing \*

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**ABSTRACT:** According to theory, direct R&D grants should be used for projects with low private returns, high social returns and high risk. R&D tax credits, on the other hand, allow firms to choose projects freely according to their private returns. Building on the standard R&D capital model, I develop a framework for estimating private returns to R&D projects with different types of funding. I apply the framework to estimate the corporate returns to subsidized R&D projects in Norway. Consistent with theory and a high quality grant allocation process, I find that projects funded through direct grants have private returns that are not significantly different from zero and with high variance, while the return to R&D projects financed by tax credits is just slightly below the return to R&D projects financed by own funds. The latter two return estimates are 16 % and 19 % respectively. I find that SMEs and small R&D performers have somewhat higher returns to R&D than larger firms. The overall return estimate across all types of finance is 15 %. This is in line with recent meta-regression results in the international literature.

JEL Codes: H25, O32, O38

Keywords: Returns to R&D; R&D capital model; Knowledge capital model; R&D subsidies; R&D grants; R&D tax credit; Innovation Policy; Technology policy; Norway

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Returns to investments in R&D and other innovation assets are a subject of considerable interest to accountants, firm managers, policy makers, and economists in general. ... [E]stimates of the ex post returns ... can ... be useful for making comparisons between various financing systems, sectors, or countries, and can also be a guide to policy-making toward R&D.

*Hall, Mairesse, Mohnen (2010)*

## 1 Introduction

Policies to stimulate innovation and economic growth are high on the policy agenda in all OECD-countries. According to OECD (2015), business R&D accounts for nearly 70 % of total R&D performed in the OECD area, and governments finance about 12 % of total business R&D.

The two most important policy tools are direct R&D grants and R&D tax credits. Tax credits, pioneered by the US, France and Canada in the 1980s, have become an increasingly popular policy tool, and is now used in more than 30 countries. Nevertheless, there are still highly R&D intensive economies like Germany, Finland and Switzerland that rely on R&D grants only (OECD 2016).<sup>1</sup> Out of total government financed business R&D in 2012, direct grants accounted for about 60 % and tax credits for about 40 % (OECD 2015).

There is a large literature evaluating the effectiveness of R&D grants and R&D tax credits separately. Authoritative surveys are David, Hall and Toole (2000) on R&D grants, and Hall and van Reenen (2000) on R&D tax credits. Recent surveys can be found in Mohnen and Lokshin (2010), OECD (2015) and Becker (2015). There are, however, only a few studies that analyse the relative merits of the two policy tools when they are used together. I expand on this small literature by comparing the corporate returns to R&D projects financed by direct grants and projects financed by tax credits in Norway.

Previous microeconomic studies that explicitly compare the two policy tools include Hægeland and Møen (2007, ch. 5) who analyse the additionality of R&D tax credits and direct R&D grants using Norwegian data.<sup>2</sup> Bérubé and Mohnen (2009) estimate the effect on innovation of Canadian R&D grants in the presence of R&D tax credits. In a similar modelling framework, Baghana (2010) estimate the additionality of R&D grants in the presence of R&D tax credits using data from Quebec. He also includes a second stage in his analysis to look at the impact on productivity growth. Foreman-Peck (2013) compares the effectiveness of R&D tax credits and other state aid on innovative output in UK SMEs, and Busom, Corchuelo and E. Martínez-Ros (2014) analyse the characteristics of Spanish firms

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<sup>1</sup> Sweden introduced tax incentives as late as 2014, while Mexico and New Zealand have abolished their schemes.

<sup>2</sup> An early comparative additionality analysis is performed by Guellec and Van Pottelsberghe de la Potterie (2003) using country level data.

that use R&D tax credits and direct funding when both are available. Finally, Busom, Corchuelo and Martínez-Ros (2017) analyse the persistence of Spanish firms' participation in R&D subsidy and tax incentive programmes.

As pointed out by Ientile and Mairesse (2009), the main advantage of direct R&D grants is that research projects proposed by firms can be examined and selected by specialized public agencies. This way, the quality and orientation of the projects can be determined, and, ideally, subsidies will be targeted to projects with high social returns and low private returns, i.e. projects that would not have been undertaken without a grant.<sup>3</sup> Often times, subsidies are also targeted at projects with high risk. See Jaffe (1997, ch. IV.A.) for a framework that explicitly lays out such criteria for project selection when the aim is to maximize social returns. A tax credit, on the other hand, has no explicit selection process attached to it, and firms will therefore rank projects according to their private returns. Much of the subsidy will then be paid to inframarginal projects that would be undertaken even without a subsidy, i.e. projects with a high private return. The mechanism utilized by the government is simply to induce more R&D by lowering the marginal price.

R&D tax credits are generally perceived to have lower administrative costs than direct grants, to be neutral with respect to industries and firms, and to be less vulnerable to government failure such as government agencies picking winners based on private rather than social returns. If the different subsidy schemes work according to "theory", R&D projects should differ with respect to private returns depending on their source of financing.

In this paper, I develop a framework for estimating the returns to R&D projects with different types of funding using firm level data. Conventional wisdom is that the return to publicly financed R&D is lower than the return to private R&D, see e.g. Scotchmer (2004) who writes that "the measured impact of public R&D spending on private indicators of value is, as expected, smaller than that of private R&D spending. In fact, many studies find no measurable effect at all."<sup>4</sup> The literature she summarizes, however, does not distinguish between different policy tools.

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<sup>3</sup> Griliches (1995, p. 82) suggest an additional reason to expect lower returns to business R&D financed by governments. In many cases, such R&D is devoted to "product innovation" for "output" that is to be sold back to government procurement agencies under the terms of "cost plus" contracts. Obviously, these projects carry less risk than R&D financed by own means and hence demands a lower return and have less direct impact on the contracting firm's own productivity.

<sup>4</sup> A very similar conclusion is reached by Hall, Mairesse and Mohnen (2010, section 3.3.2). See also OECD (2015, Box 2) for references to this literature. I am only aware of two papers that find larger returns to government funded business R&D than to privately funded R&D. These are Hall and Mairesse (1995, Appendix B) for France and Griliches and Regev (2001) for Israel. See also Bönte (2003) whose results of a cointegration analysis on US data suggest that the rate of return to government financed R&D is equal to that of privately financed R&D at the aggregate level.

I find that projects funded through direct grants have, on average, returns that are not significantly different from zero and with high variance. Although the return is probably underestimated, this finding is consistent with a high quality grant allocation process as direct subsidies should be targeted at projects with low private returns. My estimate for the return to R&D projects financed by tax credits, on the other hand, is just slightly below the estimated return to R&D projects financed by own funds. This is also as expected since firms are free to choose projects under a tax credit scheme.

All the estimated returns are surprisingly low. First, R&D investments are considered to have high risk, and should therefore earn a risk premium. Second, the estimates represent “gross” returns, meaning that depreciation of the knowledge capital stock is not accounted for. However, the estimates are likely to be downward biased by specification errors and measurement errors in the R&D variables, see Møen and Thorsen (2017) and Ugur et al. (2016) for recent discussions.<sup>5</sup>

## 2 Previous estimates of the returns to R&D

There is a large international literature on the returns to R&D. Good surveys are provided by Mairesse and Sassenou (1991), Griliches (2000), Hall, Mairesse and Mohnen (2010), OECD (2015) and Ugur et al. (2016). OECD (2015) includes both a narrative survey and an exploratory meta-analysis of R&D return estimates while Ugur et al. (2016) is a comprehensive meta-analysis following best-practice guidelines.

Private rates of return to R&D, gross of depreciation, vary considerably. OECD (2015) report that the median private rate of return from firm level studies is 23 %. The corresponding result that I present based on Norwegian data is 15 % and on the low side, but by no means unusual. It is slightly above the lower quartile according to the OECD survey and very close to Ugur et al. (2016) who present a combined gross private firm level rate of return to R&D of 14 %.<sup>6</sup>

The most important previous study using Norwegian data is Klette and Johansen (1998). They analyse a panel of manufacturing plants with data from 1980 to 1992. They measure R&D at the line-of-business level within firms, and present estimates based on several specifications. When using the Griliches R&D-capital framework that I base my analysis on, they get gross rate of return estimates ranging from –17% to 51%, depending on the specification. The mean and median values across their 17 estimates are 12 % and 6 % respectively. The specification most similar to what I use in Table 1 gives an estimated

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<sup>5</sup> A particularly important specification issue may be that the theory behind the commonly used R&D intensity version of the R&D capital model assumes the use of net investment in R&D, while only gross R&D is available in empirical work. Using an R&D measure that is too large, obviously causes the return coefficients to be underestimated, and Hall et al. (2010) show that this bias may be substantial.

<sup>6</sup> Note also that Møen and Thorsen (2017) do a formal meta-analysis on the studies included in Hall, Mairesse and Mohnen (2010) and find a combined return estimate of 17.9 %. When correcting for publication bias, the combined return estimate drops to 13.3 %.

rate of return that is very close to zero. Their preferred overall estimate, 9 percent, is based on an alternative framework with a multiplicative knowledge capital accumulation function replacing equation (6) below.

Cappelen, Raknerud and Rybalka (2007) analyse the effect of R&D financed by the Norwegian R&D tax credit on firm productivity and calculate private net returns to the subsidy. Their results indicate that the productivity effect of projects under the R&D tax credit scheme is modest, but similar to ordinary R&D projects. They emphasize that these results are highly preliminary and should be interpreted with care. Cappelen, Raknerud and Rybalka (2013) address the question of whether the returns to R&D projects funded by direct grants from the Research Council of Norway differ from the returns to R&D in general. Their estimate of the average rate of return to R&D is about 10 %, and they find that the returns to direct R&D grants do not differ significantly from this overall average. Their point estimate for the return to direct R&D grants is, however, negative and with a large standard error. In a similar analysis, Baghana (2010) finds that the additional return of direct subsidies is positive, but lower than the return on the R&D financed by own funds or R&D tax credits using data from Canada. His return estimates are higher than the Norwegian ones, 13.4 % for R&D funded by public grants and 32.2 % for privately funded R&D expenditures.

In this paper, I estimate the private return to R&D and distinguish between R&D that firms finance by own funds, R&D financed by direct grants, and R&D financed by tax credits. I am not aware of any studies that directly compare the returns to different types of public R&D subsidies. My analysis complements the analyses of Cappelen, Raknerud and Rybalka (2007, 2013) and Baghana (2010) since I focus on the relative merit of the tax credit vs. direct subsidies in a single regression. I also use data for a longer time period.

## **3 Institutional details and data**

### **3.1 *Direct R&D grants***

Most direct grants to commercial R&D in Norway are awarded through industry led programmes administered by the Research Council of Norway.<sup>7</sup> These programmes seek to promote R&D initiatives in industrial circles and comprise the Research Council of Norway's main instrument for achieving its industry-oriented R&D objectives. The programmes are of the matching grants type, and funding

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<sup>7</sup> Industry led R&D is called "user directed innovation programmes" (BIP) in the terminology of the Research Council of Norway. See [http://www.rcn.no/en/Research\\_programmes/1184159006970](http://www.rcn.no/en/Research_programmes/1184159006970).

requires at least 50 per cent co-financing from private enterprise. According to the Research Council, the average co-financing is 60-65 %, but as pointed out by Klette and Møen (2012), it is an open question to what extent the programmes induce firms to increase their total R&D investments as they may reduce non-subsidized R&D activities upon receiving an R&D grant. Research by Klette and Møen (2012), and Henningsen, Hægeland and Møen (2015) suggests that the own risk money is to a large extent taken from ordinary R&D budgets, implying that the firms would have spent this money on R&D anyway. However, firms do not seem to reduce their private R&D budgets when they receive subsidies. This implies that the “additionality” is around one, i.e. one unit in subsidy makes firms invest one unit more in R&D.

In addition to direct R&D grants from the Research Council of Norway, firms can receive grants from EU bodies and from Norwegian ministries and Innovation Norway. Innovation Norway is a government office for the promotion of nationwide industrial development.

### **3.2 The Norwegian R&D tax credit scheme**

The Norwegian R&D tax credit scheme, called “Skattefunn”, was introduced in 2002 and implies that firms can deduct from payable taxes a certain amount of their R&D expenditures.<sup>8</sup> The deduction is subject to specific criteria. A firm must meet the relevant terms and have its project plan approved by the Skattefunn secretariat that is part of the Research Council of Norway. The actual R&D expenditures have to be approved by the tax authorities, who mainly base their judgement on a statement from the applying firm’s auditor.

In order to qualify for the tax credit, the R&D must be aimed at generating new knowledge, information or experience which is presumed to be of use for the enterprise in developing new or improved products, services or manufacturing/processing methods. Standard product development with no research component is not covered by the scheme.

Enterprises that are not currently liable for taxation are also eligible. If the tax credit exceeds the tax payable by the firm, the difference is paid to the firm like a negative tax or a grant. In practice, this has turned out to be a very important feature as around three-quarters of the total support given through the scheme is paid out as grants.

The R&D tax credit is neutral as between 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 no incentive on the

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<sup>8</sup> See Cappelen et al. (2010) for an overall evaluation of the programme up to 2007.

margin to increase R&D investments, although they have a clear incentive to qualify for the scheme and receive the tax deduction.<sup>9</sup>

The total maximum tax deduction for a small establishment was at the outset 200 000 Euros per year (20 % of a 1 million Euro cap on the project size).<sup>10</sup> For large establishments, included in the scheme in 2003, it was 180 000 Euros (18 % of 1 million).<sup>11</sup> However, the average tax deduction per tax credit project has been much lower than this.

### **3.3 Data**

My sample consists at the outset of all observations in the Norwegian R&D surveys from 1993 to 2005. The R&D surveys have been conducted by Statistics Norway every second year up to 2001 and annually thereafter.<sup>12</sup> All firms with more than 50 employees are included, and a stratified sample of firms with 10-50 employees. The variables in the surveys are self-reported by the firms, but the numbers are thoroughly revised by Statistics Norway. I merge these data with Statistics Norway's "firm capital database" that has detailed information on output and inputs for manufacturing firms. Hence, the final sample covers only manufacturing. The firm capital database is documented in Raknerud, Rønningen and Skjerpen (2004, 2007) and contains basic firm level information regarding sales, investments, employment etc. The source of the information is a combination of administrative registers, financial accounts and the questionnaire-based manufacturing census of Statistics Norway.

I remove observations with missing variables and outliers defined as observations with R&D-intensities large than 0.5 and TFP-growth (log difference) outside the  $\pm 50$  % interval. These two trimming criteria remove about 2.5 % of the sample.

There are 17 290 firm year observations in the R&D surveys in the years 1993-2001, i.e. prior to Skattefunn. 26 % of these report positive R&D (intramural, extramural or both). After the introduction of Skattefunn, in the years 2002-2005, there are 16 464 firm year observations. Out of these 33 % report positive R&D and 20 % have received an R&D tax credit.<sup>13</sup>

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<sup>9</sup> In theory, the presence of liquidity constraints or internal political processes related to the investment budget could also give firms above the maximum amount an incentive to increase their R&D investments.

<sup>10</sup> The exact amounts are NOK 1.6 million which is 20 % of an NOK 8 million cap on the project size. This includes both intramural and extramural R&D. In addition, there was a separate NOK 4 million cap on intramural R&D.

<sup>11</sup> The maximum deductions increased in 2009 and again in 2014, 2015, 2016 and 2017. The effect of these expansions is currently under evaluation. I study the early phase of the Norwegian R&D tax credit scheme before the cap increased.

<sup>12</sup> The form (RA-0479) and further information is available at <https://www.ssb.no/innrapportering/naeringsliv/fou>. See SSB (2004) for information in English.

<sup>13</sup> See Hægeland and Møen (2007) for more detailed descriptive statistics.

### 3.4 Variables

The following variables are used in the empirical analysis:

**R&D** is total costs to intramural and extramural R&D as reported by the firms in the annual R&D surveys conducted by Statistics Norway and described above.

**R&D<sup>Direct subsidies</sup>** is the size of the subsidized intramural R&D projects.<sup>14</sup> We assume that all direct subsidies are given as matching grants and calculate the size of the subsidized R&D projects ( $R^G$  in equations 14 and 18 below) as two times the grants. The main source of funding is the Research Council of Norway, but the variable also includes grants from the EU, Innovation Norway, ministries etc. The variable is constructed based on information in the annual R&D surveys conducted by Statistics Norway and described above.

**R&D<sup>Tax credit</sup>** is the size of the R&D project that has been accepted under the tax credit scheme ( $R^T$  in equation 18). If the project does not exceed the maximum amount liable for deduction, the project size will be about five times the actual tax credit given.<sup>15</sup> The variable is from the tax register and delivered to Statistics Norway by the Norwegian Tax Administration.

**R&D<sup>Own funds</sup>** is R&D projects financed by own funding ( $R^P$  in equations 14 and 18) and calculated residually as  $R\&D - R\&D^{Direct\ subsidies} - R\&D^{Tax\ credit}$ .

**Sales** ( $Q$  in equations 1-18) is annual operating income from financial statements. The source of the variable is Statistics Norway's firm capital database described above.

**Materials** ( $M$  in equation 1) is annual operating costs minus wage costs, depreciation and amortization and rental costs. These variables are from financial statements and the manufacturing census. The source of the constructed materials variable is Statistics Norway's firm capital database described above.

**Labour** ( $L$  in equation 1) is annual hours worked from the manufacturing census. The source of the variable is Statistics Norway's firm capital database described above. The wage cost used to construct the factor share of labour is from financial statements and also included in the capital database.

**Capital services** ( $C$  in equation 1) is calculated as rental costs plus an imputed rental rate on the capital stock. Following Klette (1994, 1999), the assumed rental rate is 9 % for buildings and 13 % for machinery. The source of the capital variables is Statistics Norway's firm capital database described above. It combines information from financial accounts and the manufacturing census.

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<sup>14</sup> Extramural R&D receive little subsidies, and data on such subsidies are only available in the early R&D surveys.

<sup>15</sup> Five times larger for SMEs and 5.6 times larger for non-SMEs who receive an 18 % tax credit.

Price deflators for sales, materials and capital are taken from the Norwegian National Accounts. R&D is deflated with a separate R&D deflator based on wage costs for R&D workers.

## 4 The profitability of R&D financed by direct grants vs R&D financed by the tax credit

### 4.1 An extended R&D capital model

The R&D capital model of Griliches (1973, 1979 and 2000) has for several decades been the ruling paradigm for researchers wanting to estimate the returns to R&D – despite the many weaknesses that Griliches and others have pointed out. As is evident from the surveys mentioned in section 2, a number of variations of the framework exist. The exact specification used typically depends both on the research question and the data available.<sup>16</sup> Doraszelskiy and Jaumadreuz (2013) offer perhaps the most recent and profound extension of the framework, making it into a dynamic investment model that accounts for uncertainty, non-linearity, and heterogeneity across firms in the link between R&D and productivity.

The work-horse R&D capital model describes the firm’s technology by an extended Cobb-Douglas production function with constant returns to scale in the conventional inputs, labour, material and physical capital.

$$(1) \quad Q_{it} = A_t L_{it}^{\beta} M_{it}^{\gamma} C_{it-1}^{1-\beta-\gamma} K_{it-1}^{\varphi} e^{\alpha_i \varepsilon_{it}}$$

$Q_{it}$  is output measured by total operational income (sales),  $A_t$  represents the general level of technology, i.e. forces outside the firm that affect output and changes systematically over time,  $L_{it}$  is labour measured by total man hours,  $M_{it}$  is materials,  $C_{it}$  is services from physical capital and  $K_{it}$  is knowledge capital (R&D capital), the variable of key interest in my analysis.<sup>17</sup> The capital stocks are considered predetermined at the beginning of period  $t$ . The parameters  $\beta$ ,  $\gamma$  and  $\varphi$  are elasticities, and  $\alpha_i \varepsilon_{it}$  is a random disturbance term. The fixed firm specific effect  $\alpha_i$  will account for such factors as unobserved variation in the quality of labour and management between firms.

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<sup>16</sup> The variations stem from whether to use total production, value added, TFP, “partial productivity” or labour productivity as left hand side variables, whether to use the knowledge capital stocks or the R&D intensity as the key right hand side variable, whether to impose constant return to scale in traditional inputs, whether to estimate equations in levels or first differences, the level of aggregation, what additional control variables to include, whether and how to handle simultaneity between input choice and production, whether to correct for double counting of inputs used for R&D, and estimation method.

<sup>17</sup> R&D man-hours should have been subtracted to avoid double counting of R&D inputs. It seems, however, that such an adjustment creates substantial noise in the TFP measure due to measurement errors in the available R&D man-year variable. According to the meta-regression in Ugur et al. (2016), lack of correction for double counting is not important in practice. It is probably more important for estimates based on level equations than on growth equations where unobserved firm fixed effects are differenced out.

Taking logs of (1) and then taking first differences, we get

$$(2) \quad q_{it} = a_t + \beta l_{it} + \gamma m_{it} + (1 - \beta - \gamma)c_{it-1} + \varphi k_{it-1} + u_{it}$$

Small letters represent log differences or growth rates so that e.g.  $q_{it} = \ln Q_{it} - \ln Q_{it-1} \approx \frac{\Delta Q_{it}}{Q_{it}}$ . The error term,  $u_{it}$ , is the first difference of  $\varepsilon_{it}$ . Note that the firm fixed (level) effect,  $\alpha_i$ , is differenced out of the transformed error term.

If we assume perfect competition, the elasticity of labour is  $\beta = \frac{w_t L_{it}}{P_t Q_{it}}$  where  $w_t$  is the wage rate, and  $P_t$  can be normalized to 1 since  $Q_t$  is measured by sales.<sup>18</sup> We can then calculate  $\hat{\beta}$  as the firms' wage share in output. Likewise,  $\hat{\gamma}$  can be calculated as the firms' share of material costs in output. This makes it possible to rewrite equation (2) in TFP growth

$$(3) \quad tfp_{it} = a_t + \varphi k_{it-1} + u_{it}$$

where  $tfp$  is the log difference of TFP and  $\ln TFP_{it} \equiv \ln Q_{it} - \hat{\beta} \ln L_{it} - \hat{\gamma} \ln M_{it} - (1 - \hat{\beta} - \hat{\gamma}) \ln C_{it}$ .

When calculating the elasticities, we allow them to vary between firms, but assume that they are positive and fixed within firms over time.

Next, if we assume that the returns to knowledge capital,  $\frac{\partial Q_{it}}{\partial K_{it}} = \rho$  is equated across firms, we can rewrite (3) as

$$(4) \quad tfp_{it} = a_t + \rho \left( \frac{\Delta K_{it-1}}{K_{it-1}} \right) + u_{it}$$

since  $\varphi = \frac{\partial Q_{it-1}}{\partial K_{it-1}} \frac{K_{it-1}}{Q_{it-1}}$  and  $k_{it-1} \approx \frac{\Delta K_{it-1}}{K_{it-1}}$ .

If knowledge capital depreciates slowly and knowledge accumulates additively, we have that  $\Delta K_{it-1} \approx R_{it-1}$  where  $R_{it-1}$  represents total R&D investments in the previous period. This gives us the

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<sup>18</sup> It is common to approximate elasticities with factor shares, but in the context of a model with R&D investments, perfect competition is obviously a rough, simplifying assumption. See Griliches (2000) p. 63-65 for a short discussion. According to Griliches (2000), building on Klette and Griliches (1996), market power may lead to a downward bias of the estimated effect of R&D on productivity.

following relationship where the returns to R&D,  $\rho$ , can be estimated directly without calculating the knowledge capital stock

$$(5) \quad tfp_{it} = a_t + \rho \left( \frac{R_{it-1}}{Q_{it-1}} \right) + u_{it}$$

$R_{it}/Q_{it}$  is known as “research intensity”. Not having to calculate the knowledge capital stock is beneficial since long time series of the firms’ R&D investments typically are unavailable.

As I have indicated in footnote 16, and throughout, there are many potential pitfalls in the framework leading up to equation (5). Even though  $\rho$  clearly tells us something about the effect of R&D on firm performance, its interpretation as “rate of return” should not be taken entirely literally. See e.g. Mairesse and Sassenou (1991) for a discussion of difficulties with this interpretation.

In the R&D capital model it is assumed that knowledge accumulates additively, i.e.

$$(6) \quad K_{it} = (1 - \delta)K_{it-1} + R_{it}$$

R&D consists of different types of projects. Let us for now abstract from projects that receive R&D tax credits and focus on pure private funding and direct public grants. As explained in the introduction, theory predicts that projects financed by public grants are less efficient in building productive knowledge for the firm (in terms of generating private return) than projects that the firms undertake without subsidies.

Inspired by Griliches (1986), let us distinguish between unweighted knowledge capital,  $K$  and efficient knowledge capital  $K^*$ . Let

$$(7) \quad K_{it}^* = K_{it}^P + (1 + \pi)K_{it}^G \quad \text{and} \quad K_{it} = K_{it}^P + K_{it}^G$$

$$\text{Then } K_{it}^* = K_{it} + \pi K_{it}^G.$$

$K^P$  represents privately financed knowledge capital and  $K^G$  represents knowledge capital financed by grants from the government. I assume that both the private and governmental part of the knowledge capital accumulates according to (6).

The efficient knowledge capital is unobserved as the efficiency weight  $(1 + \pi)$  is unknown. However, if  $\pi$  is different from zero, equations (1) – (5) are misspecified. Taking the loglinear version of the production function (1) as our point of departure, we find that the following term is missing

$$(8) \quad \varphi \ln(K_{it} + \pi K_{it}^G) - \varphi \ln K_{it} = \varphi \ln\left(1 + \frac{\pi K_{it}^G}{K_{it}}\right) \approx \varphi \pi \cdot \frac{K_{it}^G}{K_{it}}$$

Hence, one possible solution is to include as a variable the ratio between the knowledge capital that is financed by the government and the total unweighted knowledge capital. This is the approach suggested by Griliches (1986). It makes it possible to estimate the efficiency parameter  $\pi$  by taking the ratio of the estimates for  $\varphi\pi$  and  $\varphi$ .

Note, however, that (8) involves an approximation, and that this approximation is only good for  $\frac{\pi K_{it}^G}{K_{it}}$

close to zero. Furthermore, in order to make the correction term in (8), knowledge stocks based on both total R&D and governmental R&D must be calculated.

An alternative avenue, not explored by Griliches (1986), is to go back to equation (4). Substituting efficient knowledge capital for unweighted knowledge capital we get

$$(9) \quad tfp_{it} = a_t + \rho \left( \frac{\Delta K_{it-1}^*}{Q_{it-1}} \right) + u_{it}.$$

Next, we have that

$$(10) \quad \Delta K_{it}^* = \Delta [K_{it}^P + (1 + \pi)K_{it}^G] = \Delta K_{it}^P + (1 + \pi)\Delta K_{it}^G$$

Inserted in (9) this gives

$$(11) \quad tfp_{it} = a_t + \rho \left( \frac{\Delta K_{it}^P}{Q_{it}} \right) + \rho(1 + \pi) \left( \frac{\Delta K_{it}^G}{Q_{it}} \right) + u_{it}$$

$$\text{where } \rho = \frac{\partial Q_{it}}{\partial K_{it}^P} \text{ and } \rho(1 + \pi) = \frac{\partial Q_{it}}{\partial K_{it}^G}.$$

The expressions for  $\rho$  og  $\rho(1 + \pi)$  follows from

$$(12) \quad \frac{\partial Q_{it}}{\partial K_{it}^P} = \frac{\partial Q_{it}}{\partial K_{it}^*} \cdot \frac{\partial K_{it}^*}{\partial K_{it}^P} = \frac{\partial Q_{it}}{\partial K_{it}^*} = \rho \quad \text{and}$$

$$(13) \quad \frac{\partial Q_{it}}{\partial K_{it}^G} = \frac{\partial Q_{it}}{\partial K_{it}^*} \cdot \frac{\partial K_{it}^*}{\partial K_{it}^G} = \frac{\partial Q_{it}}{\partial K_{it}^*} (1 + \pi) = \rho(1 + \pi)$$

The coefficients,  $\rho$  and  $\rho(1 + \pi)$ , therefore can be interpreted as the returns to private and governmental knowledge capital respectively. If we again assume a low rate of depreciation so that  $\Delta K_{it-1}^P \approx R_{it-1}^P$  and  $\Delta K_{it-1}^G \approx R_{it-1}^G$ , we can estimate (11) by using R&D intensities rather than knowledge capital stocks:

$$(14) \quad tfp_{it} = a_t + \rho \left( \frac{R_{it-1}^P}{Q_{it-1}} \right) + \rho(1 + \pi) \left( \frac{R_{it-1}^G}{Q_{it-1}} \right) + u_{it}$$

So far I have, for simplicity, abstracted from R&D projects that receive tax credits. The framework I have developed, however, is easy to generalize to an arbitrary number of knowledge capital components. Let the knowledge capital built up on R&D projects that receive an R&D tax credit be  $K^T$ . Let its efficiency relative to privately financed knowledge capital be  $(1+\tau)$ . Then

$$(15) \quad K_{it} = K_{it}^P + K_{it}^G + K_{it}^T,$$

$$(16) \quad K_{it}^* = K_{it}^P + (1 + \pi)K_{it}^G + (1 + \tau)K_{it}^T = K_{it} + \pi K_{it}^G + \tau K_{it}^T \quad \text{and}$$

$$(17) \quad \Delta K_{it}^* = \Delta K_{it}^P + (1 + \pi)\Delta K_{it}^G + (1 + \tau)\Delta K_{it}^T$$

The equation to be estimated is then

$$(18) \quad tfp_{it} = a_t + \rho \left( \frac{R_{it-1}^P}{Q_{it-1}} \right) + \rho(1 + \pi) \left( \frac{R_{it-1}^G}{Q_{it-1}} \right) + \rho(1 + \tau) \left( \frac{R_{it-1}^T}{Q_{it-1}} \right) + u_{it}.$$

In the empirical application, I add time dummies, industry dummies and a dummy for firms that report zero R&D. I will also allow  $u_{it}$ , the unobserved innovations in productivity growth, to have a firm specific random component.<sup>19</sup>

I assume that direct subsidies are given as matching grants and calculate  $R^G$ , R&D projects financed by public grants, as two times the grant.  $R^T$  is measured as the size of the R&D project accepted under the tax credit scheme, i.e. about five times the actual tax credit given that the project does not exceed the maximum amount liable for deduction. R&D projects financed by own funding are calculated as total R&D minus the two other components.

## 4.2 Identification

As pointed out by Griliches and Mairesse (1998) and many others, the main challenges of estimating production functions is simultaneity. Obviously, R&D investments and other input decisions are endogenous choices, and R&D subsidies are not distributed randomly. A positive productivity shock will induce the firm to increase input use and may affect the probability of receiving R&D subsidies. Using ordinary least square on the variables in levels, the researcher will then attribute the production gain to the increased use of inputs rather than the effect of the unobserved shock.

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<sup>19</sup> Note that a fixed effect in the level of productivity is already differenced out in equation (2).

The natural solution to the general endogeneity problem is to utilize instrumental variables or natural experiments. Unfortunately, the data at hand do not lend themselves to either strategy. Following much of the R&D capital model literature, I rely instead on what Griliches and Mairesse call the panel data response and a partial productivity equation. It should be noted, however, that the introduction of the R&D tax credit scheme in 2002 is exogenous to the firms, and that the increasing awareness of the scheme over time also represents partly exogenous variation. Likewise, there is year to year exogenous variation in R&D subsidies directed to various industries although the exogenous variation cannot be isolated in a satisfactory manner.

The identification strategy utilized rests on two assumptions. First, that a large part of the unobserved heterogeneity that causes the endogeneity problems is stable over time and absorbed by the firm fixed effect  $\alpha_i$ . This is the panel data response. Such effects, like differences in technological opportunities and availability of subsidies between industries, differences in the quality of the workforce, the knowledge base, previous patents, networks, experience with the application process, location, size of market, strength of brands and management quality, is removed by first differencing in equation (2).

A second assumption is that there is a one-year time lag between productivity and investments in both physical capital and R&D. This allows these variables to be treated as predetermined and not correlated with contemporaneous revenue shocks. Labour and material inputs which are flexible in the short run, are moved to the left hand side of the equation together with physical capital services, when equation (2) is rewritten as TFP growth in equation (3). This is a “partial productivity equation” since the productivity effect of R&D is left on the right hand side.

Needless to say, this identification strategy may be subject to substantial reservations. One obvious problem is potential autocorrelation in the contemporaneous productivity shocks making  $R_{i,t-1}$  correlated with  $u_{it}$ .<sup>20</sup> As pointed out by Griliches (1986), the results presented should not be considered proof of the effect of R&D investments, but rather as evidence supporting the interpretation that is implicit in the model.

## 5 Results

I start out estimating equation (5) which gives the overall return to R&D. The results are reported in Table 1, column (1). The overall estimate suggests a 15 % gross private return to R&D investments. This estimate seems low. R&D investments should earn a risk premium and “gross” means that depreciation is not accounted for (assumed to be zero).<sup>21</sup> Measurement errors in the R&D variable and

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<sup>20</sup> See Jaffe (2002) for a summary of relevant selection issues in public research-support programmes.

<sup>21</sup> Depreciation of the existing knowledge capital stock has to be deducted before the “net” return can be calculated. Depreciation of the private stock of knowledge capital is commonly assumed to be 15 %.

specification errors are likely to give a downward bias, however, and the estimate is in line with the international literature and previous work on Norwegian data, cf. section 2.

**Table 1. Returns to R&D investments in Norway**

	(1) All firms	(2) SME	(3) Large firms	(4) R&D below 4 million	(5) R&D above 4 million
R&D <sub>t-1</sub> /Sales <sub>t-1</sub>	0.15*** (0.03)	0.19*** (0.04)	0.11*** (0.04)	0.17*** (0.04)	0.11*** (0.04)
R-square	0.03	0.04	0.03	0.03	0.04
No. of obs.	12081	7544	4537	9646	2435

The dependent variable is TFP-growth measured by log differences. Standard errors are in parentheses. The estimation method is GLS with firm random effects in the error term. A dummy for zero R&D, time dummies and 30 industry dummies are included, but not reported. SME are firms fulfilling two out of the following three criteria: (i) Fewer than 100 employees (ii) an annual turnover less than 10 million Euros (NOK 80 million) (iii) an annual balance sheet total less than 5 million Euros (NOK 40 million). R&D below and above 4 million refers to average intramural R&D being above or below the NOK 4 million tax credit cap before the tax credit scheme was introduced. The sample consists of observations in the R&D surveys from 1993 to 2005. Outliers, defined as observations with R&D-intensities large than 0.5 and TFP-growth outside the  $\pm 50\%$  interval, are removed.

\* Significant at the 10 percent level \*\* Significant at the 5 percent level \*\*\* Significant at the 1 percent level.

In Table 1, columns (2)-(5), I explore whether the return varies with firm size and the size of the R&D investments. This can also be thought of as a robustness exercise as it shows the stability of the results across different subsamples. All samples give reasonable estimates. I find that SMEs and small R&D performers have somewhat higher returns to R&D than larger firms. Small firms are defined according to the 2002 rules of the tax credit scheme, and small R&D performers are defined as firms with R&D investments below the cap for internal R&D investments in the tax credits scheme, i.e. firms with R&D below 500 000 Euros (NOK 4 million).

Before turning to the framework developed in section 4, I explore the returns to R&D funded by direct R&D grants and R&D tax credits by using a simple dummy approach. In Table 2, column (1), we see that interaction terms between R&D intensity and dummies for receiving direct subsidies and/or tax credits suggest that the return to R&D in firms that use the tax credits scheme is higher than the return to R&D in firms that receive direct R&D subsidies – at least for firms with high R&D intensity. The results in columns (2)-(5) show that the basic pattern found in column (1) is quite robust to various ways of splitting the sample.

**Table 2. Returns to R&D by source of funding – interaction terms**

	(1) All firms	(2) SME	(3) Large firms	(4) R&D below 4 million	(5) R&D above 4 million
R&D <sub>t-1</sub> /Sales <sub>t-1</sub>	0.14*** (0.04)	0.14*** (0.05)	0.19*** (0.06)	0.11* (0.06)	0.11* (0.06)
Dummy for direct subsidies <sub>t-1</sub>	0.01* (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
Dummy for tax credit <sub>t-1</sub>	-0.01** (0.00)	-0.01* (0.01)	-0.00 (0.01)	-0.01 (0.01)	-0.02*** (0.01)
R&D <sub>t-1</sub> /Sales <sub>t-1</sub> * Dummy for direct subsidies <sub>t-1</sub>	-0.10* (0.06)	-0.09 (0.08)	-0.16** (0.08)	-0.10 (0.09)	-0.10 (0.08)
<sup>1</sup> * Dummy for tax credit <sub>t-1</sub>	0.12** (0.05)	0.15** (0.07)	-0.06 (0.08)	0.17** (0.08)	0.12 (0.08)
R-square	0.03	0.04	0.03	0.03	0.05
No. of obs.	12081	7544	4537	9646	2435

The dependent variable is TFP-growth measured by log differences. Standard errors are in parentheses. The estimation method is GLS with firm random effects in the error term. A dummy for zero R&D, time dummies and 30 industry dummies are included, but not reported. SME are firms fulfilling two out of the following three criteria: (i) Fewer than 100 employees (ii) an annual turnover less than 10 million Euros (NOK 80 million) (iii) an annual balance sheet total less than 5 million Euros (NOK 40 million NOK). R&D below and above 4 million refers to average intramural R&D being above or below the NOK 4 million tax credit cap before the tax credit scheme was introduced. The sample consists of observations in the R&D surveys from 1993 to 2005. Outliers, defined as observations with R&D-intensities large than 0.5 and TFP-growth outside the  $\pm 50\%$  interval, are removed.

\* Significant at the 10 percent level \*\* Significant at the 5 percent level \*\*\* Significant at the 1 percent level.

Estimates based on the main specification in equation (18) are given in Table 3. The pattern found in Table 2 is confirmed. The estimate for the return to R&D projects financed by direct subsidies is not significantly different from zero. The point estimate is actually negative, but it has low precision. The estimate for the return to R&D projects financed by tax credits is just slightly below the return to R&D projects financed by own funds. Although the estimated return to projects financed by direct subsidies is surprisingly low, the basic pattern fits the predictions given in section 1. R&D subsidies are given to projects with low private returns while projects that receive an R&D tax credit are quite similar to projects financed by own funds, but have slightly lower returns. Remember that the key success criteria for projects financed by direct subsidies are their social returns which I do not estimate.

**Table 3. Returns to R&D by source of funding - intensities**

	(1) All firms	(2) SME	(3) Large firms	(4) R&D below 4 million	(5) R&D above 4 million
R&D <sup>Own funding</sup> /Sales	0.19*** (0.04)	0.25*** (0.05)	0.13*** (0.05)	0.19*** (0.06)	0.16*** (0.05)
R&D <sup>Direct subsidies</sup> /Sales	-0.09 (0.06)	-0.11 (0.08)	-0.01 (0.10)	-0.02 (0.11)	-0.14* (0.08)
R&D <sup>Tax credit</sup> /Sales	0.16*** (0.04)	0.17*** (0.04)	0.17 (0.17)	0.19*** (0.06)	0.12** (0.06)
R-square	0.03	0.04	0.03	0.03	0.05
No. of obs.	12081	7544	4537	9646	2435

The dependent variable is TFP-growth measured by log differences. Standard errors are in parentheses. The estimation method is GLS with firm random effects in the error term. A dummy for zero R&D, time dummies and 30 industry dummies are included, but not reported. SME are firms fulfilling two out of the following three criteria: (i) Fewer than 100 employees (ii) an annual turnover less than 10 million Euros (NOK 80 million) (iii) an annual balance sheet total less than 5 million Euros (NOK 40 million). R&D below and above 4 million refers to average intramural R&D being above or below the NOK 4 million tax credit cap before the tax credit scheme was introduced. The sample consists of observations in the R&D surveys from 1993 to 2005. Outliers, defined as observations with R&D-intensities large than 0.5 and TFP-growth outside the  $\pm 50\%$  interval, are removed.

\* Significant at the 10 percent level \*\* Significant at the 5 percent level \*\*\* Significant at the 1 percent level.

Turning to Table 3, columns (2)-(5), we find that the estimated pattern is quite robust to splitting the sample according to firm size. The estimated returns are however, not stable over time. When estimating the return parameters year by year from 1993 to 2005, they vary considerably (not reported). This may suggest a problem with the specification, but it may as well reflect a reality with large variance in the returns to R&D projects. Typically, a few projects are major successes while most projects have a low or negative return, see e.g. Scherer and Harhoff (2000).

## 6 Conclusions

When awarding direct R&D grants, public agencies explicitly choose the projects that receive financing. The aim is to select projects with large externalities that would not have been undertaken without the subsidy, i.e. projects that have a low private return (Jaffe 1997, ch. IV.A.). A tax credit, on the other hand has no such selection process attached to it, hence firms will rank projects according to their private return. Much of the subsidy will then be paid to inframarginal projects that would be undertaken even without a subsidy, i.e. projects with a high private return. The mechanism utilized by the government is simply to induce more R&D by lowering the marginal price. If the different subsidy schemes work according to “theory”, projects should differ with respect to private returns depending on their source of financing.

I develop a framework for estimating the returns to R&D projects with different type of funding, and find support for this prediction. I find that projects funded through direct grants are not significantly different from zero and with high variance. Direct R&D subsidies are meant for projects with low private

return, high social return and high risk. This finding is therefore consistent with a high quality grant allocation process. The actual point estimate is probably downward biased due to specification and measurement errors.

My estimate for the return to R&D projects financed by tax credits is just slightly below the return to R&D projects financed by own funds. The estimated returns are 16 % and 19 % respectively. These estimates are surprisingly low for two reasons. First, R&D investments are considered to have high risk, and should therefore earn a risk premium. Second, the estimates represent “gross” returns, meaning that depreciation of the knowledge capital stock is not accounted for. As mentioned above, however, the estimates are likely to be downward biased by measurement errors. Furthermore, there is large variance in the returns to R&D projects. When I estimate the return parameters year by year, I find that they vary considerably around the estimated mean value for the full sample period.

A final caveat to reiterate is that the results rest on the rather restrictive assumptions of the R&D capital model such as the Cobb-Douglas functional form. Griliches (2000) suggests that the model should be thought of as “a first approximation to a potentially much more complex relationship”. In a similar vein, Hall, Mairesse and Mohnen (2010) close their large review of the literature by stating that “further work on the best way to model the R&D input would be extremely desirable”.

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