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PUBLIC FUNDING OF R&D AND GROWTH: FIRM-LEVEL EVIDENCE FROM FINLAND

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ABSTRACT: This study considers employment and productivity growth generated by the public funding of R&D using linked employer-employee data in Finland. Public subsidies, instrumented by available public R&D funding in the industry/region, have a positive effect on productivity growth in small and medium-sized firms and in firms close to the top of their field in productivity.

JEL classification: O30, O32, O40, O52, R11

KEYWORDS: R&D, public expenditures, endogenous growth, linked employer-employee data.

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Tutkimuksessa tarkastellaan miten julkiset Tekesin rahoittamat T&K tuet vaikuttavat tuottavuuden ja työllisyyden kasvuun. Aineistona on yhdistetty työnantaja-työntekijä aineisto Suomessa. Julkiset T&K panostukset, joita on instrumentoitu mahdollisuudella hakea niitä toimialalla/alueella, lisäävät tuottavuuden kasvua vain pienissä ja keskisuurissa yrityksissä ja yrityksissä, jotka ovat lähellä tuottavuuden huippua toimialallaan.

1. INTRODUCTION

This study explains growth in productivity and employment generated by public R&D subsidies in Finland. We use linked employer-employee data. The data of the firms cover almost the entire manufacturing sector with detailed information on occupations and R&D-related work. Linked data is extensively used in the study of human capital formation, starting with Abowd, Kramarz and Margolis (1999). The key variables in measuring innovative capacity and knowledge capital here are the workers engaged in R&D and human capital measured by compensation for skills. We distinguish human capital specific to the firm, including R&D work, which is not directly transferable to work done in other firms. R&D work can be thought of as one form of occupation human capital. Moreover, R&D work is not necessarily the highest paid white-collar profession. Piekkola (2005) finds that in Finland the wage level is lower than the average for white-collar workers.

Knowledge capital is the basis for competitiveness, which Klette and Kortum (2004) define as skills, techniques and know-how that a firm draws on as it attempts to innovate. Knowledge capital is also an essential part of the catching-up process and explains the non-linear nature of the catching-up found in Benhabib and Spiegel (2005). Catching-up applies to the diffusion of technology within industries, with the firm leading in total factor productivity representing the technological frontier. Griffith, Redding et al. (2004) find in their cross-country study that human capital is important for both the innovations and the catching-up process. These spillovers take place in excess of the private returns. Piekkola (2005) finds that since 1996 regional growth at the NUTS 4-level in Finland has diverged and regions abundant in knowledge capital have grown faster.

Finland is ranked one of the most competitive countries, see Global Competitiveness Report 2005-2006 (www.weforum.org/gcr). Potential factors behind this good performance are high tertiary enrolment and heavy investment in R&D personnel (researchers and others), which is 2.4% of total employment in 2003 (the EU24 average is 0.44% and that of Sweden is 1.7%, see OECD Science, Technology and Industry Scoreboard 2005). It is clear that the support of knowledge capital is an important tool for future growth.

Public subsidies by the National Technology Agency, Tekes, have been publicly recorded since 2004. Tekes is responsible for about 80% of all public subsidies for R&D in Finland, or 409 million euros in 2004. As regards large firms, public subsidy awards require a joint project with small firms. These projects usually last a long time, up to five years. It is thus important to control the size of the firm. Small firms also participate less frequently in various support programmes and those that do can be more easily be the most technologically advanced. Small firms can also have a higher cost for alternative external finance. It is also important to separate subsidies for imitation and new innovations. Governmental grant regime which stimulates only imitation can lower the incentives for successful innovations by making them more short-lived and less profitable. Davidsson and Segerstrom (1998) argue that only innovative R&D subsidies lead to faster economic growth. The line between innovative activity and support for knowledge capital in general may be hard to draw. Aghion, Harris and Vickers (1997) introduce a leapfrogging model where a firm, by incurring an appropriate cost, must first catch-up the technological leader in the industry, which should be subsidised, before being able to overtake the technological leadership.

We pay considerable attention to the instrumentation of public subsidies using the information of available R&D subsidies in each industry and region. The main finding in our study is that public subsidies have an independent positive effect on productivity growth in small and medium-sized firms. We not only analyse how public subsidies are used to foster innovation capacity and growth, but also whether this has had a positive impact on employment, which we do not find to be the case.

The rest of the paper is structured as follows: Section 2 presents a literature review of the role of public R&D subsidies in creating growth. Section 3 presents the data and Section 4 the results of the estimation. Section 5 concludes with some evaluation of the subsidy policy in Finland.

2. LITERATURE REVIEW

The rate of return on private R&D has increased over the decades, see Wieser (2005) and Kafouros (2005) for the UK. Wieser (2005) in his surveys also finds that the rate of return does not significantly differ between countries, whereas the estimated elasticities do because of the difference in R&D intensities. Public subsidies can be defended on the grounds of the social rate of return exceeding the private return and by liquidity constraints in capital market. Jones (1995) shows evidence against the scale effect so that the level of resources devoted to R&D would increase the growth rate of the economy. Nevertheless, most of the studies regarding public R&D expenditures have examined whether these are substitutes or complements for private R&D expenditures. David, Hall *et al.* (2000) in their survey report complementarity of public subsidies and private R&D expenditure in the aggregate studies made at industry or country-level. The complementarity in Levy and Terleckyj (1983) and Diamond (1999), among others, can also be partly explained by the absence of instruments to control for the business cycle, and by unobserved inter-industry differences in the technological opportunity set that relates positively to both the public and private R&D expenditures. One explanation for overestimates in favour of complementarity is that private R&D spending effects include the positive price effects when the R&D supply is inelastic. The macroeconomic impacts relating to the relative size of the public sector in R&D output, the elasticity of the labour supply of qualified R&D and the choice of direct subsidies – loans mix are important areas for further research.

In firm-level studies, the findings about complementarity or substitutability are ambiguous, although complementary appears to be the rule in European studies. Using instrumenting techniques, Wallsten (2000) finds in the US that the public R&D subsidies have a strong crowding out effect on private investment and no effect on employment. Most of the other studies do not find full crowding out. Busom (1999) in Spain and Hussinger (2003) in Germany find evidence that public funding has real effects on private innovations. Later studies with this conclusion includes matching methods, see Czarnitzki and Fier (2001), Almus and Czarnitzki (2003) and Duguet (2004). Sorensen, Kongsted *et al.* (2003) in Denmark find that subsidies increase private R&D expenditures. Ebersberger (2004) in Finland utilises differences-in-differences techniques to analyse the innovation and labour demand effects of public R&D funding in Finland. The results suggest that subsidies have a positive impact on innovation output, and in the long run on employment, see also Lehto (2000).

Productivity growth effects can be said to be less clear than the complementarity to private R&D. This is not surprising given that the productivity growth effects of R&D in general are unclear. Klette and Kortum (2004) summarises as the main findings in the literature that while productivity and R&D across firms are positively related, the effect of R&D on productivity growth is unclear. Kletter, Möen, Griliches (2000) earlier survey the econometric evidence on the effectiveness of fiscal incentives for R&D. They highlight the problems faced by the receivers not being a random sample. The very low or negative productivity effect in Norway in some studies is explained by government policy to save some of the main high-tech firms as they encountered problems towards the end of the 1980s. Picking up the potential losers thus creates a negative section bias. On the other hand, Kletter et al. refer to Lerner (1996) who finds that in the small and medium-sized firms in the US the awards have been successful in high-technology firms and have played an important role in certifying the firm's quality and technological merit. One reason can be positive selection bias in picking up the winners. The role of generating new innovations in some small firms should not be ignored. Baumol (2004) explicitly emphasises the innovative role of many small high-technology firms. Large firms are better in adapting the development projects and implementing the innovations. Finally, subsidies have fared better in supporting marginal investment or the initial start up of new projects rather than when forming the major share of R&D investment. Guellec and Pottelsberghe (2003) find 10% to be the optimum level of public subsidies relative to the total R&D expenditures.

3. THE DATA

The labour data are from the Confederation of Finnish Industry and Employers, where 75% of the firms are in the manufacturing sector. The original data with 3.09 million person-year observations cover 1996-2002 and include both blue- and white-collar employees. The data include a rich set of variables covering compensation, education and profession. The white-collar employees receive salaries and the blue-collar workers receive an hourly wage. Employee data are linked to public financial statistics data provided by the Balance

Consulting and Suomen Asiakastieto, to include information on profits, value added and capital intensity (fixed assets). We have no information on R&D expenditures at the firm level, but have information on white-collar workers in R&D work.

3.1 Estimation of Knowledge Capital

Using the linked employer-employee data analysis starting with Abowd, Kramarz and Margolis (1999), we divide knowledge capital into that relating to individual and firm heterogeneity. Abowd, Creecy and Kramarz (2002) develop a numerical solution to deal with the large set of firm dummies in Least Squares Dummy Variables Estimator. Piekkola (2005) uses the two-step method suggested by Andrews, Schank and Upward (2004).

The estimation includes dummy variables for the firms estimated at the first step in data covering only individuals that move from one firm to another and sweep out the worker heterogeneity by taking deviations from individual means. Before this was done, firm births and deaths are considered as a mere transfer of the firm in instances where people employed either at the old firm at date t-1 or at the new firm at date t constitute more than 40% of all employees working in these firms at dates t-1 and t. These unnatural deaths and births account for approximately 3% of all firm births and deaths. Many of the old or new firms are large and, hence, recoding will affect 9% of the employees. Employers with one or more job transferees (286,000) then account for 13% of all observations. These firms, at the same time, cover most of the person-year observations, 2.09 million out of 2.76 million. Log hourly wages $y_{j(i,t)}$ for person i at period t attached in firm j is first expressed as a function of individual heterogeneity, firm heterogeneity and measured time-varying characteristics for movers as a deviation from individual means.

$$\ln(y_{j(i,t)})\text{-}\mu_{yi} = \beta(x_{it} - \mu_{xi}) + \gamma(w_{it} - \mu_{wi}) + \sum_{j=1}^{J} \psi_j (D_{it}^j\text{-}\mu_{Di}^j) + e_{ijt}, \qquad (6)$$

where $\beta(x_{it} - \mu_{xi})$ shows the compensation for time-varying human capital stated as a deviation from the person mean human capital: hence it contains time dummies and experience expressed up to the fourth power. $\gamma(w_{it} - \mu_{wi})$ shows the respective time-demeaning for all firm-specific variables: occupations, seniority, R&D work and performance-related pay. ψ_j captures the effect of unmeasured employer heterogeneity. $D_{it}^j\text{-}\mu_{Di}^j$ is the firm dummy as a deviation from the person mean μ_{Di}. e_{ijt} represents a statistical error term. The firm-effect could be identified for 1,421 firms with at least 30 job transferees (the original data included 2,359 firms). The second step estimation, with the same explanatory variables amended by the estimated firm effect, covers all workers in the sample of firms for which the firm effects were identifiable.

$$\ln(y_{j(i,t)})\text{-}\mu_{yi} = \beta(x_{it} - \mu_{xi}) + \gamma(w_{it} - \mu_{wi}) + \delta(\hat{\psi}_{j(i,t)} - \mu_{\psi i}) + e_{ijt}, \qquad (7)$$

where $\mu_{\psi i}$ is the person mean of the firm effect $\hat{\psi}_{j(i,t)}$. The person fixed effect is the person average using the second-step estimation results: $\theta_i = \mu_{yi} - \hat{\beta}\mu_{xi} - \hat{\gamma}\mu_{wi} - \mu_{\psi i}$, where $\hat{\beta}$ and $\hat{\gamma}$ are the estimated values of the coefficients. The person effect θ_i is then regressed against all education-level dummies and gender. The rate of return on education degrees is done separately for technical and non-technical fields. Unobserved human capital is the unexplained part of the person fixed effect. The estimation results are shown in Piekkola (2005). Worker-specific knowledge (work experience, education and unobserved) does not depend on the firm's assets, and the worker can transfer this knowledge to other firms in job transfers. In the Benhabib and Spiegel (2005) framework catching-up plays an important role and a large enough human capital base is required for imitation to succeed. The most important part of the worker-specific human capital is the returns on education.

Firm-specific knowledge (firm effect, occupation human capital, compensation for seniority, performance-related pay) is part of knowledge capital and includes returns on R&D work. Occupation human capital is firm-specific and can be also thought of as promoting new innovations. We select knowledge capital essential for productivity growth in Piekkola (2005), which leads to the following categories:

Table 1. Knowledge Capital: Firm-Specific, Worker-Specific

Knowledge Capital: Firm-Specific
Share of White-Collar Workers in R&D Work
R&D Agglomeration
Occupation Capital
Occupation Capital, Education Human Capital Interaction
Knowledge Capital: Worker-Specific
Education Human Capital
Workers Above 75% for Unobserved H.C.
Workers Below 25%, Workers Above 75% for Experience H.C. Interaction

The shares 25%, 75% use as the reference the overall distribution across firms over the period.

R&D agglomeration consists of the spillover from the share of white-collar workers in R&D in the NUTS 4-level region and the influence of other regions. Spatial weights are based on a negative exponential function with the distance decay parameter depending on the distances between neighbouring regions, following Funke and Niebuhr (2000). The half-decay distance that reduces the spatial interaction by one-half is set, on average, at 289 km (an average twice as high in Northern Finland with its long distances). *Occupation human capital* is based on occupation movement that may also include job transferees. *Education human capi-*

tal is measured in efficiency units and uses the relative rate of return of five educational degrees for five fields in explaining the person effect, and measures the share of the highly educated group using these relative returns as weights

$$\textit{Educational HC}_{j,t} = \sum_{i_t=1}^{I_t} z_{i_t \in H} u_H \eta_H \Big/ \sum_{i_t=1}^{I_t} i \,, \tag{8}$$

where $z_{i \in H}$ indicates that the worker belongs to the highly educated group H among the workers i=1,…,I.. The difference from a pure, weighted average measure is that the denominator is not the number of highly educated workers, but all the workers in the firm. We also include non-technical lower-level tertiary degrees in the highly educated group. The selected workers closely form the share of workers belonging to the highest quartile in education human capital. In the estimations, we also use the interaction with education and occupation human capital.

Unobserved human capital is a person-specific fixed effect in wage estimations that cannot be explained by education and sex and is hence unobserved to the econometrician. Unobserved human capital above 75% is the share of workers in the firm belonging to the highest quartile in the distribution of overall unobserved human capital in all firms. *Experience human capital* shows returns on work experience, which is age minus years in education (from 7 to 14 depending on the educational degree) minus 6 years. Heterogeneity of work experience, good for performance in Piekkola (2005), is measured by the interaction of the worker shares belonging to the lowest 25% and the highest 75% quartile in the overall distribution of work experience in all firms. In the estimations, we also use *seniority* to capture job experience, which is job duration in the firm.

3.2 R&D Subsidies and Knowledge Capital in the Firms

We use the publicly available information on public subsidies by the National Technology Agency, Tekes, also including information provided by Tekes on firms that have applied for subsidies and yearly information on actual imbursement. Public subsidies for R&D, 80% of them coming from Tekes, are 1% of GDP and 3.7% of value added, which is above the EU25 average of 0.6%, or 0.5% in the US (OECD Science, Technology and Industry Scoreboard 2005). The subsidies are measured in the year when granted and not when paid. Firstly the distribution of payments can be arbitrary. Secondly, as noted by Lichtenberg (1984), firms undertake significant preparatory R&D in order to qualify for grants and thus the productivity effects may occur at an early stage. In Finland subsidies for innovation activities are concentrated on Tekes with a budget of 409 million euros used in 2,000 projects in 2004. The data from the Confederation of Finnish Industries cover, in particular, all large firms getting public funding as part of their investment. Nearly one fourth of the firms recorded in the data from the Confederations of Finnish Industries have applied for public funding.

We use instrumenting to control for the positive bias in selecting the winners or losers (e.g. due to regional policy) in the public subsidy programme. An ideal instrument for R&D subsidies reflects the potentially available subsidies for the firm (see Lichtenberg, (1988)). Tekes funding has a clear industry variation as the share of risk taking and innovative firms, the target group, is likely to vary from one industry to another. The potentially available subsidies, the Tekes budget for each industry, can also be said to be independent of the firm's unobserved abilities in the industry. As an instrument for applicants with awards, Wallsten (2000) uses the sum of sector-level R&D total funding for the sectors where the firms have won public funding. The instrument for applicants with rejections is the sum of the sector-level R&D total funding for the sectors where the firm has applied for public funding. For the firms that have not applied for public R&D funds, he uses the sector-specific total funding multiplied by the probability of receiving them, which is awards per applications in the sector. His data cover 367 firms with awards, 90 rejected firms and 22 firms that have not applied and chosen from the Compustat data base to represent this group.

We analyse Tekes funding in 26 industries further divided into 6 regions: Greater Helsinki region, city, provincial centre, industrial region, countryside, periphery. Public awards are allocated unevenly across industries with an emphasis on the technology industry. Thus, it is likely that the potential for (knowledge capital intensive) firms to apply for or receive subsidies is lower outside the technology industry. The Tekes administration also has a regional dimension. Firms situated closer to the regional centres or in manufacturing intensive areas may have better opportunities to apply for Tekes funding than firms far away. Tekes funding is deliberately used to strengthen the growing sectors/areas in the economy.

Nearly half of the firms have no R&D employees. The probability for applying for subsidies is twice as high for firms that have permanent R&D activities, see also Czarnitzki and Fier (2002) for evidence in Germany. Despite this, we use data for the 1,662 firms (or 1,428 firms in the estimation sample) and not just for the 836 firms that have had R&D workers in some years. We discuss robustness checks that also relate to the use of the partial data in Appendix A. For the firms with awarded public funding in some year, the instrument we use is the employment weighted average of Tekes R&D funding per sales in the awarded firms in the industry and in the 6 regions. For the firms that have not applied for, or have applied but not received, public R&D funds in any year, we use as a measure of available public funding the same measure multiplied by the probability of applying for R&D subsidies in the industry/region. The probability is measured by the share of firms that have applied for funding from Tekes. 380 firms have received Tekes funding and 107 firms have applied but not received Tekes funding in any year. 941 firms have not applied for Tekes funding. The use of the applicants/the number of firms ratio in the industry/areas as the probability measure, and not the awarded firms/applicants ratio, and applying this probability also for the firms that have applied for but not received subsidies, differs from Wallsten (2000) and Ali-Yrkkö (2005). The applicants are a rather high share of all firms and most firms that apply for subsidies are also awarded them. It is likely, and also true after trials for alternative instrumenting, that the applicants/the number of firms ratio in the industry and region better captures the public finance potential of non-awarded firms.

We refer to a firm with an average workforce below the median average workforce of 161 workers as a small and medium-sized firm (SME). It is noteworthy that the estimation results would have been the same if the limit of the SME category were the usual 250 employees. It is useful to show, besides descriptive statistics, the correlation of growth, R&D intensity (share of white-collar workers in R&D), Tekes funding and available Tekes funding in each industry and region (our instrument). We also show the share of highly-paid R&D workers from all white-collar workers who earn above the median level in the overall distribution of R&D pay.

Table 2. Descriptive Statistics and Correlation of Growth, R&D work and Tekes Funding

	Mean	Standard Deviation	Mean SME	Standard Deviation SME	Mean Large	Standard Deviation Large
Average Employment	570	2600	59	44	1451	4147
Total Factor Productivity Growth	-0.014	0.566	-0.015	0.591	-0.013	0.521
Employment Growth	0.068	0.521	0.065	0.539	0.072	0.492
Tekes R&D Funds (per Sales)	0.010	0.062	0.010	0.071	0.009	0.042
R&D Intensity	0.085	0.150	0.061	0.149	0.126	0.143
R&D Agglomeration	0.011	0.020	0.009	0.019	0.013	0.021
Catching Up Frontier Firm	4.511	1.642	4.694	1.648	4.195	1.584
Occupation Human Capital	0.155	0.072	0.159	0.076	0.147	0.064
Education Human Capital	0.093	0.108	0.081	0.110	0.112	0.100
Workers Above 75% for Unobserved	0.215	0.221	0.201	0.222	0.239	0.217
Workers Below 25%, Above 75% for Experience H.C.	0.047	0.029	0.044	0.032	0.053	0.021

Correlations	TFP Growth	Labour Growth	White-Collar in R&D	White-Collar in High-Paid R&D	Tekes Funding / Sales	Potential Subsidies / Sales
Labour Growth	0.17	1	0.00	-0.03	0.00	-0.01
White-Collar in R&D	0.02	0.00	1	0.57	0.17	0.20
White-Collar in High-Paid R&D	0.00	-0.03	0.57	1	0.07	0.09
Subsidies/Sales	0.06	0.00	0.17	0.07	1	0.53
Potential Subsidies/Sales	0.05	-0.01	0.20	0.09	0.53	1.00

It is seen that the average Tekes funding per sales is almost the same in SMEs and large firms in the estimation sample. Large firms have twice as high R&D intensity and are located in regions agglomerated with R&D. Large firms have more highly educated workers, while small firms are more intensive in occupation human capital. It is seen that Tekes funding per sales is weakly positively correlated with the share of R&D workers but has little correlation with the share of white-collar workers in highly-paid R&D work. It can be still said that Tekes funding is somewhat more frequent in firms that have a more innovative investment base. The instrument for Tekes, subsidies per sale by Tekes in each industry, correlates highly with the granted subsidies at firm level but fairly little with growth, satisfying the requirement of an ideal instrument.

Table 3 Distribution of R&D Activity and Subsidies

	White-Collar Share in R&D Work	White-Collar Share in Highly-Paid R&D Work	R&D Subsidy per Sales
1 %	0	0	0
5 %	0	0	0
10 %	0	0	0
25 %	0	0	0
50 %	0.354	0.054	0
75 %	0.917	0.111	0
90 %	0.000	0.182	0.021
95 %	0.000	0.250	0.060
99 %	0.000	0.768	0.243
Mean	0.144	0.084	0.013
Std. Dev.	0.172	0.123	0.075
Skewness	2.192	4.189	15.774

The average R&D intensity of 14.4% in manufacturing is very non-linearly distributed. The distribution of this, as well as highly-paid R&D intensity and subsidies per sales, is shown in the following table

It is seen that the R&D intensity of 14.5% (the average white-collar worker share in R&D work) is fairly high. There have been no R&D workers in over 25% of the years. We find it appropriate to use the second potency of the share of white-collar workers to account for the non-linearity. It is seen that subsidies are given on average around 10% of the firm-year observations and the average compensation is 1.3% of sales. The median change in R&D subsidies per sales is 3.3%. The magnitude of R&D per sales when first granted is 6.9% for SMEs and only 1.8% for large firms. Kletter, Möen, Griliches (2000) discuss that the economic benefits from research projects are likely to have a highly skewed distribution so that a few projects generate a high return. The subsidies themselves also have a skewed distribution. We take this into account by analysing public subsidy intensity up to the second potency.

4. ESTIMATION

We explain firm-level productivity growth by the knowledge capital variables shown in table 1 using the dynamic framework described in equation (5). As a productivity measure we use the multilateral productivity index described by Caves (1982). Productivity is compared relative to the average in 19 industries. The index has the advantage of being based on a translog production function thus being a second-order approximation of the true but unknown production function.

4.1 Productivity and Employment Growth

Following Benhabib and Spiegel's (2005) framework, we explain the impetus for growth by the knowledge intensity. We do not use a difference estimation that would ignore the important long-run effects. Growth in productivity is here first explained by both private R&D and public subsidies on R&D.

$$d \ln A_{jt} = \beta_0 + \beta_1 \ln G_{jt}/\mathrm{Y}_{\mathrm{jt}} + \beta_{2l} \ln I_{jt}/\mathrm{Y}_{\mathrm{jt}} + \beta_3 \ln \mathrm{X}_{\mathrm{jt}} + \beta_3 \ln \overline{\mathrm{Y}}_{\mathrm{j}} + \beta_4 \ln \frac{A_{Mt}}{A_{jt}} + \varepsilon_j , \qquad (9)$$

where $d \ln A_{jt}$ represents the growth rate in log TFP of firm j in year t, $\ln G_{jt}/\mathrm{Y}_{\mathrm{jt}}$ is the R&D subsidy intensity (up to second potency), $\ln I_{ljt}/\mathrm{Y}_{\mathrm{ljt}}$ is knowledge capital (firm-specific includes the R&D white-collar share up to the second potency), X_{jt} is other firm characteristics, which include industry dummies and region dummies, $\ln \overline{\mathrm{Y}}_{\mathrm{j}}$ is average firm size (log of average employment) to capture scale size effects and $\ln A_{Mt} / A_{jt}$ is the productivity gap with the leading firm M in the industry. All estimations also include industry, region and year dummies.

Table 4 shows the estimation results in explaining total factor productivity. Column 1 in table 4 reports the OLS estimation. The remaining columns report instrument variable estimation results. We pay most attention to the instrumental variable estimates. In column 3 subsidies are also interacted with the interaction of occupation and education human capital. The latter captures education human capital in highly-paid occupations. Columns 4 and 5 show the effectiveness of subsidies in SMEs and large firms and columns 6 and 7 in firms far from and near the leading firm in productivity in the industry. This division is based on the median value of the productivity gap in each of the 19 industries.

Davidson and MacKinnon (1993) test indicates that instruments are jointly significant in all estimations. In this test the predicted values for the endogenous variables, here public subsidies, are first estimated using the instruments and control variables. At the second stage, the predicted values together with original values are used in the same regression. Instruments are valid if the predicted values are of significance, as is found to be the case.

Our focus of study is the coefficients for private R&D accumulation and R&D subsidies that are here assumed to have independent effects. It is seen in table 4 from column 2 that the private R&D worker share has a non-linear effect, with the coefficient for the first potency coefficient being negative and that of second potency positive. Productivity growth is thus strongest in high-technology firms. It appears from column 2 that public subsidies raise productivity growth at a decreasing rate. Subsidies have fared better in supporting marginal investment rather than when being a large share of sales (non-linearity is, however, not very large, see later Monte Carlo experiment). The productivity effects are clearest for SMEs in column 4, while absent for large firms in column 5.

Table 4. Public Subsidies by Tekes and Total Factor Productivity Growth

	OLS	IV No Inter-action	IV	IV SMEs	IV Large Firms	IV Far from Leaders	IV Close to Leaders
Tekes R&D Funds	0.591***	2.044***	0.669	2.039***	0.728	0.935	2.512***
	[2.8]	[4.6]	[0.8]	[4.2]	[0.6]	[1.1]	[3.0]
Tekes R&D Funds^2	-0.656***	-1.702***	-1.707***	-1.676***	-0.907	-1.344	-1.932***
	[4.2]	[6.9]	[7.4]	[6.4]	[0.6]	[1.2]	[4.8]
Tekes R&D Funds, Education H.C.,			8.062*				
Occupation H.C.*10 Interactions			[1.8]				
White-Collar in R&D	-0.317**	-0.347**	-0.510***	-0.259	-0.809***	-0.1	-0.847***
	[2.5]	[2.2]	[3.6]	[1.4]	[3.7]	[0.6]	[3.8]
White-Collar in R&D^2	0.436**	0.549***	0.707***	0.361	1.173***	0.127	1.260***
	[2.5]	[2.6]	[3.7]	[1.5]	[3.4]	[0.5]	[4.4]
R&D Agglomeration	0.793*	0.615	0.789*	0.712	1.047*	0.657	0.582
	[1.9]	[1.1]	[1.8]	[1.3]	[1.7]	[1.2]	[0.9]
Catching Up Frontier Firm	0.202***	0.190***	0.205***	0.239***	0.201***	0.247***	0.282***
	[22.5]	[15.8]	[21.4]	[18.6]	[12.3]	[17.4]	[18.1]
Occupation Human Capital	0.902***	0.475*	0.908***	0.716***	0.853**	0.904***	0.752***
	[5.4]	[1.8]	[5.1]	[3.4]	[2.5]	[4.0]	[2.8]
Knowledge: Worker-Specific							
Education H.C., Occupation H.C.*10	0.308**	0.532***	0.239	0.325*	0.680***	0.803***	-0.05
Interaction	[2.3]	[2.8]	[1.6]	[1.8]	[2.8]	[4.2]	[0.2]
Education Human Capital	0.245*	0.011	0.268*	0.077	0.401	-0.284	0.455**
	[1.9]	[0.1]	[1.9]	[0.4]	[1.6]	[1.4]	[2.3]
Workers Above 75% for Unobserved H.C.	-0.046	-0.05	-0.022	0.004	-0.023	-0.059	-0.03
	[1.5]	[1.1]	[0.7]	[0.1]	[0.4]	[1.4]	[0.6]
Workers Below 25%, Above 75%	0.102	1.258***	0.178	0.153	0.612	-0.411	0.793**
for Experience H.C. Interaction	[0.4]	[3.0]	[0.7]	[0.5]	[1.0]	[1.2]	[2.0]
Observations	6557	3348	5654	3579	2075	2740	2914
R-squared	0.113	0.121	0.116	0.127	0.125	0.158	0.145

Absolute value of z statistics in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Estimation includes seniority, seniority squared, firm-size, 5 area, 19 industry and year dummies.

R&D workers are part of the firm-specific knowledge capital. Other knowledge capital listed in table 1 has similar productivity growth effects to those reported in Piekkola (2005). Education human capital has in general a direct positive effect on growth and most clearly so in firms with well-paid occupations. Piekkola (2005) indicated that blue-collar workers have more occupational human capital (after controls for education and other). The interaction with education human capital then deals with the occupation human capital of white-collar workers, in particular. We interact this with R&D subsidies in column 3, which thus has a significant positive sign. R&D subsidies allocated to highly-paid-occupations and high-education firms generate stronger growth.

It is noteworthy that large firms are on average 22% more productive than the average benchmark firm in the industry; whereas SMEs are on average 10% less productive (productivity growth rates were the same in table 2). One argument to explain the small gains in large firms is that they already belong to the productivity frontier. Columns 5 and 6 in table 4 explain the effectiveness of subsidies in firms far away from and near the leaders in productivity. It is seen that subsidies are most effective in firms near the leaders. It thus appears that the small productivity improvement in large firms is not explained by them already being near the frontier. Finally, catching-up (coefficient for the difference between the TFP and the most productive firm in 19 industries) is not more important driving force for SMEs than for large firms.

Table 5 shows the employment growth effects. In the employment growth analysis, we interact subsidies with the R&D intensity.

Comparing tables 4 and 5 it is seen that firms improving in productivity are on average growing in size so that productivity and employment growth effects of knowledge capital

Table 5. Public Subsidies by Tekes and Employment Growth

	OLS	IV
R&D Intensity	-0.41	-0.256
	[1.2]	[0.4]
R&D Intensity^2	0.196	0
	[0.5]	[.]
R&D Intensity, White-Collar in R&D Interaction	0.978	1.005
	[0.4]	[0.2]
R&D Intensity, White-Collar in R&D^2 Interaction	0.049	1.013
	[0.0]	[0.2]
White-Collar in R&D	-0.112	-0.098
	[0.8]	[0.6]
White-Collar in R&D^2	0.131	0.113
	[0.7]	[0.5]
R&D Agglomeration	0.840**	0.816**
	[2.1]	[2.0]
Catching Up Frontier Firm	0.084***	0.074***
	[9.2]	[7.5]
Occupation Human Capital	0.242	0.241
	[1.4]	[1.3]
Knowledge: Worker-Specific		
Education H.C., Occupation H.C.*10 Interaction	0.847***	0.875***
	[6.1]	[5.9]
Education Human Capital	-0.513***	-0.555***
	[3.7]	[3.7]
Workers Above 75% for Unobserved H.C.	0.025	0.019
	[0.8]	[0.6]
Workers Below 25%, Above 75% for Experience H.C. Interaction	0.644**	0.906***
	[2.5]	[3.2]
Observations	5564	4791
R-squared	0.075	0.078

Absolute value of z statistics in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Estimation includes seniority, seniority squared, firm size, 5 area, 19 industry and year dummies.

usually go in the same direction. However, R&D subsidies have no employment growth effects. The interaction term to the share engaged in R&D work is also insignificant. R&D spillovers are instead positively related to employment growth. In line with Piekkola (2005) growth is concentrated in knowledge capital intensive areas.

4.2 Productivity Growth and R&D Work: A System Approach

This section examines the productivity growth effects of subsidies taking into account the possible crowding out of private R&D. We use two-stage-estimates, which include a separate equation to explain the private R&D worker share by Tekes subsidies.[1] The empirical testable specifications may be written as

$$d\ln A_{jt} = \beta_0 + \beta_{1l}\ln I_{ljt}/\mathrm{Y}_{\mathrm{ljt}} + \beta_2 \ln \mathrm{X}_{\mathrm{jt}} + \beta_3 \ln \overline{\mathrm{Y}}_{\mathrm{j}} + \beta_4 \ln \frac{A_{Mt}}{A_{jt}} + \varepsilon_{1j}, \qquad (10)$$

$$\ln I_{ljt}/\mathrm{Y}_{\mathrm{ljt}} = \beta_5 + \beta_6 \ln G_{jt}/\mathrm{Y}_{\mathrm{jt}} + \beta_7 \ln Z_{jt} + \varepsilon_{2j}. \qquad (11)$$

where explanatory variables are the same as before with Z_{jt} variables including productivity gap to the frontier and firm size. Both equations thus include industry, region and year dummies. The R&D subsidy intensity and its square are instrumented by potential R&D subsidies in the industry and its square, as explained in previous section 3.2. Estimation results are reported in table 6.

The 2SLS estimation explains productivity growth as driven by R&D work. Compared with the earlier estimations in table 4 the coefficients for R&D intensity are of a reversed sign. The first-potency coefficient is positive and that of the second-potency is negative. The explanation for this is that R&D workers are also considered the channel for the productivity growth created by the R&D subsidies.

1 Two-stage least squares in models that have nonlinear variable have been discussed in Green (2003) in section 15.5.6.

Table 6. Two-Stage Least Squares Estimation of Total Factor Productivity Growth and White-Collar Share Engaged in R&D

	TFP Growth	White-Collar Share in Skilled R&D	TFP Growth SMEs	White-Collar Share in Skilled R&D	TFP Growth Large Firms	White-Collar Share in Skilled R&D
Constant	-1.588***	-0.028*	-1.659***	0.022	-8.267	-0.035
	[6.5]	[1.7]	[5.5]	[1.0]	[0.0]	[1.1]
R&D Intensity		0.995***		0.594***		3.189***
		[10.1]		[5.2]		[9.5]
R&D Intensity^2		-0.275***		-0.083		-2.888***
		[4.9]		[1.4]		[7.1]
White-Collar in R&D	2.389		3.038		-68.016	
	[1.4]		[1.1]		[0.0]	
White-Collar in R&D^2	-7.601***		-7.923***		177.968	
	[4.0]		[2.9]		[0.0]	
R&D Agglomeration	1.494*		1.502		-22.793	
	[1.8]		[1.4]		[0.0]	
Catching Up Frontier Firm	0.172***	-0.002	0.243***	0.003	2.296	-0.010***
	[7.4]	[0.9]	[8.2]	[1.1]	[0.0]	[3.1]
Occupation Human Capital	2.590***		2.144***		-39.08	
	[7.2]		[5.5]		[0.0]	
Knowledge: Worker-Specific						
Education H.C., Occupation H.C.*10	-0.158		-0.42		4.034	
	[0.3]		[0.8]		[0.0]	
Education Human Capital	2.655***		2.349***		-33.543	
	[5.3]		[3.6]		[0.0]	
Workers Above 75% for Unobserved H.C.	-0.123***		-0.083		1.792	
	[2.6]		[1.4]		[0.0]	
Workers below 25%, Above 75% for Experience H.C.	-0.094		0.048		14.616	
	[0.3]		[0.1]		[0.0]	
Observations	5654	5654	3579	3579	2075	2075
"R Squares"	-0.627	0.225	-1.147	0.294	-0.034	0.315

Absolute value of z statistics in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. All estimations includes seniority, seniority squared, firm size, 5 area, 19 industry and year dummies as controls. Instruments include the control variables and potential Tekes budget in the industry.

Subsidies raise the R&D workers share (and growth), but not for those at the highest level. The complementarity/substitutability dilemma is complicated by the non-linear effects. Subsidies complement private R&D work at a decreasing rate.

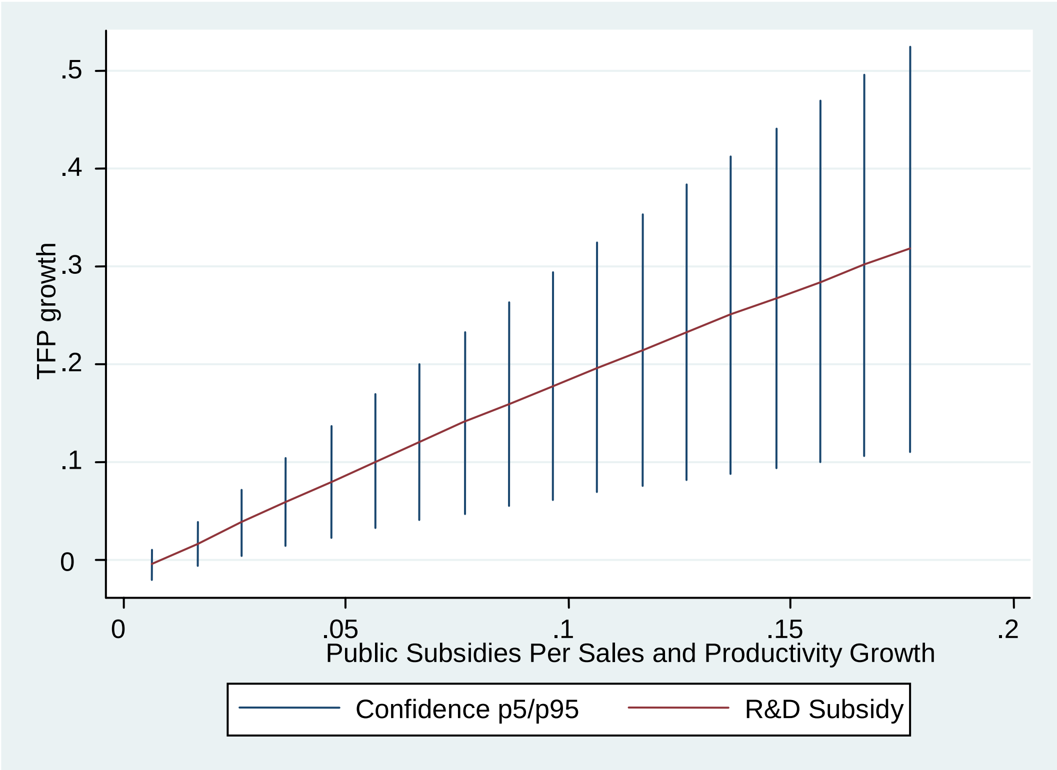
Columns 3 and 6 reveal that the productivity effects of the share of white-collar workers in R&D are positive for the SME sub-sample but not for large firms. Public subsidies do raise R&D intensity in large firms even more than in small firms. However, the productivity effects of private R&D workers are insignificant.

Monte Carlo Simulation

We use the Monte Carlo simulation to determine the magnitude of the productivity effects depending on the subsidy intensity for SMEs (see King, Tomz and Wittenberg, (2000)). We use the predicted values of subsidies given the same instruments as before. The coefficients are almost the same as before, but the standard deviation of the predicted values is one-third lower. Thus, the true confidence intervals are likely to be higher. We ran 10,000 simulations, and the quantitative effects are estimated from the average of each variable. The X-axis is set to reflect the actual distribution of R&D subsidies per sales from the 1st (0%) to the 99th percentile (18%). We show the estimation results separately for SMEs here.

Figure 1 show that the productivity effects for SMEs is around 0.12 log points when subsidies are 7% of sales, as is usual when first received. The productivity effects are reasonable given the 0.57 standard deviation of productivity growth. The confidence interval is, however, fairly wide ranging from 0.01 to 0.22.

Figure 1. Public Subsidies by Tekes and Productivity Growth in SMEs



The basic conclusion is that public subsidies have contributed to productivity growth in SMEs. Subsidies have important direct effects on productivity growth that are independent of them being substitutes or complements to private R&D work. It is noteworthy that the productivity effects would have remained the same when dropping the private white-collar share in R&D work (and its square) in the estimation of (9).

5. CONCLUSIONS

We find significant impacts of R&D funding on productivity growth for small and medium-sized firms. Subsidies have important direct effects and complement company-financed R&D. Similarly to Ali-Yrkkö (2005a) subsidies increase the share of workers engaged in R&D work. The complementarity/substitutability dilemma is, however, complicated by non-linearity. Firms use subsidies to raise R&D employment at a decreasing rate. The complementarity is also strongest in large firms, while having a negligible effect on productivity growth.

The paper offers some insights to assess the public subsidy policy by Tekes. The primary aim of Tekes subsidies is to encourage companies to improve their ability to develop and apply new technologies. Activities are targeted at new technology based firms and SMEs in particular, as well as new businesses and international co-operation (see www.tekes.fi). The target of improving productivity growth is well met in the financing of high-productivity firms. Public subsidies have the clearest positive effect on productivity growth in firms near the leaders in productivity. As discussed, stimulating imitation can instead lower the incentives for successful innovation by making it more short-lived and less profitable.

Tekes subsidies are granted to SMEs in short term projects that last one or two years and we can clearly observe productivity improvements. We find instead little evidence that subsidies improve employment, which differs from the knowledge capital in general. One reason can be that subsidies are used to raise the wage-level rather than employment in firms that have low-paid R&D workers. Alternatively, this suggests a long delay from R&D to pilot production.

We find important R&D spillovers in productivity and employment growth. Growth is concentrated in areas rich in knowledge capital including R&D. This is not to say that subsidies do not promote growth in areas not intensive in R&D. Many studies, including, for example, Baldwin and Martin (2005), show that although R&D research, which benefits from local knowledge capital, leads to increased spatial inequality, it is not a catastrophe as long as all firms can buy the particular R&D research knowledge from another region (see, however, Aiello and Cardamone (2005)). However, R&D subsidies appear not to be very effective for any regional policy aiming at creating new jobs.

Public subsidies overall fail to augment growth in large firms. One reason can be that public subsidy awards require a joint project with small firms. These projects are usually long-term, up to five years. Productivity effects are unclear and the effects on the small firm partner are hard to judge. Admittedly, one reason for meagre productivity long-term effects can also be the short time period of seven years in the data used. The productivity effects in the long-term projects are reaped after a considerable time, if at all. But long-term financing can also lead to too low a level of initial funding. Subsidies per sales at the start of the project (but not necessarily distributed) are twice as high, 7%, for SMEs than for large firms.

Large firms with the most promising projects may also be reluctant to participate in research consortia, as argued by Branstetter and Sakakibara (1998). There is, therefore, a significant role for new independent public subsidies targeted at the most innovative large firms. SMEs may gain a significant reputation in being accepted for the subsidy programme, while such an objective appears to be absent for large firms. Another reason for the productivity gains already at the start of project is that SMEs have to undertake significant preparatory R&D in order to qualify for grants and thus the productivity effects may occur at an early stage.

Finally, Tekes subsidies interact surprisingly little with other knowledge capital. We find the only important link to be the share of highly-educated workers in highly-paid occupations.

This hints at R&D subsidies being too narrowly defined to cover the development of new technology that does not take advantage of the full potential of knowledge capital.

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Appendix A. Robustness Checks

The results are sensitive to the regional aspects in the choice of instruments. Using industry-level potential Tekes funding without the regional division would yield qualitatively similar but insignificant productivity effects. One line of reasoning for this difference is that the probability of applying and receiving for Tekes funding varies in different areas. Probit estimates, after controlling for the industry, indicate that, relatively to the Greater Helsinki region, the probability of applying for Tekes funding is 12% higher in manufacturing regions and 25% lower in the countryside and periphery.

The estimations included all firms with 5,654 firm-year observations, whereas firms with some R&D workers in some years include only 3,348 observations. The coefficients are somewhat lower but of the same sign and standard errors are higher if those firms with only R&D workers in some years are included in the analysis. OLS estimations were also done including those with no R&D workers with very similar results.

One line of reasoning for the insignificant positive effect in SMEs is that low-profit firms are liquidity constrained and cannot finance innovative activity. The profitability of the firm (log of net profits before extraordinary items and appropriations) relates positively but insignificantly to the productivity in SMEs and negatively to the productivity in large firms. We find no significant effects from interacting subsidies with profitability. Thus, the liquidity constraint argument cannot be used to defend the effectiveness of public subsidies awarded to SMEs. Our results are similar to Ali-Yrkkö (2005) but contrast with those of Toivanen and Niininen (2000) for all firms. Toivanen and Niininen apply a simultaneous equations approach and find evidence that public subsidies foster R&D expenditure in Finnish firms with only a moderate cash flow.

We also experimented with interacting subsidies with the agglomeration and found this to be unimportant. Thus subsidies have not been less efficient in areas, where there is little R&D activity.

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