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Jyrki Ali-Yrkkö

ESSAYS ON THE IMPACTS OF TECHNOLOGY DEVELOPMENT AND R&D SUBSIDIES

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To Tanja, Mikael and Luukas

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I dedicate this dissertation to my dear family Tanja, Mikael and Luukas.

Helsinki, March 2008

Jyrki Ali-Yrkkö

ALI-YRKKÖ, Jyrki. **ESSAYS ON THE IMPACTS OF TECHNOLOGY DEVELOPMENT AND R&D SUBSIDIES**

ABSTRACT: This thesis studies the impacts of technology development and R&D subsidies. The first essay examines whether public and private R&D funding are substitutes or complements. Particular attention is paid to capital market imperfections by examining what kind of effect financial constraint has on the relationship between public and private funded R&D. According to empirical analyses, public R&D funding does not crowd out privately financed R&D. Instead, the results suggest that receiving a positive decision regarding public R&D funding increases privately funded R&D. The second essay analyses how public R&D financing impacts the labour demand of companies. Empirical results suggest that public R&D financing increases both group-level and domestic R&D employment. However, public funding does not have a statistically significant effect on non-R&D employment. The third essay focuses on the productivity effects of R&D. The results of empirical analyses are two-fold. In the short run (in 1-2 years), no statistically significant productivity impact of R&D is found. However, R&D does have an economically and statistically significant impact when R&D efforts made 3-5 years earlier are taken into account. Hence, a window of almost 5 years is needed to capture the productivity impact of R&D. The fourth essay studies how patent quality impacts the likelihood of a merger or acquisition. To proxy the quality of patents, both forward and backward citations are used. Multinomial logit estimations show that owning patents correlates with becoming a target for a foreign company. The same does not apply to targets for domestic firms. However, the results also indicate that the quality of patents does not have a statistically significant impact on the likelihood of becoming target for a domestic or foreign company.

Key Words: R&D, public support, subsidy, impact, productivity, patent, acquisition

ALI-YRKKÖ, Jyrki. ESSEITÄ TEKNOLOGIAN KEHITYKSEN JA JULKISEN T&K-RAHOITUKSEN VAIKUTUKSISTA

TIIVISTELMÄ: Tutkimuksessa tarkastellaan teknologian kehityksen ja julkisen t&k-rahoituksen vaikutuksia yrityksiin. Ensimmäisessä esseessä tutkitaan, ovatko julkinen ja yksityinen t&k-rahoitus toisiaan korvaavia vai täydentäviä. Esseessä selvitetään myös rahoitusmarkkinoiden epätäydellisyyksien vaikutusta tarkastelemalla sitä, millainen vaikutus rahoitusrajoitteella on yksityisen ja julkisen t&k-rahoituksen väliseen suhteeseen. Tulosten mukaan julkinen ja yksityinen t&k-rahoitus eivät ole toisiaan korvaavia vaan pikemminkin täydentäviä. Toisessa esseessä analysoidaan julkisen t&k-rahoituksen vaikutusta yritysten henkilökunnan määrään. Tulosten mukaan julkinen t&k-rahoitus lisää yritysten t&k-henkilöstöä sekä kotimaassa että koko konsernin tasolla. Esseessä tarkastellaan myös t&k-tukien vaikutuksia myös muuhun kuin t&k-henkilöstöön. Tulosten mukaan julkisella tuella ei ole vaikutusta tähän muun henkilöstön määrään. Kolmannessa esseessä selvitetään tutkimus- ja tuotekehitystoiminnan vaikutusta yritysten tuottavuuteen. Analyysin tulokset ovat kaksitahoiset. Lyhyellä aikavälillä t&k-toiminnalla ei näytä olevan tuottavuusvaikutuksia, jotka olisivat tilastollisesti merkitseviä. Tämä tulos muuttuu merkittävästi, kun analyysissä otetaan huomioon 3-5 vuotta sitten tehty t&k-toiminta. Tällöin t&k-toiminnalla on selvä tilastollisesti ja myös kokoluokaltaan merkittävä tuottavuusvaikutus. Tulosten mukaan kestää siis noin kolmesta viiteen vuotta ennen kuin t&k-toiminta näkyy yritysten tuottavuudessa. Neljännessä esseessä tarkastellaan, miten patenttien laatu vaikuttaa todennäköisyyteen, että yrityksestä tulee yrityskaupan kohde. Patenttien laatua mitataan käyttämällä patenttiviittauksia. Tulosten mukaan, patenttien omistaminen korreloi sen kanssa, että yrityksen ostaa joku ulkomainen yritys. Sen sijaan patenttien omistus ei vaikuta todennäköisyyteen, että kotimainen yritys ostaa patenttien haltijayrityksen. Tutkimuksen toinen keskeinen tulos on se, että patenttien laadulla ei ole vaikutusta todennäköisyyteen tulla yrityskaupan kohteeksi. Tulos pysyi samana koskien sekä kotimaisten yritysten kohteita että ulkomaisten yritysten kohteita.

LIST OF ESSAYS

Ali-Yrkkö, J. (2005). Impact of Public R&D Financing on Private R&D - Does Financial Constraint Matter? ENEPRI. Working Papers no 30, European Network of Economic Policy Research Institutes, Brussels, Belgium.

Ali-Yrkkö, J. (2005). Impact of Public R&D Financing on Employment. ENEPRI. Working Papers no 39, European Network of Economic Policy Research Institutes, Brussels, Belgium.

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Ali-Yrkkö, J. (2006). Technology Sourcing Through Acquisitions – Do High Quality Patents Attract Acquisitions? Etla - The Research Institute of the Finnish Economy, Discussion Papers no. 1025

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1 INTRODUCTION

1.1 Background

On the general level, economists have long recognised the importance of inventions and technological change for economic development (see Smith 1776, p. 8). New ideas and inventions play a central role in the structural change in the economic system:

> *"Capitalism, then is by nature a form or method of economic change and not only never is but never can be stationary. ...The Fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates. ... The opening up of new markets, foreign or domestic, and the organizational development from the craft shop and factory to such concerns as U.S Steel illustrate the same process of industrial mutation – if I may use that biological term – that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. "*
> Schumpeter (1975), pp. 82-83

The importance of technological development

In traditional growth models (e.g. Solow 1956), the generation of new technological inventions is thought to be independent of economic factors. In other words, technology change is treated exogenously in these models. It can be argued that the key unsatisfactory feature of this traditional framework is the lack of technological change arising from intentional investment decisions by individual agents (Romer 1990, see also Romer 1986).

Research and development (R&D) activities are the key intentional investment for discovering new knowledge affecting technological development and change (Romer 1990). Resources are allocated to universities, research institutes and firm's R&D to generate new technological solutions and improvements. In Romer's (1990) model, innovation causes productivity growth by creating new varieties of goods. Based on modern industrial organisation theory, Aghion and Howitt (1992) focused on quality improving innovations that are associated with creative destruction. Thus, new goods replace old goods causing a higher rate of firm turnover.

On the firm level, the role of R&D activity is not only limited to generating new technological solutions but also to in-house R&D helping companies follow externally available information generated, for example, by universities and public research institutes (Cohen & Levinthal 1989). Griffith, Redding and Van Reenen (2003) incorporate this R&D-based absorptive capacity view into a general equilibrium model of endogenous innovation and growth. According to their model, absorptive capacity is one of key sources behind productivity growth.

Government intervention and private R&D

Although both economic theory and empirical evidence indicate that technological progress is one of key determinants of long-run economic growth, this does not in itself provide an economic justification for government intervention to provide resources in favour of R&D. Government intervention in a market economy is usually justified by market failure.

The two most often mentioned rationales for government support are both based on the market imperfections leading to underinvestment in private R&D. *First*, the output of R&D is knowledge or know-how that usually cannot be kept completely secret (spillovers).This spillover effect potentially declines with distance (Keller 2002). However, foreign direct investment might boost global technological spillovers (Baldwin, Braconier and Forslid 2005). Due to the diffusion of the results of R&D uncontrolled by the original investor, the social return to R&D exceeds its private return (e.g. Arrow 1962). Some R&D projects would have positive impacts on society but they are not carried out because they are unprofitable. Hence, the amount of R&D investment invested by private sector is likely to be below the socially optimal level. In his review, Griliches (1992) concludes: "*Taken individually, many of the studies are flawed and subject to a variety of reservations, but the overall impression remains that R&D spillovers are both prevalent and important.*"

The second rationale for government funding relies on capital market imperfections such as informational asymmetries (Akerlof 1970). Entrepreneurs and firms are unable to transfer information to investors about the quality of the R&D project (Tanayama 2007). In some cases, firms are reluctant to reveal detailed information about the project because there is a risk that this information will leak to rivals (Kamien and Schwartz 1978)[1]. Because of both of these, investors have difficulty distinguishing good R&D projects from bad ones preventing external financiers from correctly estimating the risk and rate of return of a project. This, in turn, may raise the cost of external finance and potentially the R&D project (with positive net present value) may not be undertaken. Hence, firms face financial constraint that creates a wedge between the costs of internal and external financing.

Financial constraints caused by asymmetric information may exist in both equity and debt markets. For instance, Stiglitz and Weiss (1981) analyse a form of credit rationing where lenders do not fund borrowers with identical characteristics to those firms that receive loans. In their theoretical model, the key unobserved factor is the risk of investment projects. The main informational problem facing lenders is that they do not know how the debt they lend will be invested. The asymmetric information problem also arises in equity markets, because equity issuers are potentially better informed than potential equity purchasers (Myers and Majluf 1984). This asymmetry may cause a financial constraint, even though managers act in the interest of shareholders. Agency models (see e.g. Jensen & Meckling 1976, Jensen 1986), in turn, typically consider the impacts of the conflict of interest between shareholders and managers.

Both the informational asymmetry and agency theories imply that it may be costly or difficult to use external financing for R&D investment.

Technology knowledge and other rationales of M&As

A recent theoretical study by Fosfuri and Motta (1999) suggests that due to the existence of local spillovers, firms have incentives to invest overseas in order to obtain access to location specific knowledge. Mergers and acquisitions (M&As) as an important mode of foreign direct investment might be a channel for acquiring local technological knowledge. M&As also provide an opportunity to exploit R&D complementarities between firms (Davidson & Ferret 2007). Patents and their quality are indicators that might reveal this complementarity and the technological

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[1] Leland and Pyle (1977) have argued that the entrepreneur's willingness to invest in his or her own project signals the quality of the project.

knowledge level of firms. Hence, acquirers can use this indicator to scan potential target firms with suitable technological know-how.

In addition to this 'technology sourcing' motive, the economic literature has also given other motives. The dominant motive of M&As in the economics is that they lead to improvements in *economic performance*. The motive suggests that M&As occur because of the economic gains that come from merging two firms. Arrow (1975) argues that a downstream firm has an incentive to acquire upstream firms. He emphasises the role of uncertainty in the supply of the upstream good with the consequent need for information by downstream firms. The theoretical literature also provides reasons for horizontal deals. Perry and Porter (1985) showed that for sufficiently convex costs, two competitors do profit from merging.

The background of *managerial motive* for M&A can be found from the principal-agent theory (Jensen & Meckling 1976) suggesting that corporate managers are an agent of the owners of a firm (principal). Agency problems arise when ownership and management of a firm are separated (Berle & Means 1932). The managerial incentives may drive a firm to grow beyond its optimal size using, for instance, M&As as a means to grow (Jensen 1986).

1.2 Inter-country variations in R&D

Next, we turn to empirics and describe the recent development of R&D expenditure in different geographical areas.

In recent years, R&D spending has increased in the OECD region. Real R&D expenditure grew by more than 30 percent between 1995 and 2004 (OECD 2006). The growth rate, however, has been less intensive between 2000 and 2004, compared to the gain in the late 1990s.

R&D intensity (R&D expenditure in relation to GDP) has also increased in the OECD region although considerable variation exists between countries and regions (Table 1.1). Between 1981 and 2004, the total R&D expenditure in Finland and Sweden rose rapidly exceeding the corresponding growth rates of almost all other industrial economies. Due to these increases, the highest R&D intensities among the OECD countries are currently registered in Sweden and Finland. The ranking of these two countries does not change if the business sector R&D as a percentage of value added is used as an indicator.

Table 1.1. R&D expenditure in relation to GDP (%)

	Finland	Japan	OECD-total	US	UK	Sweden
1981	1.16	2.31	1.92	2.34	2.38	2.2
1985	1.54	2.75	2.22	2.75	2.24	2.75
1990	1.86	2.97	2.27	2.65	2.15	3.035
1995	2.26	2.9	2.07	2.51	1.95	3.32
2000	3.38	2.99	2.23	2.74	1.86	3.53
2004	3.51	3.13	2.26	2.68	..	3.74

Data source: OECD

R&D efforts are often broken down among performances. As can be seen in Table 1.2, in the OECD region, the business sector has continued to be the major R&D performer. In 2003, approximately two-thirds of the total R&D effort was carried out by firms.

Table 1.2. The share of the business sector of the total R&D expenditure (%)

	Finland	Japan	OECD-total	US	UK	Sweden
1995	63.2	70.3	67.3	71.8	65	74.3
1997	66	72	68.8	74.1	65.2	74.9
1999	68.2	70.7	69.3	74.9	66.8	75.1
2001	71.1	73.7	69.3	73	66.2	77.8
2003	70.5	75	67.3	68.9	65.7	74.1
2005						

Data source: OECD

Even though the business sector accounts for the majority of R&D efforts, it does not mean that they finance all of it. The public sector's role in private R&D funding differs considerably between countries (Table 1.3). Surprisingly, the share of public finance (of the private sector R&D) in the United States substantially exceeds the OECD average. Hence, the public sector evidently finances more of the US private sector R&D than in the other countries. This is partly due to the public funding to firms that develop technology related to military applications. It may also be a signal that in the United States companies are encouraged to invest in higher risk R&D projects.

Table 1.3. Business sector R&D expenditure financed by public sector (%)

	Finland	Japan	OECD-total	US	UK	Sweden
1989	3.1	1.2	16.8	26.4	17.2	12.6
1991	5.4	1.4	13.9	21	14.6	10.3
1993	6.1	1.4	12	18.1	11.1	10.8
1995	5.6	1.6	11	16.3	10.5	9.5
1997	4.1	1.3	9.6	14	9.6	7.6
2000	3.5	1.7	7	8.6	8.8	6.8
2003	3.3	1.4	7.5	10.1	10.9	5.9
2004	3.7	1.3	7.7	10.7	..	..

Data source: OECD

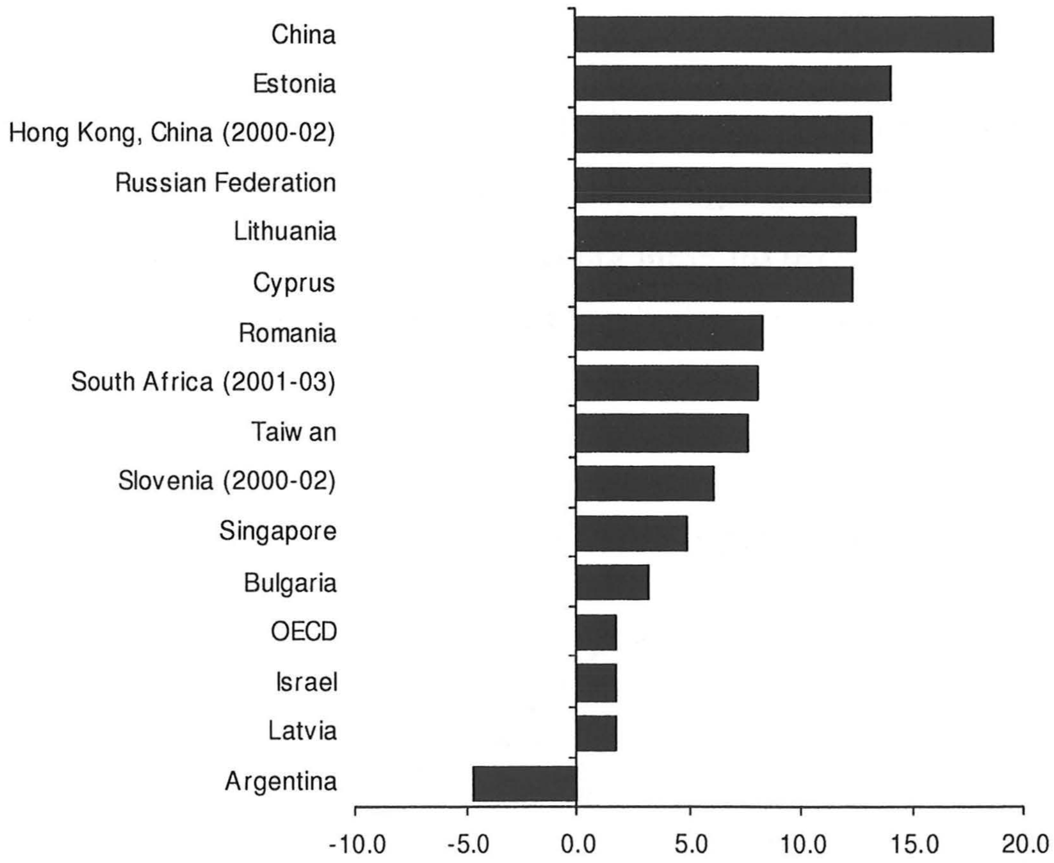
In Finland and Sweden the public sector finances a significantly smaller share of the private sector or business R&D than in the OECD and EU countries on average. In Finland only 3.7 % of the business R&D is financed by the public sector. Excluding Nokia from the figures, in 2000 the share of public sector funding of the total private R&D expenditure was approximately 5.8 % (Ali-Yrkkö & Hermans 2004).

The above comparison shows that the private sector clearly has a more central role in private research and development financing in Finland and Sweden than in many other countries. In this sense, these Nordic countries are more market-oriented than traditional Anglo-Saxon countries such as the United States or the United Kingdom.

1.3 The challenge raised by developing countries

Even though OECD countries currently account for most global R&D, the share of developing countries is growing. In most of the non-OECD countries covered, the latest growth rates substantially exceed the OECD average (Figure 1.1). A significant share of the jobs being lost to offshoring currently are manufacturing and service sector jobs such as call centers. However, offshore activities are not limited to low-skilled jobs alone. China, India and Russia are often mentioned as candidates for R&D location in the future investment strategies of companies. There are concerns that a loss of knowledge worker jobs to developing countries erodes the innovative capability of western nations.

Figure 1.1. The evolution of R&D expenditure (GERD) in non-OECD countries, 2000-2003 (annual average growth rate)



Source: OECD (2006)

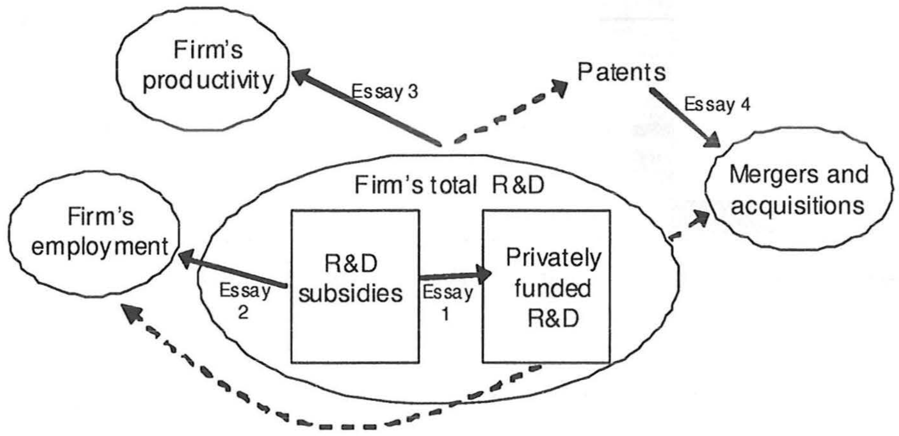
Even though the availability of R&D data in developing countries is limited, some preliminary conclusions can be proposed. *First*, the role of the private sector as a performer of R&D differs substantially among non-OECD countries (OECD 2005, p. 20). In China, Russia, Slovenia, Romania and South Africa, the business sector accounts for most R&D activity. In contrast, the government and higher education sector carry out most of the R&D in Bulgaria, Lithuania, Estonia, Argentina and Latvia. *Second*, also in developing countries, the public sector provides R&D funding for the business sector (see Appendix). Governments use a variety of instruments to support private sector R&D and innovation. *Third,* the role of the public sector as a financier of the private sector's R&D efforts varies significantly among non-OECD economies.

To sum up, R&D efforts have increased in both developed and developing countries. In most of the countries, the business sector accounts for the vast majority of R&D efforts. Like developed countries, developing countries also provide funding for the private sector to stimulate R&D. These observations have offered an interesting starting point to this dissertation. My general goal has been to increase the knowledge about impacts of innovation activity on firms and the effects of public R&D finance.

1.4 Outline of the thesis

The thesis comprises four separate empirical essays dealing with the innovation activity of firms. The following Figure (1.2) illustrates the outline of the thesis and links between the essays. Two different kinds of arrows are used to show connections between issues. Solid arrows indicate the studied connections of this work while dotted arrows indicate potential, but not studied in this thesis, links between issues.

Figure 1.2. The schematic description of the outline of the thesis



The main results of this thesis can be summarised as follows. *First*, our empirical evidence suggests that public R&D funding correlates positively with the private R&D activity. Hence, due to R&D grants, R&D activities have increased in Finland. In this sense, the Finnish innovation policy has been successful. *Second*, from the firm perspective, however, rather than an ultimate goal, R&D activity is a means to some other aims, such as improved financial performance. Our empirical analyses indicate that R&D has really yielded economically significant productivity impacts. *Third*, the innovation activity of a firm increases the likelihood that the firm is acquired by a foreign-owned firm. Hence, the benefits of R&D, such as patents, also resulting from government funded R&D are not limited to a home country. Through cross-border M&As at least some these benefits spread to other countries. Next, the essays are described at a more detailed level.

Essay 1: Impact of Public R&D Financing on Private R&D – Does Financial Constraint Matter?

The first essay of this dissertation studies the relationship between publicly and privately funded R&D. The aim is to study whether public and private R&D funding are substitutes or complements. Particular attention is paid to capital market imperfections by examining what kind of effect financial constraint has on the relationship between public and private funded R&D. Market imperfections raise the cost of external capital or even prevent its use in R&D projects implying that the role of public R&D potentially differs between financially constrained firms and other firms. To my knowledge, no existing study in this field has focused on the role or impact of financial constraint (see however Niininen & Toivanen 2000)

This essay contributes to the existing R&D literature by applying the financial constraint and fixed investment literature (see Fazzari, Hubbard, Petersen 1988) to study the relationship between financial constraint and the impact of public R&D funding. The dataset consists of 441 Finnish companies covering 1996 – 2002. It was found that public R&D funding does not crowd out privately financed R&D. Instead, the results suggest that receiving a positive decision regarding public R&D funding increases privately funded R&D. In contrast to Wallsten (2000), this result holds true after the potential endogeneity of public funding is taken into account. Another finding of the first essay is related to the role of financial constraint. To classify companies as financially constrained and unconstrained, the firm size and indebtedness were used as classification criteria. Econometric results suggest that the additionality impact of public funding is bigger in large firms than in small ones. However, results also indicate that there are no differences in the size of the coefficient of public funding between indebted and non-indebted companies.

Essay 2: Impact of Public R&D Financing on Employment

The second essay analyses how public R&D financing impacts the labour demand of companies. The public sector in practically all industrial countries tries to accelerate technological change by using a range of policy instruments, such as public R&D funding, national R&D laboratories and tax credits. However, the stimulation of the total R&D is hardly the ultimate goal of economic policy. Instead, the fundamental issue concerning the public R&D funding is whether it finally leads to improved productivity, increased sales, higher GDP, employment and welfare. This essay focuses on the impacts on employment.

This second essay contributes to the literature in two ways. *First*, employment impacts are studied by distinguishing domestic and overseas effects. The foreign direct investment (FDI) statistics show that during the last 20 years overseas operations have substantially increased (see UNCTAD 2005). From the perspective of national innovation policy, it is essential to take into account the possibility that the impact on global employment might differ from that on domestic employment. *Second*, the impact of public R&D funding on employment is studied by distinguishing between R&D employment and non-R&D employment. One key motivation to this separation is that an aggregate labour demand model potentially leads to erroneous conclusions if the employment of a given category decreases while it increases for others.

To analyse the impact of public R&D funding on employment, firm level panel data consisting of 560 firms in 1997-2002 was examined. On average, approximately 40% of these companies have received public funding. Regression results indicate that public R&D funding has a positive impact on domestic R&D employment. However, the impact of public R&D funding on domestic and global non-R&D employment is not statistically significantly different from zero. From the perspective of the recent discussion about production offshoring, this latter result is highly relevant. One fear of national R&D funding is that even though the funded R&D projects succeed, the result of the project, such as a new product, is completely manufactured in the company's overseas production units. The result above does not indicate that such an operation mode has been prevailing.

Essay 3: Impact of R&D on Productivity – Firm Level Evidence from Finland

As showed in Table 1.1, in relative terms Finland is one of the leading countries investing in R&D. However, the higher R&D expenditure is only a sign of greater input in innovation activities but it says nothing about the output of these efforts.

The third essay focuses on the productivity effects of R&D. The starting point of this essay is the empirical study by Bond, Harhoff and Van Reenen (2002). Bond *et.al* (2002) employed a dynamic production function approach to compare the

R&D elasticity of output in Germany and the United Kingdom. The key caveat of that model is that it takes into account the potential productivity effects of R&D dated *t* and *t-1* but no longer lags. However, implicitly it potentially takes a substantially longer time before R&D efforts become new products or processes and finally productivity improvement.

To investigate the relationship between R&D efforts and productivity, a panel data consisting of Finnish firms was analysed. The results of the empirical analyses are two-fold. In the short run (in 1-2 years), no statistically significant productivity impact of R&D was found. However, R&D does have an economically and statistically significant impact when R&D efforts made 3-5 years earlier are taken into account. Hence, a window of almost 5 years is needed to capture the productivity impact of R&D.

Essay 4: Technology Sourcing Through Acquisitions – Do High Quality Patents Attract Acquisitions?

In addition to in-house R&D, firms also have other means to acquire technological knowledge. By purchasing other firms, the internal R&D assets can be complemented. Acquisition is also potentially more rapid means of increasing a firm's technological know-how than expanding internal R&D resources. Moreover, in fields with rapid technological development it is extremely difficult to predict which technologies will be relevant. M&As offer firms an option to wait and see which technology seems to be a winner and then acquire firms with the winning technology.

The fourth essay examines mergers and acquisitions as a means of acquiring technology. If a firm owns high quality or valuable patents, other firms may be interested in buying the firm to obtain the ownership of these patents. To proxy the quality of patents, both forward and backward citations are used in econometric analyses.

The first main result of this essay is that owning patents correlates with becoming a target for a foreign company. The same does not apply to targets for domestic companies. Hence, the results suggest that some firms use M&As as a means of acquiring technology from other countries. There are at least two potential reasons for this. On the one hand, M&As can serve as a mechanism whereby the companies with inefficient intellectual property management are attractive targets. On the other, combining the intellectual properties of target and acquirer potentially creates synergist benefits. The second main result is that the quality of the patent does *not* increase the likelihood of becoming the target of domestic or foreign companies.

1.5 Appendix

Table A.1. Business sector R&D expenditure financed by public sector (developing countries),%

	Argentina	China	Romania	Russian Federation	Slovenia	South Africa	Taiwan
1995	..	..	49.3	51.1	8.0	..	..
2000	8.7	6.8	34.0	45.5	7.0	..	2.1
2001	8.7	..	31.0	49.0	5.0	9.6	1.8
2002	6.4	..	33.0	50.6	5.1	..	1.7
2003	8.4	4.9	28.2	51.5	12.8	6.4	2.1
2004	6.9	4.8	26.8	53.0	4.5	..	2.5

Data source: OECD

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ESSAY 1: IMPACT OF PUBLIC R&D FINANCING ON PRIVATE R&D – DOES FINANCIAL CONSTRAINT MATTER?

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ABSTRACT: This study analyses how public R&D financing impacts companies. Our main goal is to study whether public and private R&D financing are substitutes or complements, and whether this impact differs between financially constrained and unconstrained companies. Our company-level panel data cover the period from 1996 to 2002. The statistical method employed in the research takes into account the possibility that receiving public support may be an endogenous factor. Our results suggest that public R&D financing does not crowd out privately financed R&D. Instead, receiving a positive decision to obtain public R&D funds increases privately financed R&D. Furthermore, our results suggest that this additionality effect is bigger in large firms than in small firms.

KEY WORDS: Public finance, R&D, research and development, substitute, financial constraint.

1 INTRODUCTION

The creation of new knowledge is often seen to play an important role as a source of economic growth (Romer 1990). Furthermore, due to the widely accepted view, the social return of R&D is greater than the private return, thus unsurprisingly the public sector in almost all industrial countries tries to foster technological change by using a variety of instruments, such as R&D loans and subsidies, national R&D laboratories and tax cuts. This study focuses on the issue of whether public R&D funding complements or substitutes private R&D and whether this impact differs between financially constrained and unconstrained companies.

Two most often mentioned rationales for government support are both based on the market imperfections leading to underinvestment in private R&D. First, the output of R&D is knowledge or know-how that usually cannot be kept secret. Due to the diffusion of the results of R&D uncontrolled by the investor, the social return to R&D exceeds its private return (e.g. Arrow 1962). Another rationale for government funding relies on capital market imperfections such as informational asymmetries. Due to these imperfections, it may be costly or difficult to use external financing for R&D investment. Hence, in some cases the capital market restrains or blocks the innovativeness of companies.

Even though public R&D funding has widely accepted theoretical roots, the question arises whether R&D policy really stimulates the total R&D activity of the private sector. Public R&D funding increases the total R&D expenditure only if the grants cause firms to undertake projects that would otherwise be unrealised or smaller. Otherwise, subsidised firms use public funding as a substitute source of financing. In sum, it is an open empirical question whether public R&D funding really complements private R&D and thus increases the total R&D expenditure. There exists an extensive empirical literature focusing on this issue (for survey, see David, Hall & Toole 2000). The majority of the studies have reported complementary effects but substitute effects have also been found. However, recent papers (see Klette, Moen & Griliches 2000 and Wallsten 2000) have questioned the results of previous studies. According to the criticism, the majority of the statistical analyses ignores the possibility that grants are endogenous. In other words, public and private R&D expenditure are correlated because companies with an increase in private spending receive subsidies not because subsidies cause private R&D to increase.

The focus of this study is to empirically examine the impact of public R&D funding on private R&D. We contribute to the literature by applying financial constraint approach (developed in fixed investment literature) to study the impact of R&D subsidies on private R&D. In other words, we pay special attention to capital market imperfections by examining what kind of effect financial constraint has on the relationship between public and private funded R&D. Due to the intangible and uncertain nature of R&D investment, external finance opportunities for inventive activities are potentially restrictive. This argument suggests that firms use primarily internal finance to fund their R&D investment. It also implies that public R&D subsidies and loans might be attractive sources of finance. If a firm suffers financial constraint to fund its R&D projects, it is less probable that this firm uses public R&D funding only as a substitute source of financing.

Contrary to most previous studies, our unique panel data enables us to distinguish companies that have applied for and obtained public funding, applied for and obtained only part of what they applied for, applied for and been rejected, and firms that have not even applied for funding.

The rest of the paper proceeds as follows. Section 2 includes relevant theoretical and empirical literature concerning the relationship between public and private R&D funding. Section 3 describes the data. Section 4 gives an empirical analysis and results. Section 5 contains a summary and concluding remarks.

2 LITERATURE REVIEW

The main argument for public R&D funding is that the social return of R&D is higher than the private return, and thus from the perspective of the national economy firms underinvest in R&D. Underinvestment occurs because imperfect capital markets prevent companies from investing in all R&D projects with positive NPV (net present value), or because the results of R&D spill over to other organisations.

The public R&D funding may impact private R&D through various direct and indirect channels. According to Lach (2002), at least three impact channels can be identified. *First*, public R&D funding can be seen as lowering the private cost of R&D project and making an unprofitable project profitable. *Second*, if R&D infrastructure, equipment or other R&D facilities are bought with an R&D subsidy, then the fixed costs of other R&D projects are lowered. *Third*, in some cases know-how or knowledge developed in subsidised projects diffuse to other projects improving their probability of success. Therefore, public R&D funding potentially increases the current and future R&D activities of companies.

Even though public R&D funding has several potential positive impacts, its real effect depends heavily on whether public R&D funding actually augments the total R&D expenditure of firms. If public funding replaces private R&D, then the public R&D policy is inappropriate. A number of empirical studies applying various degrees of data aggregation have addressed this issue. While some studies have used macro-level data (e.g. Levy 1990, Guellec & van Pottelsberghe 2003), others have utilised plant-level (e.g. Lichtenberg 1984) or firm-level datasets. Due to the limited possibilities of macroeconometric models to take into account heterogeneities between firms, we focus on empirical studies where micro-level data has been utilised.

Irwin & Klenow (1995) evaluate the Sematech programme by the US government, which was a research consortium consisting of large US semiconductor companies. Findings of the study suggest that public funding decreases companies' R&D expenditure that might be the result of eliminating overlapping R&D efforts. Contrary to the Sematech programme, the Small Business Innovation Research (SBIR) programme was directed to small companies in order to stimulate their technological innovations. The results by Lerner (1999) indicate that the subsidised firms in the areas with a high degree of venture-capital activity increase employment and sales more rapidly than other firms do. The study by Branstetter & Sakakibara (1998) focuses on the performance of heavily subsidised Japanese research consortia. The results suggest that frequent participation in R&D consortia has a positive impact on firms' R&D expenditure and research productivity. The evidence from Norway (Klette & Moen 1998) suggests that public R&D funding does not replace private R&D efforts, and that subsidies do not increase their privately financed R&D either. Moreover, Klette & Moen find that subsidies stimulate R&D expenditure particularly by small and large firms as opposed to medium size firms. The recent literature (see e.g. Wallsten 2000, Klette, Moen & Griliches 2000) has questioned the results by numerous previous studies with an argument that only a few studies have explicitly taken into account the potential endogeneity of public funding.

Wallsten (2000) examines the same SBIR programme as Lerner (1999) but points out the importance of controlling for the endogeneity of grants. Using the instrumental variable approach Wallsten reports an (almost) complete crowding out effect. Busom (2000) analyses 154 Spanish firms of which roughly 50 per cent had received public subsidies. Due to the data limitations, Busom is unable to make an exact estimate of crowding out or complementary. However, her endogeneity controlled analyses suggest that 41 companies spend more on R&D than they would have without the subsidy and 29 firms would have spent at least as much as in the case of no subsidy. Czarnitzki and Fier (2002) examine 210 German firms operating in the service sector. Applying a non-parametric matching approach, they find evidence that public funding has fostered the private innovation efforts of firms. By analysing more than 1,600 French firms Duguet (2003) concludes that no significant substitution effect appears. Similar results have also been reported by Almus & Czarnitzki (2003), Hussinger (2003) and Gonzalez, Jaumandreu & Pazo (2004). The evidence from Israel (Lach 2002) suggests that subsidies do not completely crowd out private R&D. Lehto (2000) analyses the effect of public funding on the total R&D spending of Finnish plants. By taking into account the potential endogeneity of public funding, he concludes that publicly funded R&D does not crowd out private R&D. Niininen & Toivanen (2000) apply a simultaneous equations approach and find evidence that Finnish firms with moderate cash flow add their own R&D expenditure as a response to a subsidy but when the cash flow is big enough, this relationship disappears.

This short survey demonstrates that existing empirical studies do not allow for a definitive conclusion regarding the sign of the relationships between publicly and privately funded R&D. Hence, it is still an open empirical question whether public R&D funding increases or decreases privately funded R&D. In order to answer this question, more research with more comprehensive datasets is needed.

To our knowledge, no existing study in this field has focused on the role or impact of financial constraint (see however Niininen & Toivanen 2000). Our purpose is to extend the public R&D funding literature by following the fixed investment and financial constraint literature (see e.g. Fazzari, Hubbard & Petersen 1988) and by studying the relationship between financial constraint and the impact of public R&D funding.

3 DESCRIPTION OF THE DATA

Our data is a unique company-level dataset consisting of Finnish companies operating in the Technology industry. The companies within the Technology industry operate mainly in the electronics and electro-technical, mechanical engineering and metals industries.

Three separate data sources have been merged making it possible to take into account a large set of explanatory variables. The R&D dataset is based on an investment survey conducted by The Confederation of Finnish Industry and Employers. Into this data, we have added the information of companies' financial statements provided by Balance Consulting and *Talouselämä* magazine. Finally, the data concerning the public R&D funding from the Finnish Technology Agency (Tekes) has been merged together with the two datasets mentioned.

In contrast to many previous studies, we are able to distinguish firms that 1) have applied for and obtained public funding, b) applied for and obtained only part of the amount they applied for, c) applied for and been rejected, d) and firms that have not even applied for public funding. Thus our dataset allows us to distinguish between firms that applied for funding but were denied and those that did not even apply.

With respect to the public funding variable, the choice between the subsidy *granted* and *actually paid* had to be made. While both alternatives include advantages and disadvantages, we follow the study by Meeusen & Janssens (2001) and use subsidies *granted*[2].

Our unbalanced database consists of 441 companies with various time series (Table 3.1)[3].

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[2] In order to keep it simple, in the rest of the paper we have used public funding and public funding granted as synonyms.

[3] To control the potential bias caused by outliers, in terms of employment 5% of the biggest firms are excluded from the sample.

Table 3.1. The structure of the panel data by observations per company

Number of annual observations	3	4	5	6	7
Number of companies	119	109	65	73	75
Share of the companies, %	27.0 %	24.7 %	14.7 %	16.6 %	17.0 %

Companies with single or two observations available are excluded from the sample, thus our data includes only those companies with three or more annual observations (Table 3.1). As can be seen from the table, we have at least four observations for more than 90% of the companies. The next table (3.2) describes the data. Details of the data are given in Appendix.

Table 3.2. Descriptive statistics (EUR. mill.)

	Count	Mean	Median	Standard Deviation	Minimum	Maximum
Total R&D, EUR mill.	1640	1.00	0.35	1.63	0.001	15.59
Private R&D, EUR mill.	1640	0.92	0.30	1.56	0	15.59
Public funding (granted), EUR mill.	1640	0.12	0	0.332	0	4.95
Public funding (paid), EUR mill.	1640	0.086	0.015	0.195	0	2.04
Public funding (applied), EUR mill.	1640	0.29	0	0.698	0	9.87
Net Sales, EUR mill.	1640	42.79	10.78	112.96	0.15	1272.6
Operating profit, EUR mill.	1640	4.25	0.93	13.34	-67.67	261.35
Long term debt, EUR mill.	1640	4.62	0.94	13.82	0	331.75
(Long term debt)^2, EUR mill.	1640	212.27	0.88	2832.21	0	110057
R&D intensity (Total R&D/Net Sales)	1640	0.07	0.028	0.17	0.00006	2.66
Operating profit,%	1640	0.086	0.101	0.23	-5.5	2.03

Our data consists of a pooled sample of companies over the seven-year period from 1996 to 2002. In Table 3.3 we report the annual breakdown of our sample concerning the number and the share of companies that have received public funding.

Table 3.3. R&D and public funding

	Number of firms	% of firms receiving subsidy	Mean (Subsidy/Total R&D) ratio for firms with subsidy>0
1996	198	16.7	0.16
1997	311	36.7	0.23
1998	363	51.2	0.28
1999	361	54.5	0.33
2000	357	55.5	0.29
2001	278	53.6	0.30
2002	213	52.6	0.31
All years	441	45.8	0.27

On average, nearly half of the companies in our data have received public funding. This share has remained rather stable during the period 1998-2002. Among the supported companies, the average share of public funding of the total R&D expenditure is 27%. Even though the most recent three years indicate a slightly increasing share of public funding, it is uncertain whether this change is permanent. Thus, while this share has varied during the period 1996-2002, no clear trend can be observed.

The existing literature suggests that R&D investments suffer from imperfections in the capital market (see e.g. Hall 1992, Hao & Jaffe 1993, Himmelberg and Petersen 1994, Hyytinen & Toivanen 2002). Due to these imperfections, some firms face financial constraint implying that in these firms the role of public R&D funding is potentially different than in some other firms[4]. We closely follow the fixed investment literature and categorise the firms employing different criteria to identify firms that are likely to face either higher costs of external finance or difficulty in getting external finance. Firm size and indebtedness are used as *a priori* criteria to classify firms that potentially suffer financial constraints and those who do not. Out of our three classifications two are based on firm size and one is based on in-

[4] Tanayama (2007) has analysed how government allocates R&D subsidies to firms. According to her results, the risk related to the economic stance of firm reduces the acceptance probability of subsidy application.

debtedness. Due to capital market imperfections, such as informational asymmetries (see e.g. Greenwald, Stiglitz & Weiss 1984), small firms are more likely to face financial constraints. Firms with a high level of debt, in turn, create a greater probability of bankruptcy that can raise the cost of borrowing or negatively affect the availability of credit. To classify firms, we use the following criteria. In classification 1, 10% of the sample has been classified as small firms (in terms of employment) and in classification 2, 25% are small. In classification 3, a firm is considered an indebted firm (in year *t*) if its interest rate expenditure exceeds its operating profit. Descriptive statistics by classifications are shown in Table 3.4.

Table 3.4. Descriptive statistics (means and two-tailed *t*-tests for means) by firm size and indebtedness

	Classification 1 10% of firms are classified as small firms		**Classification 2** 25% of firms are classified as small firms		**Classification 3** Indebtedness[5]	
	Small	Large	Small	Large	Indebted	Non-indebted
Total R&D, EUR mill.	0.18	1.06***	0.24	1.2***	1.13	1.00
Private R&D, EUR mill.	0.146	0.974***	0.20	1.10***	0.92	0.98
Public funding (granted), EUR mill.	0.06	0.13**	0.07	0.13***	0.22	0.11***
Public funding (paid), EUR mill.	0.04	0.09***	0.05	0.10***	0.15	0.08***
Net Sales, EUR mill.	1.76	45.83***	2.37	53.25***	27.79	44.32
Operating profit, EUR mill.	0.162	4.55***	0.24	5.28***	-2.29	4.75***
Long term debt, EUR mill.	2.59	4.77	1.22	5.50***	6.16	4.58
(Long term debt)^2, EUR mill.	130.28	218.34	44.22	255.73	229.17	214.46
R&D intensity	0.24	0.06***	0.18	0.04***	0.27	0.06***
Public funding (paid) /Total R&D	0.26	0.15***	0.28	0.13***	0.28	0.15***
Operating profit, %	-0.06	0.1***	0.03	0.10***	-0.29	0.11***

*** = significant at the 1% level, ** = significant at the 5% level, * = significant at the 10% level

[5] We define a firm as indebted if its interest rate expenditure exceeds its operating profit.

Table 3.4 reveals some interesting differences between the groups. According to classifications 1 and 2, small firms seem to invest more on R&D (relative to net sales) than larger firms. Similarly, indebted firms invest more on R&D than the reference group. These differences are statistically significant at the better than 1% level. The table also indicates that small firms obtain more public R&D funding (relative to the total R&D) than large firms. Correspondingly, there seems to be a similar difference between indebted and non-indebted firms. However without more rigorous analysis, it is not easy to reach any conclusions about the relationship between R&D, public R&D funding and financial constraint.

4 EMPIRICAL ANALYSIS

Our main interest is to examine whether the public R&D funding crowds out or stimulates privately financed R&D. To analyse the impact we use privately financed R&D as a dependent variable. We follow the existing literature and add several control variables to our regressions. To capture the size effects, net sales is added to the model (see e.g. Klette & Moen 1998). Net sales might also serve as a proxy for expected market demand (see Swenson 1992). As described in the literature review, both theoretical and previous empirical studies suggest that financial factors affect R&D investment. To control the effect of financial variables, profit or cash flow (Toivanen & Niininen 2000, Klette & Moen 1998), debt (Toivanen & Niininen 2000) and its squared term (see Hall 1991) have been included in the regression equation.

Our baseline specification for the estimation is:

$$\begin{aligned} RD\_PRIV_{it} &= \alpha + \beta_1 PUBLIC_{it} + \beta_2 Y_{i,t-1} + \\ &\quad \beta_3 \Pi_{i,t-1} + \beta_4 B_{i,t-1} + \beta_5 B_{i,t-1}^2 + v_{it}, \end{aligned} \tag{1}$$

where subscripts i and t are the firm and time indexes, respectively, RD_PRIV_{it} is the firm's private funded R&D, $PUBLIC_{it}$ is the amount of public R&D funding, $Y_{i,t-1}$ is sales, $\Pi_{i,t-1}$ is profit, $B_{i,t-1}$ is long-term debt, $B_{i,t-1}^2$ is squared long-term debt, and v_{it} is an error term.

To capture the 'one-to-one' relationship between public R&D funding and private R&D, we use the levels of private R&D and of public R&D funding.

Our estimation strategy proceeds as follows. First, we estimate the model (1) by using the ordinary least-squares (OLS) method. This method, however, ignores the possibility that public funding is an endogenous variable. To control the potential endogeneity, the instrument variable (IV) method is used. An appropriate instrument correlates with the endogenous public funding variable but is not correlated with unobserved factors that have an impact on the dependent variable. According to Lichtenberg (1988) and Wallsten (2000) one ideal instrument is the value of funds that are potentially awardable to firm i in year t. In our case, the budget of the Finnish Technology Agency (Tekes) represents these funds and thus affects the amount of public R&D funding a firm can potentially obtain. However, the total budget of Tekes is not really awardable to each firm. The Tekes' budget dedicated to each industry (or technological area) is likely to be correlated with the amount of public funding to firms operating in a given industry. This variable is also expected to be exogenous with respect to unobserved variables affecting the innovativeness of the firm.

Following Wallsten (2000), for firms that have applied for public funding, we define the instrument, $BUDGET_{it}$, as follows:

$$BUDGET_{it} = AWARD_{at}^{i} \times (TEKESBUDGET_{at}), \tag{2}$$

where subscripts i, a, and t refers firm, industry and year, respectively[6]. The dummy variable $AWARD_{at}^{i}$ gets a value 1 if the company i operating in industry a obtains public funding in the year. The variable $TEKESBUDGET_{at}$ is Tekes's budget for industry a (at the 2-digit level) in year t. Similarly, for a firm that applied in year t but was rejected, $BUDGET_{it}$ is defined as Tekes's budget for industry a in year t.

For firms that have never applied for Tekes funding, the calculation of $BUDGET_{it}$ is more complicated. In this case, we have first calculated the probability of receiving funding if the firm had applied for it. The probability has been calculated by dividing the number of firms in industry a that received public funding by the total number of firms that applied for it in industry a. Then this probability, $p(AWARD_{at})$, has been multiplied by Tekes's budget ($TEKESBUDGET_{at}$) for industry a in year t (equation 3).

$$BUDGET_{it} = p(AWARD_{at}) \times (TEKESBUDGET_{at}) \tag{3}$$

In addition to the $BUDGET_{it}$ instrument, we also use another instrument. Presumably, the amount that a company has applied for ($APPLIED_{it}$) in year t correlates with the amount granted to the company in the same year. However, it is hard to see why $APPLIED_{it}$ should correlate with the unobserved determinants of pri-

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[6] Approximately one-third of our sample companies operate in the electronics industry and two-thirds operate in the metal and engineering industry.

vate R&D, conditional on the actual R&D funding received[7]. Since it is known that IV estimates based on weak instruments are biased (see, e.g., Bound et al. 1995), two instrument tests are conducted. We report F-tests for the joint significance of the instrument set in first-stage regression. However, in the case of multivariate linear models with several endogenous regressors, the first-stage F-statistic has important limitations (Shea 1997). Hence, we also report Shea's (1997) partial R2 measure of instrument relevance for multivariate models.

Table 4.1 reports the results of OLS and instrument variable (IV) regressions of equation (1).

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[7] We also estimated our models by using only *Budget* as an instrument (see Robustness tests).

Table 4.1. Effects of public funding on private R&D

	(a) Pooled OLS	(b) IV	(c) Pooled OLS	(d) IV
$(\text{Public funding})_t$	.617*** (.152)	.865*** (.249)		
$(\text{Public funding})_{t-1}$			1.022*** (.175)	1.256*** (.235)
Sales_{t-1}	.003** (.002)	.003 (.002)	.0032** (.001)	.003 (.002)
Profit_{t-1}	.0266* (.016)	.026 (.018)	.0279* (.0146)	.028* (.017)
$\text{Long-term debt}_{t-1}$	.071*** (.012)	.069*** (.0199)	.0716*** (.0119)	.071*** (.019)
$(\text{Long-term debt})^2_{t-1}$	-.0007*** (.0002)	-.0007*** (.0003)	-.0008*** (.0002)	-.0008*** (.0003)
Constant	.344*** (.076)	.319*** (.083)	.334*** (.075)	.318*** (.082)
+ Year dummies				
Number of observations	1640	1640	1640	1640
F-test (joint)	19.10	11.14	22.88	15.99
P-value	<0.001	<0.001	<0.001	<0.001
R^2	0.39	0.39	0.41	0.41
Shea's partial R2: public funding		0.9		0.91
F-test of joint significance of instrument set		282.7		437.1
P-value		<0.001		<0.001

NOTES: Heteroscedasticity-corrected standard errors in parentheses.
Instruments (column b): Year dummies, BUDGET(t), APPLIED(t), Sales(t-1), Profit(t-1), Long-term debt(t-1), Long-term debt^2(t-1)
Instruments (column d): Year dummies, BUDGET(t-1), APPLIED(t-1) , Sales(t-1), Profit(t-1), Long-term debt(t-1), Long-term debt^2(t-1)
F-test (joint) = tests the hypothesis that all coefficients excluding constant are zero.
*** = significant at the 1% level
** = significant at the 5% level
* = significant at the 10% level

According to the OLS estimation (columns *a* and *c* in Table 4.1), the coefficient for the public funding both in time *t* and *t-1* are positive and statistically significant at the 1% level suggesting additionality between public and privately funded R&D. Moreover, the coefficients of sales, profit and debt are also positive and statistically significant.

These estimates, however, might be biased because of the presence of endogeneity of public funding variables. To control the potential endogeneity of public funding, IV estimation was carried out (columns *b* and *d*)[8]. In both IV estimations, the partial R-squared values based on Shea (1997) indicate that the instruments for *Public funding* explain a substantial fraction of its variation. Moreover, F-test of joint significance of instrument set rejects the null that the instruments are jointly insignificant.

Again, the public funding has a positive and statistically significant impact on private R&D. Interestingly, the coefficients of public funding in IV estimations are even higher than in OLS estimations. Hence in contrast to Wallsten's study (2000), controlling endogeneity does not change the positive impact of public funding. The results of IV models (columns *b* and *d*) also suggest that debt has a statistically significant (non-linear) positive effect on private R&D. Furthermore, the results (weakly) indicate that profit increases private R&D.

In sum, all regressions in Table 4.1 indicate that public R&D funding does not crowd out privately financed R&D. Instead, they suggest that receiving a positive decision to obtain public R&D finance increases private R&D efforts.

4.1 Does liquidity constraint matter?

Next, we ask whether there are differences in the impact of public funding between financially constrained and unconstrained firms. To do this we follow the fixed investment literature and use *a priori* criteria to classify our firms into constrained and unconstrained firms as introduced in Section 3. We employ three distinct methods to categorise our firms and include a dummy variable (=1 for financially constrained firms) denoted by *D* and its interaction with the regressors into the model. In the following regressions, the instrument variable method has been used. The first seven coefficients relate to the sub-sample with no financial constraint, while the remaining seven coefficients estimate the difference of the coefficients on each variable across the two sub-samples.

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[8] Our first-stage estimations (see Appendix) suggest that *Budget* and *Applied* are positively and statistically significantly correlated with *public funding*.

Table 4.2. The impact of public funding and financial constraint

	(Model 1) **Classification 1** (10% are small)		(Model 2) **Classification 2** (25% are small)		(Model 3) **Classification 3** (Indebtedness)	
	(a)	(b)	(c)	(d)	(e)	(f)
Public funding$_t$	.878*** (.253)		.878*** (.261)		.904*** (.282)	
Public funding$_{t-1}$		1.239*** (.236)		1.251*** (.243)		1.234*** (.26)
Sales$_{t-1}$	.0031 (.002)	.003 (.002)	.003 (.002)	.0029 (.002)	.003 (.003)	.0678 (.374)
Profit$_{t-1}$	.026 (.018)	.028* (.017)	.026 (.018)	.028* (.016)	.0272 (.025)	.0273 (.023)
Debt$_{t-1}$	.072*** (.02)	.073*** (.019)	.068*** (.02)	.0689*** (.0198)	.075*** (.021)	.076*** (.02)
$(\text{Debt})^2_{t-1}$	-.0007*** (.0002)	-.0008*** (.0002)	-.0007*** (.0002)	-.0007*** (.0003)	-.0008*** (.0002)	-.0008*** (.0003)
Constant	0.339*** (.088)	0.342*** (.086)	0.419*** (.099)	0.413*** (0.09)	0.506*** (.112)	0.482*** (.107)
D (Dummy)	-.18*** (.061)	-.196*** (.055)	-.206*** (.068)	-.212*** (.062)	.324* (.177)	.193 (.143)
D*Public funding$_t$	-.865*** (.275)		-.504*** (.306)		-.465 (.346)	
D*Public funding$_{t-1}$		-.55* (.334)		-.776 (.315)		.067 (.374)
D*Sales$_{t-1}$	-.022 (.0231)	-.011 (.0167)	-.009 (.015)	.005 (.013)	.007 (.007)	.0077 (.007)
D*Profit$_{t-1}$	-.032 (.097)	-.056 (.067)	-.168*** (.056)	-.173*** (.048)	.078 (.091)	.106 (.08)
D*Debt$_{t-1}$	-.133*** (.021)	-.133*** (.02)	-.124*** (.032)	-.109*** (.031)	-.01 (.048)	-.0008 (.0475)
D*$(\text{Debt})^2_{t-1}$	.002*** (.0003)	.002*** (.0003)	.0017*** (.0005)	.0015*** (.0005)	-.0003 (.0007)	-.0004 (.0007)
+ year dummies						
Number of observations	1640	1640	1640	1640	1610	1610
F-test (joint)	44.63	56.97	24.25	33.78	10.35	12.3
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Shea's partial R2: public funding	0.9	0.91	0.89	0.9	0.9	0.9
Shea's partial R2: D*public funding	0.98	0.94	0.96	0.95	0.96	0.94
F-test of joint significance of instrument set	845.5	457.3	255.9	293,3	162.2	237.9
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

NOTES: Heteroscedasticity-corrected standard errors in parentheses.

Instruments: Columns a, c and e: BUDGET(t), APPLIED (t), Sales(t-1), Profit(t-1), Long-term debt(t-1), Long-term debt^2(t-1), dummy*BUDGET(t), dummy*APPLIED (t), dummy*Sales(t-1), dummy* Profit(t-1), dummy* Long-term debt(t-1), dummy* Long-term debt^2 (t-1)

Columns b, d and f: BUDGET(t-1), APPLIED (t-1), Sales(t-1), Profit(t-1), Long-term debt(t-1), Long-term debt^2(t-1), dummy*BUDGET(t-1), dummy*APPLIED (t-1), dummy*Sales(t-1), dummy* Profit(t-1), dummy* Long-term debt(t-1), dummy* Long-term debt^2 (t-1)

F-test (joint)= tests the hypothesis that all coefficients excluding constant are zero.
*** = significant at the 1% level, ** = significant at the 5% level, * = significant at the 10% level

First, we analyse the results of instrument tests. In all six models, Shea's (1997) Partial-R^2 measures get high values ranging from 0.89 to 0.98. Second, *F*-tests reject the null that the instruments are jointly insignificant in the first-stage regressions.

The results of the first two columns (*a* and *b*) indicate that the additionality effect of public funding on privately funded R&D is clearly smaller in small firms (10% of firms are small) than larger firms. The statistic of the F test (not reported in the table) also suggests that the coefficient of public funding is different in small firms and large firms. However, even though the impact of $public\ funding_t$ (.878-.865) on private R&D is close to zero in small firms (column *a*), the result does not alter the conclusion that the impact of public funding on the total R&D of small firms is positive. When 25% of the firms are classified as small firms, the estimation echoes the result that the additionality effect of public R&D funding is bigger in large firms than in small firms (column *c*). Another interesting result is that while debt seems to increase the private R&D of large firms, it decreases the private R&D of small firms. In columns (*e*) and (*f*), firms with poor interest coverage have been defined as financially constrained. Again, the results indicate that public funding increases private R&D efforts. However, all interaction terms are statistically insignificant indicating that the coefficients are the same across the two sub-groups.

It is notable that we have used three distinct methods to find firms that potentially suffer financial constraints, and none of the estimations suggest that public R&D finance crowds out the privately funded R&D of non-financially constrained firms. Instead, the additionality effect seems to be even larger in large firms that *a priori* were classified as non-financially constrained firms. One potential explanation is that small firms are partially financially constrained. Thus, they can not afford to increase privately funded R&D as much as larger firms.

The important implication of our results is that our evidence does not support the view that the public sector should just finance those firms that suffer financial constraints.

4.2 Robustness tests

Next, we perform a number of robustness tests. To save space we do not report these tests in detail.

Robustness test 1: To test to what extent our results depend on the choice to estimate the model by using both *Budget* and *Applied* as instruments, we re-run the regressions (Table 4.1.) by using only *Budget* as an instrument. In this case, the number of instruments does not exceed the number of endogenous regressors. Hence, the equation to be estimated is exactly identified. According to the results of these new IV regressions, our major result that public R&D funding increases (coefficient 2.7 with p-value 0.001) privately funded R&D holds.

Robustness test 2:

Do our results change if we use public funding *paid* instead of public funding *granted?* To address this concern, we run a model by using public funding *paid* as a regressor. Our estimations based on the alternative public funding variable show that the coefficient of the public funding variable remains positive and statistically significant. We also re-ran the regressions in Table 4.2. Again, our result that the impact of public funding on private R&D is smaller in the case of small firms (10% are small) holds (the coefficient of interaction term is -2.9 with p-value 0.001). However in contrast to the results in column *c* (Table 4.2), when 25% of the smallest firms are classified as financially constrained, we do not find a statistically significant difference between the coefficient of large firms and small ones (the coefficient of interaction term is -1.32 with p-value 0.27). The results also show that the impact of public funding do not differ between indebted and other non-indebted firms (the coefficient of interaction term is -1.66 with p-value 0.17).

Robustness test 3:

To what extent are our results specific to the period on which we focus? To address this question, we ran our models separately for the period 1997-1999 and 2000-2002. The results of these new regressions show that our basic qualitative results hold: *First*, the coefficient of public R&D funding remains positive and statistically significant. *Second*, this additionality effect is stronger in larger firms than in smaller ones.

Robustness test 4:

Does the exclusion of 5% of the largest firms as outliers bias our results concerning the difference between small and large firms? To test this concern, we re-ran models by excluding only 3% of the biggest firms. Again, our result that the impact of public funding on private R&D is smaller in the case of small firms holds.

Robustness test 5:

The models reported in Tables 4.1 and 4.2 did not include industry dummies because all firms in our sample operate in the same industry (the Technology industry). However, there is industry variation in our sample if a more detailed industry classification is used, and this variation potentially drives our results. To take this into account, we added industry dummies (at the 2-digit level) to the models. The results of these new estimations echo our previous findings. *First*, in a basic IV model, the coefficient of current public R&D funding is 0.74 (with p-value 0.003) and the coefficient of lagged public R&D funding is 1.15 (significant at better than 0.001% level). *Second*, the results of financial constraint models (Table 4.2) also remained. For instance, when the basic group's coefficient of current public R&D funding remains positive (0.78 with p-value 0.005) and the interaction term (firms with poor interest coverage have been defined as financially constrained) is again statistically insignificant (the coefficient of this interaction term is -0.28 with p-value 0.42). As an additional robustness test, we included industry dummies at the 4-digit level to the models. Again, the results of these new estimations show that our basic qualitative results hold

5 DISCUSSION AND CONCLUSIONS

This study analysed the impact of public R&D funding on privately financed R&D using data on Finnish firms during 1996-2002. Moreover, we studied the impact of financial constraint on the relationship between public and privately funded R&D.

The findings of this paper did not support the view that public R&D funding crowds out privately financed R&D. Instead, our analysis suggests that receiving a positive decision to obtain public R&D funds increases privately financed R&D. The results indicated that public R&D funding crowds *in* privately funded R&D approximately euro for euro. Our results hold after we took into account the potential endogeneity of public funding. Moreover, our regressions suggest that a firm's debt has a statistically significant negative but nonlinear effect on privately financed R&D. The results (weakly) indicate also that profit increases private R&D.

This paper also contributes to the existing literature by analysing whether the impact of public R&D financing on private R&D is different in potentially financial constrained and unconstrained firms. To classify firms as financially constrained and unconstrained, we followed the fixed investment literature and used a firm size and the firms' indebtedness as classification criteria. Our econometric results suggest that the additionality effect of public funding on private R&D is bigger in large firms than in small ones. However, according to our results there are no differences in the size of coefficient of public funding between indebted and non-indebted companies.

The important policy implication of our results is that public R&D funding increases firm's total R&D expenditure also in the case of non-financially constrained firms. Thus, our evidence does not support the view that the public sector should finance only financial constrained firms. It is, however, unclear how generalisable our results are to other industries because our data consisted of companies operating only in one industry. Hence, a more extensive dataset is needed to get a more comprehensive conclusion about the impacts of public R&D funding.

6 APPENDIX

Data appendix

The data related to financial reports came from Balance Consulting Ltd. and from *Talouselämä* magazine's top 500 database. All variables are deflated using the GDP price index (1995=100).

Total R&D expenditure

Total R&D expenditure (irrespective of financing) of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers.

Public R&D funding

This data came from the National Technology Agency (Tekes). Public funding includes R&D loans and subsidies.

Privately financed R&D

Privately financed R&D has been calculated by subtracting public R&D funding from the total R&D expenditure.

Sales

Net sales came directly from the income statements of firms.

Profit

Operating profit came directly from the income statements of firms.

Debt

Long-term debt came directly from the balance sheets of firms.

Table A.2. Correlation matrix

	Private R&D$_t$	Public funding$_t$	Public funding$_{t-1}$	Net sales$_{t-1}$	Profit$_{t-1}$	Debt$_{t-1}$	(Debt$_{t-1}$)^2	Budget$_t$	Budget$_{t-1}$
Private R&D$_t$	1.0000								
Public funding$_t$	0.3664	1.0000							
Public funding$_{t-1}$	0.4366	0.3416	1.0000						
Net sales$_{t-1}$	0.4389	0.1387	0.2137	1.0000					
Profit$_{t-1}$	0.4765	0.1820	0.2730	0.7985	1.0000				
Debt$_{t-1}$	0.3186	0.0902	0.1534	0.5906	0.6085	1.0000			
(Debt$_{t-1}$)^2	0.2107	0.0252	0.0728	0.4046	0.4507	0.8975	1.0000		
Budget$_t$	0.1678	0.3108	0.1182	0.0346	0.0673	-0.0371	-0.0710	1.0000	
Budget$_{t-1}$	0.1455	0.0448	0.2252	0.0559	0.0770	-0.0011	-0.0129	0.0079	1.0000

Table A.3. First-stage regressions (IV regressions in Table 4.1)

	Column *b* in Table 4.1	Column *c* in Table 4.1
Dependent variable	Public funding$_t$	Public funding$_{t-1}$
$(\text{Budget})_t$	.0007***	
	(.0002)	
$(\text{Budget})_{t-1}$		.0005**
		(.0002)
$(\text{Applied})_t$	.3783***	
	(.0033)	
$(\text{Applied})_{t-1}$		.3941***
		(.0032)
Sales$_{t-1}$	-.0001**	-.00006
	(.00004)	(.00004)
Profit$_{t-1}$	-.0001	-8.83e-06
	.0003	(.0003)
Long-term debt$_{t-1}$	.0013**	.0005
	(.0006)	(.0006)
$(\text{Long-term debt})^2_{t-1}$	-.00002**	-.00001**
	(7.64e-06)	(7.05e-06)
Constant	-.0204	-.0048
	(.01315)	(.0104)
+ Year dummies		
Number of observations	1640	1640
F-test (joint)	1366.25	1503.27
P-value	< 0.001	< 0.001
R^2	0.902	0.91

Table A.4.Robustness test 1: Effects of public funding on private R&D

	(a) IV	(b) IV
$(\text{Public funding})_t$	1.728*** (0.493)	
$(\text{Public funding})_{t-1}$		2.294*** (0.492)
Sales_{t-1}	0.003 (0.0022)	0.003 (0.002)
Profit_{t-1}	0.026 (0.017)	0.029* (0.016)
$\text{Long-term debt}_{t-1}$	0.063*** (0.0195)	0.067*** (0.018)
$(\text{Long-term debt})^2_{t-1}$	-0.001*** (0.0002)	-0.0008*** (0.0003)
Constant	0.233*** (0.088)	0.246*** (0.085)
+ Year dummies		
Number of observations	1640	1640
F-test (joint)	9.34	11.41
P-value	<0.001	<0.001
R^2	0.33	0.35

NOTES: Heteroscedasticity-corrected standard errors in parentheses.
Instruments (column b): Year dummies, BUDGET(t), APPLIED(t), Sales(t-1), Profit(t-1), Long-term debt(t-1), Long-term debt^2(t-1)
Instruments (column d): Year dummies, BUDGET(t-1), APPLIED(t-1) , Sales(t-1), Profit(t-1), Long-term debt(t-1), Long-term debt^2(t-1)
F-test = tests the hypothesis that all coefficients excluding constant are zero.
*** = significant at the 1% level
** = significant at the 5% level
* = significant at the 10% level

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ESSAY 2: IMPACT OF PUBLIC R&D FINANCING ON EMPLOYMENT

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ABSTRACT: This study analyses how public R&D financing impacts the labour demand of companies. To our knowledge, no previous studies have distinguished the impact on the firm's global and domestic employment. Our company-level panel data covers a period from 1997 to 2002. The statistical method employed in the study takes into account the possibility that receiving public support may be an endogenous factor. Our results suggest that public R&D financing increases both group-level and domestic R&D employment. We also analysed the impact of public R&D funding on other than R&D employment. According to our results, public funding does not have an effect on other than R&D employment. However, it is possible that these impacts exist in the longer run.

KEY WORDS: Public finance, R&D, employment, research and development, substitute, endogeneity.

1 INTRODUCTION

According to the widely accepted view, the social return of R&D by firms is higher than the private return, thus unsurprisingly the public sector in almost all industrial countries tries to speed up technological change by using a variety of policy instruments, such as public R&D funding, national R&D laboratories and tax credits. However, the stimulation of the total R&D activity is hardly the ultimate goal of economic policy. Most of previous studies have ignored the fundamental issue whether public R&D funding finally leads to improved productivity, higher GDP, employment and welfare. This study focuses on the issue of how public R&D funding impacts employment.

Even though innovation is widely seen as an important source of growth, the impact of innovation on employment at the firm level remains unclear. One source of this uncertainty is the different nature of process and product innovations. Process innovations aim to improve productivity by enabling firms to achieve the same output with fewer resources. Thus, at least in the short run, process innovation may lead to job losses. In the long run, however, the improved competitiveness of the firm may stimulate demand leading to increases in output and employment (Harrison, Jaumandreu, Mairesse and Peters 2005). Thus, unsurprisingly the empirical evidence is mixed. While a number of studies have found a negative correlation between process innovations and employment (e.g. Antonucci and Pianta 2002), some other studies have reported a positive relationship (Blanchflower and Burgess 1998). Successful product innovations, in turn, likely lead to increases in employment. In practice, however, the distinction between process and product innovation is not always clear. New products potentially imply changes in the production process leading to productivity increases.

In sum, the results of existing studies concerning the relationship between innovation and employment vary. In this paper, we study a special kind of innovation namely firms' R&D funded by government. In light of the above, it is hard to assess *a priori* how the public R&D funding does affect employment.

In this study, we analyse the impact of public R&D funding on employment. To our knowledge, no previous studies have distinguished the impact on the firm's global employment and the impact on domestic employment. The stylised line of reasoning behind this issue is that the primary aim of technology policy is to promote the competitiveness of the national economy by technological means. Because the objective is to create domestic benefits, it is essential to differentiate between domestic and overseas impacts of the public R&D funding. Another new aspect of this study is that we also distinguish the impacts of public funding on R&D and non-R&D employment. However, our data does not allow us to distinguish non-R&D employment further (e.g. production employment, maintenance employment).

The remainder of the paper proceeds as follows. Section 2 includes relevant theoretical and empirical literature concerning the relationship between public and private R&D funding and the impacts on employment. Section 3 contains the description of the data. Section 4 gives an empirical analysis and results. Section 5 contains a summary and concluding remarks.

2 LITERATURE REVIEW

The main argument for public R&D funding is that the social return of R&D is higher than the private return, and thus from the perspective of the national economy firms under invest in R&D. Under-investment occurs because imperfect capital markets prevent companies from investing in all R&D projects with a positive net present value (NPV), or because the results of R&D spill over to other organisations.

Even though public R&D funding has several potential positive impacts, its real effect depends heavily on whether public R&D funding actually augments the total R&D expenditure of firms. Even though a number of empirical studies have addressed this issue, recent literature (Wallsten 2000 and Klette, Moen & Griliches 2000) has questioned the results of numerous previous studies with an argument that only a few studies have explicitly taken into account the potential endogeneity of public funding. Next, we shortly review the empirical literature where the endogeneity of public funding is controlled.

Wallsten (2000) examines the same SBIR programme as Lerner (1999) but points out the importance of taking into account the endogeneity of grants. Using the instrumental variable approach Wallsten reports an (almost) full crowding out effect. Busom (2000) analyses 154 Spanish firms of which roughly 50 per cent have received public subsidies. Due to the data limitations, Busom is unable to make an exact estimate of crowding out or complementary. However, her endogeneity-controlled analyses suggest that 41 companies spent more on R&D than they would have without the subsidy and 29 firms would have spent at least as much as in the case of no subsidy. Czarnitzki and Fier (2002) examine 210 German service firms. Applying a non-parametric matching approach, they find evidence that public funding has fostered the private innovation efforts of firms. By analysing more than 1,600 French firms, Duguet (2003) concludes that no significant substitution effect appears. Similar results have also been reported by Almus & Czarnitzki (2003), Hussinger (2003) and Gonzalez, Jaumandreu & Pazo (forthcoming). The evidence from Israel (Lach 2002) suggests that subsidies do not completely crowd out private R&D. Lehto (2000) analyses the effect of public funding on total R&D spending of Finnish plants and concludes that publicly funded R&D does not crowd out private R&D. Niininen & Toivanen (2000) apply a simultaneous equations approach and find evidence that Finnish firms with moderate cash flow add their own R&D expenditure as a response to a subsidy but when the cash flow is large enough, the positive relationship between subsidy and private R&D disappears. By examining Finnish firms in the period 1996-2002, Ali-Yrkkö (2004) concludes that receiving a positive decision to obtain public R&D funding increases privately financed R&D. The results also suggest that this additionality effect is bigger in large firms than in small firms.

To our knowledge, only a few studies have analysed the employment effect of public R&D funding. According to Lerner (1999), public R&D funding increases the labour demand of firms located in geographic areas with a high degree of venture-capital activity. Using the instrumental variable approach, Wallsten (2000) concludes that public funding has no effect on employment. Suetens (2002) reports the opposite result by analysing the impact of public R&D funding on R&D employment using a panel data of Flemish firms. Ebersberger (2004) utilised kernel-based matching and differences-in-differences techniques to analyse the labour demand effects of public R&D funding in Finland. The results suggest that during the R&D project the employment growth rates do not differ between subsidised and non-subsidised firms. However after the project, the average growth of employment is positive in subsidised firms but negative in non-subsidised firms. Thus, the results imply that in the longer run public R&D funding has a positive impact on employment.

There are two main caveats in the existing literature. *First*, employment impacts have been studied at the business group level without distinguishing domestic and overseas effects. Foreign direct investment (FDI) statistics show that during the past decade overseas operations have substantially increased (World Investment Report 2004). Thus, it is essential to take into account that global impacts might differ from impacts domestically. *Second*, the existing evaluation studies have not distinguished between impacts on heterogeneous workers. It is possible that public R&D funding impacts differently on R&D employees and non-R&D employees (all other than R&D employees)[9]. Our purpose is to extend the existing public R&D funding literature by distinguishing the impact on the total (global) employment and domestic employment. Furthermore, we analyse separately the impact of public funding on R&D employment and non-R&D employment.

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[9] We define non-R&D employment as follows: Non-R&D employment = Total employment – R&D employment

3 DESCRIPTION OF THE DATA

Our data is a unique company-level dataset consisting of Finnish companies operating in different industries. Three separate data sources have been merged which make it possible to take into account a large set of explanatory variables. The information of both the total and the domestic employment is based on an investment survey conducted by The Confederation of Finnish Industry and Employers. Into this data, we have added the information of companies' financial statements provided by Balance Consulting and *Talouselämä* magazine. Finally, the data concerning the public R&D funding from the Finnish Technology Agency (Tekes) has been merged together with the two datasets mentioned.

In contrast to many previous studies, we are able to distinguish firms that 1) have applied for and obtained public funding, b) applied for and obtained only part of the amount for which they applied, c) applied for and been rejected, d) and firms that have not even applied for public funding. Thus, our dataset allows us to distinguish between firms that applied for funding but were denied and those that did not even apply.

With respect to the public funding variable, the choice between the subsidy *granted* and *actually paid* had to be made. While both alternatives include advantages and disadvantages, we follow the study by Meeusen & Janssens (2001) and use subsidies *granted*[10].

Our unbalanced database consists of 187 companies with various time series[11]. Companies with single observations available are excluded from the sample, thus our data includes only those companies with two or more annual observations. The next table (3.1) describes the data.

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[10] For the sake of simplicity, in the rest of the paper we have used public R&D funding, public funding and public funding granted as synonyms.

[11] To control the potential bias caused by outliers, in terms of net sales 5% of the biggest firms are excluded from the sample.

Table 3.1. Descriptive statistics

	Number of observations	Mean	Median	Standard Deviation	Minimum	Maximum
Global R&D employment	560	25.38	7	79.66	1	849
Global non-R&D employment	557	424.39	229	525.36	1	3734
Domestic R&D employment	560	21.45	7	56.54	1	586
Domestic non-R&D employment	492	358.29	213	401.12	1	2860
Total R&D, (EUR. mill.)	560	1.88	0.6	4.69	0.0075	49.88
Private R&D (EUR. mill.)	560	1.80	0.57	4.62	0.0075	49.88
Public funding (granted), (EUR. mill.)	560	0.096	0	0.32	0	5.06
Public funding (paid), (EUR. mill.)	560	0.075	0	0.2	0	2.04
Public funding (applied), (EUR. mill.)	560	0.24	0	0.77	0	11.23
Net Sales, (EUR mill.)	560	71.9	36.7	87.04	0.89	461.2
Wages/User cost	557	0.2	0.19	0.08	0.0025	0.58
Operating profit/Net sales	560	0.11	0.11	0.1	0	0.69

Our data consists of a pooled sample of companies over the six-year period from 1997 to 2002. On average, approximately 40% of the companies in our sample have received public funding. This share has remained rather stable during the period 1997-2002. Among the subsidised companies, during 1997-2002 the average amount of public R&D funding is EUR 210,000. During the same period, the share of public funding of the total R&D expenditure is 12%. In terms of this ratio, no trend can be observed from 1997 to 2002.

The comparison between the subsidised and non-subsidised (see appendix) suggests that in terms of net sales the subsidised are, on average, larger than the non-subsidised. Furthermore, the subsidised have more employees both at the global and the domestic level.

The existing literature indicates that foreign direct investment (FDI) in research and development (R&D) activities has increased (see e.g. Jungmittag, Meyer-Krahmer & Reger (1999). The annual breakdown of our sample shows that also in Finland overseas R&D operations have increased. In terms of R&D employees, on average 9% of firms have foreign R&D operations, which represent, on average, 24% of their total R&D employment. The share of R&D employees abroad of the total R&D employment has risen during the past years. While in 1998, the R&D employees abroad represented 17% of the total R&D employment of those companies with R&D employees abroad, in 2002 the share had risen to 32%. Evidently, foreign R&D is not a marginal operation mode in technology development.

4 EMPIRICAL ANALYSIS

Our estimation strategy proceeds as follows. First, we present OLS and instrumental-variable regressions of R&D employment on subsidies. Our data enables us to distinguish the impact on total and domestic R&D employment. We then extend the analysis to also cover other employees than those working in R&D. Hence, in these cases our dependent variables are the total non-R&D and domestic non-R&D employment.

4.1 Impact on R&D employment

We use a standard textbook model (see Bresson, Kramarz and Sevestre 1996) and consider an output constrained firm having a technological constraint which can be represented by a Cobb-Douglas production function and facing quadratic adjustment costs. Denoting by $E_t Z_{t+\tau}$ the expectation about $Z_{t+\tau}$, formed at time *t*, the path of firm's future employment is determined by minimising its expected costs (C_t)

$$C_t = E_t \sum_{\tau=0}^{\infty} \left(\frac{1}{1+r}\right)^{\tau} \left[c_{t+\tau} K_{t+\tau} + w_{t+\tau} L_{t+\tau} + \frac{d}{2}(\Delta L_{t+\tau})^2 + \frac{e}{2}(\Delta K_{t+\tau})^2 \right] \quad \forall t \qquad (1)$$

Subject to

$$g(K_{t+\tau}, L_{t+\tau}) = Q_{t+\tau} \qquad \forall \tau \qquad (2)$$

where L_t is the number of employees, K_t is the capital stock, Q_t is the production, *r* is the discount rate, c_t is the user cost of capital, w_t is the wage rate, *d* and *e* define the quadratic adjustment costs. Through Euler conditions and using the log approximation, the final dynamic employment equation added by an error term (v_t) is (for derivation, see Bresson, Kramarz and Sevestre 1996, p. 666-669)[12]

[12] Bresson et. al. 1996, p.666 note:."*As current decisions are based on unobserved expectations, the realized values of period (t+1) can be, in the rational expectations context, substituted for their expectations of one period ahead. ... Because of the replacement of the expectations by the observed values, one has to use instrumental variables or GMM estimation techniques, where instruments belong to the information set of the firm at the time t*" . However, by taking first differences and constructing an appropriate instrument set, we lose several cross-sections. Because of that we

$$\log L_t = \alpha + \beta_1 \log L_{t-1} + \beta_2 \log Q_t + \beta_3 \log Q_{t-1} +$$

$$\beta_4 \log\left(\frac{w}{c}\right)_t + \beta_5 \log\left(\frac{w}{c}\right)_{t-1} + v_t \tag{3}$$

where subscript t is time index, L_t is the number of employees, Q_t is production, w_t is wage per employee, c_t is user cost of capital and v_t is an error term. To capture the potential impact of public R&D funding, we include the lagged public R&D funding regressor ($PUBLIC_{t-1}$) in the equation (3) leading to:

$$\log L_t = \alpha + \beta_1 \log L_{t-1} + \beta_2 \log Q_t + \beta_3 \log Q_{t-1} +$$

$$\beta_4 \log\left(\frac{w}{c}\right)_t + \beta_5 \log\left(\frac{w}{c}\right)_{t-1} + \beta_6 PUBLIC_{t-1} + v_t \tag{4}$$

In equation (4) our special interest is focused on the coefficient β_6 measuring the relative response of employment to an absolute change of public R&D funding (in EUR millions). Thus, it describes the relative (percent change if the relative change is multiplied by 100) change of firms' employment if public R&D funding changes by EUR 1 million.

First, we estimate the model (4) by using the ordinary least-squares (OLS) method. This method, however, ignores the possibility that public funding is an endogenous variable. To control the potential endogeneity, an instrument variable (IV) method is used. An appropriate instrument correlates with the endogenous public funding variable but is not correlated with unobserved factors that have an impact on the dependent variable. According to Lichtenberg (1988) and Wallsten (2000), one ideal instrument is the value of funds that are potentially awardable to firm i in year t. In our case, the budget of the Finnish Technology Agency (Tekes) represents these funds and thus affects the amount of public R&D funding a firm can potentially obtain. However, the total budget of Tekes is not really awardable to each firm. The Tekes' budget dedicated to each industry (or technological area) is likely to be correlated with the amount of public funding to firms operating in a

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do not use GMM technique in our basic estimations. However in Robustness tests section, we subject our estimates to a number of alternative specifications in order to address potential concerns about model specification and other estimation issues.

given industry. This variable is also expected to be exogenous with respect to unobserved variables affecting the innovativeness of the firm.

Following Wallsten (2000), for firms that have applied for public funding, we define the instrument, $BUDGET_{it}$, as follows:

$$BUDGET_{it} = AWARD^{i}_{at} \times (TEKESBUDGET_{at}), \qquad (5)$$

where subscripts *i*, *a*, and *t* refers firm, industry and year, respectively. The dummy variable $AWARD^{i}_{at}$ gets a value 1 if the company *i* operating in industry *a* obtains public funding in year *t*. The variable $TEKESBUDGET_{at}$ is Tekes's budget for industry *a* (at the 2-digit level) in year *t*. Similarly, for a firm that applied in year *t* but was rejected, $BUDGET_{it}$ is defined as Tekes's budget for industry *a* in year *t*.

For firms that have never applied for Tekes-funding, the calculation of $BUDGET_{it}$ is more complicated. In this case, we have first calculated the probability of receiving funding if the firm had applied for it. The probability has been calculated by dividing the number of firms in industry *a* that received public funding by the total number of firms in industry *a* that applied. Then this probability, $p(AWARD_{at})$, has been multiplied by Tekes's budget ($TEKESBUDGET_{at}$) for industry *a* in year *t* (equation 3).

$$BUDGET_{it} = p(AWARD_{at}) \times (TEKESBUDGET_{at}) \qquad (6)$$

Because the number of instruments does not exceed the number of endogenous regressors, the equation to be estimated is exactly identified.

The columns (a) and (b) in Table 4.1 report the results of the OLS and instrument variable (IV) regressions of equation (4) by using the total number of R&D employees as a dependent variable. In columns (c) and (d) we have replaced the dependent variable and used the number of domestic R&D employees as a dependent variable.

Table 4.1. Effects of public R&D funding on R&D employment

Dependent variable	log(Global R&D employment)		log(Domestic R&D employment)	
	(a) OLS	(b) IV	(c) OLS	(d) IV
log(Global R&D employment $_{t-1}$)	.922*** (.027)	.906*** (.023)		
log(Domestic R&D employment$_{t-1}$)			.923*** (.027)	.908*** (.024)
(Public funding)$_{t-1}$	.114*** (.025)	.36* (.2)	.087*** (.023)	.333* (.196)
Log(wages$_t$/user cost$_t$)	.131*** (.052)	.113** (.053)	.138*** (.05)	.12** (.052)
Log(wages$_{t-1}$/user cost$_{t-1}$)	-.116** (.049)	-.0.99* (.05)	-.129*** (.048)	-.11** (.05)
Log(Production$_t$)	.008 (.08)	-.012 (.08)	-.03 (.08)	-.051 (.07)
Log(Production$_{t-1}$)	.044 (.078)	.059 (.073)	.077 (.07)	.09 (.07)
Constant + Industry dummies + Year dummies				
Number of observations	560	560	560	560
F-test (joint)	721.69	7.32	907.2	7.31
P-value	<0.001	<0.001	<0.001	<0.001
R^2	0.95		0.95	

NOTES: Heteroscedasticy-corrected standard errors in parentheses.
Instruments (column b): Year dummies, industry dummies, BUDGET(t-1), Total R&D employment (t-1), wages/user cost (t), wages/user cost (t-1), Production (t), Production (t-1).
Instruments (column d): Year dummies, industry dummies, BUDGET(t-1), Domestic R&D employment (t-1), wages/user cost (t), wages/user cost (t-1), Production (t), Production (t-1).
F-test = tests the hypothesis that all coefficients excluding constant are zero.
*** = significant at the 1% level
** = significant at the 5% level
* = significant at the 10% level

According to the OLS estimation (column *a* in Table 4.1), the coefficient for the public funding in time *t-1* is positive and statistically significant at the 1% level suggesting the positive correlation between public R&D funding and the total R&D employment. The coefficient of the wage/user cost ratio in time *t* is surprisingly positive and statistically significant. However, the coefficient of the lagged wage/user cost is negative and statistically significant. Some previous studies (e.g.

Bresson *et. al.* 1992) have also reported opposite signs of the coefficient of wage/user cost variable in different periods[13].

These OLS estimates, however, might be biased because of the presence of the endogeneity of public funding variable (see Wallsten 2000). To control the potential endogeneity of public funding, IV estimation was carried out (column *b*)[14]. Again, the public funding has a positive and statistically significant impact on labour demand. Hence in contrast to Wallsten's study (2000), controlling endogeneity does not change the positive impact of public funding.

These two estimations (columns *a* and *b*), however, do not take into account the possibility that firms have increased their R&D employment abroad instead of domestically. From the perspective of the national economic policy, decision-makers are primarily interested in impacts on the domestic economy. To address this concern, we have re-estimated the models by using domestic R&D employment as a dependent variable (columns *c* and *d*). The results of these estimations suggest that there is a positive correlation between public R&D funding and domestic R&D employment. To calculate the economic magnitude of our results (column *d*), we multiply the coefficient of public funding (0.3325) by the mean of R&D employment (21.45). Thus, domestic R&D employment increases by 7 employees when a company obtains EUR 1 million public funding. Respectively, the global (total) R&D employment increases by 9 employees when a company obtains EUR 1 million public funding (column *b*). In sum, our results indicate that public R&D funding impacts positively both domestic and global R&D employment[15]. We also used a generalised method of moments (GMM) estimator (see

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[13] We also estimated equations without the public funding regressor (see appendix). According to the results of these estimations, the coefficients of wage/user cost and production were very similar as in equations with public funding (Tables 4.1 and 4.2).

[14] Our first-stage estimation (see Appendix) suggests that *Budget* is positively and statistically significantly correlated with *public funding* .

[15] We also estimated equations by using foreign R&D employment as the dependent variable (not reported). The results of these estimations suggest that public funding does not correlate statistically significantly with foreign R&D employment.

Blundell & Bond 1998) to estimate equation 4 (see Robustness tests). However, in constructing first differences and instruments, we lose several observations.

4.2 Impact on non-R&D employment

Next, we ask how public R&D funding impacts other than R&D employment. If R&D employees succeed in developing new products or increasing the competitiveness of firms, presumably also employment other than only R&D staff will increase. Product innovations are more likely to lead to increases in employment but also process innovations potentially lead to employment increases in the long run. However, in some cases the short-term impacts of process innovations probably are negative. The previous literature (e.g. Bresson, Kramarz and Sevestre 1992) suggests that an aggregate labour demand model can lead to erroneous conclusions if the employment of a given category of employees decreases while it increases for others.

To analyse the effect on the total employment, we use other than R&D employment (non-R&D employment) as a dependent variable. We first estimate the equation (4) by OLS and IV using global non-R&D employment as a dependent variable and then re-estimate equations by using domestic non-R&D employment as the dependent variable. The results are presented in Table 4.2.

Table 4.2. The impact of public funding on non-R&D employment

Dependent variable:	log(global non-R&D employment $_t$)		log(domestic non-R&D employment $_t$)	
	OLS (a)	IV (b)	OLS (c)	IV (d)
log(non-R&D employment $_{t-1}$)	.826*** (.09)	.825*** (.069)		
log(domestic non R&D employment $_{t-1}$)			.831*** (.072)	.829*** (.075)
(Public funding)$_{t-1}$	.017 (.028)	.179 (.178)	-.003 (.029)	.199 (.161)
Log(wages$_t$/user cost$_t$)	.05 (.04)	.037 (.056)	.118** (.045)	.1** (.05)
Log(wages$_{t-1}$/user cost$_{t-1}$)	.027 (.067)	.038 (.063)	-.07 (.052)	-.059 (.052)
Log(Production$_t$)	.293* (.154)	.28** (.136)	.194** (.092)	.177** (.088)
Log(Production$_{t-1}$)	-.237* (.14)	-.231* (.137)	-.118 (.077)	-.11 (.07)
Constant + Industry dummies + Year dummies				
Number of observations	554	554	456	456
F-test (joint)	653.2	6.49	484.63	5.25
P-value	<0.001	<0.001	<0.001	<0.001
R^2	0.94		0.91	

NOTES: Heteroscedasticy-corrected standard errors in parentheses.

Instruments: Column c: Year dummies, Industry dummies, BUDGET(t-1), Global other than R&D employment (t-1), wages/user cost (t), wages/user cost (t-1), Production (t), Production (t-1)

Column d: Year dummies, Industry dummies, BUDGET(t-1), Domestic other than R&D employment(t-1), wages/user cost (t), wages/user cost (t-1), Production(t), Production(t-1)

F-test = tests the hypothesis that all coefficients excluding constant are zero.

*** = significant at the 1% level

** = significant at the 5% level

* = significant at the 10% level

The first point worth noticing is that in terms of public R&D funding all methods yield quite similar results. We find no evidence that public funding increases non-R&D employment. All the coefficients of public R&D funding in Table 4.2 are statistically insignificant indicating that public R&D funding has no effect on other than R&D employment.

In sum, our estimations suggest that public funding has a positive and statistically significant impact on R&D employment. However, we found no evidence that public funding impacts non-R&D employment (e.g. employees in production).

However, caution must be adopted when interpreting the latter result. Implicitly, it may take a substantially longer time than one year before the public R&D funding turns to new or improved products and to increased demand of these products, and finally to increases in non-R&D employment. Due to data limitations, we are not able to add longer lags of public R&D funding variable to models.

4.3 Robustness tests

Next, we perform a number of robustness tests. To save space we do not report these tests in detail.

Robustness test 1:

Does the problem of weak instruments cause a bias in our results? To address this question, we re-estimate our models by using an additional instrument. While the correlation between $BUDGET_{it}$ and $PUBLIC_{it}$ is 0.22 (see appendix, Table A.2), the correlation between $PUBLIC_{it}$ and $APPLIED_{it}$ (the amount of public funding that a company has applied for) is as high as 0.979. However, it is hard to see why $APPLIED_{it}$ should correlate with the unobserved determinants of private R&D, conditional on the actual R&D funding received. We re-ran our models using this additional instrument. According to the results of these new regressions, our major result that public R&D funding increases domestic R&D employment (t-value 3.6) holds.

Robustness test 2:

Do our results change if we take into account firm-specific effects? To test this concern, in dynamic models it is necessary to use a generalised method of moments (GMM) estimator (see Appendix, Table A.4). However, by taking first differences and constructing an appropriate instrument set, we lose several cross-sections. We follow Blundell & Bond (1998) and use both lagged level and differenced variables as instruments. The results of these system GMM estimations show that our basic results hold (see Appendix). *First*, when domestic R&D employment is used as the dependent variable, the coefficient of public R&D funding remains positive and statistically significant (*t*-value 3.01). *Second,* public R&D funding does not have a statistically significant impact on non-R&D employment (*t*-value 0.92).

The diagnostics in these two estimations are satisfactory. Sargan tests do not reject the validity of instrument sets. Furthermore, in both columns the test statistics indicate that there is evidence of first (as assumed) but not of second order serial correlation. The latter result is important because the consistency of GMM estimator requires that there is no second-order serial correlation in the error term of the first-differenced equation.

Robustness test 3:

To test whether the public R&D funding impacts non-R&D employment in the longer run, we re-ran our models three times by lagging the public funding regressor two, three and four years, respectively. The results of these new estimations support our previous estimations that public R&D funding does not have a statistically significant effect on non-R&D employment.

Robustness test 4:

To what extent are our results specific to the period on which we focus? To address this question, we run our models separately for the period 1997-2000 and 2001-2002. The results of these new regressions indicate the following: *First*, public R&D funding has no statistically significant impact on other than R&D employment either in the period 1997-2000 or in 2001-2002. *Second*, public funding increases domestic R&D employment in the period 2001-2002 (t-value 2.3) but not in 1997-2000 (t-value -1.4). Even though our sample is too short to reach a definite conclusion, the result potentially indicates that the impact of public R&D funding is different during economic booms and recessions. The wage inflation of R&D employees is one interpretation of the empirical result that during the economic boom in 1997-2000, the public funding did not increase employment. Thus during the economic boom in 1997-2000, a significant fraction of increased R&D spending potentially went into higher wages of R&D employees (as proposed by Goolsbee 1998) instead of the number of R&D employees. However, during the recession in 2001-2002, the public funding increased the number of domestic R&D employees.

5 CONCLUSIONS

This study analysed the impact of public R&D funding on employment by using firm level data on Finnish companies during 1997-2002. This paper contributed to the existing literature in two ways. *First*, we distinguished between the impacts of public funding on firm's total and domestic employment. Due to the increasing overseas activity both in production and R&D operations, it is essential to distinguish between global and domestic impacts. *Second*, we also estimated separately the impact on R&D and other than R&D employment.

Our results suggest that public R&D funding has a positive and economically significant impact on domestic R&D employment. From the perspective of national economic policy, it is important that the policy has positively impacts particularly domestically.

We also examined whether the public funding impacts other than R&D employment (non-R&D employment). However, we found no evidence that public funding affects non-R&D employment in domestically. This result did not change when we examined the impacts on the other employment at the group's global level.

Our results have several important policy implications. *First*, our results do not support the view that the only effect of public R&D financing is to raise the wages of researchers (Goolsbee 1998). In contrast, our results show that public R&D funding does have a positive impact on the R&D labour demand. However, according to our results during economic booms the impact of public funding on R&D employment is potentially different than during recessions. While our estimations suggest that during the economic slowdown (2001-2002) public funding increased the number of R&D employees, we do not observe a similar relationship during the economic boom in 1997-2000. *Second*, we found no evidence that at least in the short run public R&D funding increases the labour demand of non-R&D employment. This is an important result because rather than the increased innovativeness, the ultimate goal of economic policy is, for example, improved competitiveness, increased exports, increased employment or finally improved welfare.

Due to data limitations, there are several topics left for future research. First, our data does not allow us to separate public funding directed at process innovations and product innovations. Thus, our estimates capture an average relationship that may hide impact differences between these two types of innovations. Second, to analyse more rigorously the impact of public funding on non-R&D employment data with a longer time series is needed. The delay from R&D to pilot production and from pilot production to full production potentially takes several years and this should be taken into account in future studies. Third, the widely accepted major rationale for public R&D is the spill over effect, that is, the output of an R&D project spills over to other organisations. To examine the aggregate impact of public funding on employment, one should also take into account the employment effects caused by spillovers.

6 APPENDIX

Data appendix

The data related to financial reports came from Balance Consulting Ltd. and *Talouselämä* magazine's top 500 database. All variables are deflated using the GDP price index (2000=100).

Employment

The total (worldwide) number of employees of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers or in the database of Balance Consulting Ltd.

Domestic employment

The total number of employees of the firm in Finland as reported in the investment survey by the Confederation of Finnish Industry and Employers.

R&D employment

The total number of R&D employees of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers.

Domestic R&D employment

The number of R&D employees of the firm in Finland as reported in the investment survey by the Confederation of Finnish Industry and Employers.

Wages

Total wages (including social expenses) came directly from the income statement of the firm. Wage per employee has been calculated by dividing total wages by total employment.

User cost

To calculate the firm-level user cost of capital c_{it} we use the following equation (Koskenkylä 1985 and Pyyhtiä 1991):

$$c_{it} = \frac{p_t^I (r_{it} - E[\dot{p}_t^I] + \delta^A)(1 - \tau_t \frac{\alpha}{r_{it} + \alpha})}{p_t^o (1 - \tau_t)} ,$$

where i=1,...,N and t=1,...,T, and

p_t^I = price of investment

$E[\dot{p}_t^I]$ = Expected change in the prices of capital goods. Calculated by taking an average of the inflation rate of capital goods (Source: Statistics Finland) during the past five years.

r_{it} = The interest rate. The firm-level interest rate has been calculated by dividing interest rate expenditure by interest-bearing debt.

δ^A = Economic rate of depreciation of the capital stock. The industry-level depreciation rate has been calculated from our sample by adding up the depreciation of all companies and dividing it by the sum of fixed assets.

τ_t = Corporate tax rate.

α = The maximum rate of depreciation in taxation on the total undepreciated capital stock.

p_t^o = Price of output (Source: Statistics Finland)

Total R&D expenditure

Total R&D expenditure (irrespective of financing) of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers.

Public R&D funding

This data came from the National Technology Agency (Tekes). Public funding includes R&D loans and subsidies.

Privately financed R&D

Privately financed R&D has been calculated by subtracting public R&D funding from the total R&D expenditure.

Sales

Net sales came directly from the income statement of the firm.

Table A.1. Descriptive statistics (Means and two-tailed *t*-tests for means) by subsidised and non-subsidised firms

	Firms without subsidy at *t*	Firms with subsidy at *t*	*t*-value	*p*-value
Global R&D employment	21.6	30.9	-1.358	0.175
Global other than R&D employment	314.2	583.4	-6.14	<0.0001
Domestic R&D employment	18.1	26.4	-1.7	0.089
Domestic other than R&D employment	271.1	490	-6.14	<0.0001
Total R&D, (EUR. mill.)	1.45	2.5	2.6	0.01
Net Sales, EUR mill.	55.71	95.47	-5.45	<0.0001
Wages/User cost	0.205	0.204	0.149	0.88
Operating profit/Net sales	0.12	0.105	2.07	0.039

Table A.2. Correlation matrix

	Total R&D expenditure	R&D employment	Domestic R&D employment	Non-R&D employ ment	Domestic non-R&D employ ment	Net sales	Wage/ user cost	Public funding (granted)	Budget	Public funding (applied for)
Total R&D expenditure	1.0000									
R&D employment	0.8529	1.0000								
Domestic R&D employment	0.8645	0.9222	1.0000							
Non-R&D employment	0.1487	0.1511	0.1554	1.0000						
Domestic non- R&D employment	0.1423	0.1171	0.1250	0.8813	1.0000					
Net sales	0.1600	0.1708	0.1482	0.8168	0.7501	1.0000				
Wage/user cost	0.0083	-0.0006	0.0042	-0.0801	-0.0423	0.0800	1.000			
Public funding	0.2274	0.1672	0.1478	0.1392	0.1410	0.1516	-0.067	1.0000		
Budget	0.0861	0.0609	0.0560	-0.1396	-0.1410	-0.2120	-0.054	0.2285	1.0000	
Public funding applied for	0.2303	0.1851	0.1575	0.1603	0.1635	0.1726	-0.062	0.9793	0.2344	1.000

Table A.3. First-stage regressions (IV regressions in Table 4.1)

Dependent variable	Column *b* in Table 4.1 Public funding (t-1)	Column *d* in Table 4.1 Public funding (t-1)
log(Global R&D employment $_{t-1}$)	.0486*** (.0129)	
log(Domestic R&D employment$_{t-1}$)		.0488*** (.0131)
(Budget)$_{t-1}$	.0156*** (.0022)	.0156*** (.002)
Log(wages$_t$/user cost$_t$)	.063 (.0426)	.0637 (.043)
Log(wages$_{t-1}$/user cost$_{t-1}$)	-.0727* (.0429)	-.073* (.0429)
Log(Sales$_t$)	.1034 (.0691)	.101 (.069)
Log(Sales$_{t-1}$)	-.075 (.07)	-.072 (.07)
Constant + Industry dummies + Year dummies		
Number of observations	560	560
F-test (joint)	7.32	7.31
P-value	<0.001	<0.001
R^2	0.21	0.21

Table A.4. Generalised Method of Moments (GMM-SYS2) estimations

	GMM	GMM
Dependent variable	(a) log (domestic non-R&D employment)$_t$	(b) log (domestic R&D employment)$_t$
log(domestic non-R&D employment $_{t-1}$)	0.71*** (0.187)	
log(domestic R&D employment $_{t-1}$)		0.974*** (0.04)
(Public funding)$_{t-1}$	0.036 (0.04)	0.112*** (0.037)
Log(wages$_t$/user cost$_t$)	0.28 (0.236)	0.35 (0.312)
Log(wages$_{t-1}$/user cost$_{t-1}$)	-0.14 (0.183)	-0.472* (0.28)
Log(Sales$_t$)	0.266 (0.187)	-0.117 (0.345)
Log(Sales$_{t-1}$)	-0.206 (0.216)	0.144 (0.353)
Constant + Year dummies		
Number of observations	264	321
Wald (joint)	472.7	1590.0
Sargan [p-value]	22.43 [0.263]	18.97 [0.459]
AR(1) test	-1.776	-2.051
AR(2) test	-0.7301	-1.568

Notes:

i) The Wald (joint) statistic is a test of the joint significance of the independent variables.

ii) Sargan is a test of the over-identifying restrictions, asymptotically distributes as χ^2 under the null of instrument validity.

iii) AR(1) and AR(2) are tests for first-order and second-order serial correlation in the first-differenced residuals, asymptotically distributed as N(0,1) under the null of no serial correlation.

iv) The GMM estimates reported are all one step estimates.

v) Public funding variable has been instrumented by BUDGET.

vi) The results are obtained using DPD for Ox (see Doornik, Arellano and Bond (2001)).

Table A.5. Employment estimations without public funding regressor

Dependent variable	log(Global R&D employment) OLS	log(Domestic R&D employment) OLS	log(global non-R&D employment $_t$) OLS	log(domestic non-R&D employment $_t$) OLS
log(Global R&D employment $_{t-1}$)	.929*** (.027)			
log(Domestic R&D employment$_{t-1}$)		.928*** (.027)		
log(global non-R&D employment $_{t-1}$)			.826*** (.088)	
log(domestic non-R&D employment $_{t-1}$)				.831*** (.0723)
Log(wages$_t$/user cost$_t$)	.139*** (.052)	.144*** (.052)	.052 (.044)	.117*** (.045)
Log(wages$_{t-1}$/user cost$_{t-1}$)	-.124** (.049)	-.135*** (.048)	.026 (.066)	-.074 (.052)
Log(Production$_t$)	.0177 (.083)	-.025 (.077)	.294* (.155)	.194** (.092)
Log(Production$_{t-1}$)	.038 (.08)	.0721 (.075)	-.238* (.141)	-.118 (.0769)
Constant				
+ Industry dummies				
+ Year dummies				
Number of observations	560	560	554	456
F-test (joint)	737.22	888.21	661.47	491.72
P-value	<0.001	<0.001	<0.001	<0.001
R^2	0.94	0.95	0.94	0.91

NOTES: Heteroscedasticy-corrected standard errors in parentheses.
F-test = tests the hypothesis that all coefficients excluding constant are zero.
*** = significant at the 1% level
** = significant at the 5% level
* = significant at the 10% level

Table A.7. The role of foreign R&D by year

Year	Number of firms	Number of firms with foreign R&D employment>0	Mean (Foreign R&D employment/Global R&D employment*100) for firms with foreign R&D employment >0
1998	81	5	16.9%
1999	108	7	19.7%
2000	119	11	27.2%
2001	130	11	25.6%
2002	122	16	31.9%

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ESSAY 3: IMPACT OF R&D ON PRODUCTIVITY – FIRM-LEVEL EVIDENCE FROM FINLAND

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ABSTRACT: This study analyses how R&D expenditure impacts the productivity of companies. We analyse the productivity impact of R&D using a large panel dataset of Finnish firms over a nine-year period from 1996 to 2004. Our results are two-fold. In the short run (in 1-2 years) we find no statistically significant productivity impact of R&D. However, R&D does have an economically and statistically significant impact when we take into account R&D efforts made 3-5 years before. Hence, a window of almost 5 years is needed to capture the productivity impact of R&D.

KEY WORDS: R&D, research and development, dynamic, productivity, lag, long run.

1 INTRODUCTION

In relative terms, Finland is among the leading countries investing in research and development (R&D). In 2003, Finland spent 3.4 % of GDP on R&D, while the U.S and Japan spent 2.6 and 3.15 %, respectively. However, the higher R&D expenditure is only a sign of greater input in innovation activities but it says nothing about the output of these efforts.

In this study, we are interested in the impact of R&D on productivity. Using a unique dataset of Finnish firms, we estimate the R&D elasticity of output. Previous panel data studies concerning R&D productivity in Finland have typically reported R&D elasticity varying between 0.02 and 0.08. Husso, Leppälahti and Niininen (1996) estimated the production function by using a sample of 74 firms in 1987-1993. They found that the R&D elasticity was 0.08 and statistically significant. Lehtoranta (1998), in turn, reports R&D elasticity of 0.06. Lehto (2000) used a large sample consisting of more than 11, 000 observations to estimate the R&D elasticity. The author found that the R&D elasticity was positive varying between 0.02 and 0.06. Instead of the R&D elasticity, Maliranta (2000) estimated the rate of return of R&D by using a sample with more than 4700 observations. In most his estimations, the coefficient of R&D was not statistically significant.

However, the results of the above-mentioned studies are based on static models. In contrast, our purpose is to study the impact of R&D on productivity in Finland by employing a dynamic production function similar to the approach by Bond, Harhoff and Van Reenen (2002). They used this approach to compare the R&D elasticity of output in Germany and the UK.

The goals of this study are two-fold. *First*, we estimate the impact of R&D on output in Finland by applying the same model as Bond *et al* (2002). The caveat of this model is that it takes into account the potential productivity effects of R&D dated t and t-1. Implicitly, it may take a substantially longer time before investment in R&D turns to productivity improvement. This thought motivated our second goal related to the longer run effect of R&D. To take into account these longer run effects, we proceed step by step by adding more lagged R&D variables to the model. The remainder of the paper proceeds as follows. Section 2 includes the description of the data. Section 3 gives an empirical analysis, main results and robustness tests. As a final sensitivity check, we use an alternative dataset to confirm our results. Finally, Section 4 contains a summary and concluding remarks.

2 DESCRIPTION OF THE DATA

Our data is a unique company-level dataset consisting of Finnish companies operating in different industries. Two separate data sources have been merged. The information of R&D expenditure is based on an investment survey conducted by The Confederation of Finnish Industries. To this data, we have added the information of companies' financial statements provided by Balance Consulting Ltd.

Our unbalanced panel data consists of 434 companies with varying time series[16]. Companies with 5 or less observations available are excluded from the sample, thus our data includes only those companies with at least 6 annual observations.

Table 3.1 presents descriptive statistics for sample firms. Mean and median turnovers are Eur 454 million and Eur 36 million, respectively. In terms of employment these firms had, on average, 1720 employees.

Table 2.1. Descriptive statistics

	N	Mean	Standard Deviation	Median	Minimum	Maximum
Value added, (EUR. mill.)	2379	139.90	673.83	12.03	0.12	12065.74
Net Sales, (EUR. mill.)	2379	454.16	2212.81	36.24	0.39	41250.47
Capital stock, (EUR. mill.)	2379	295.21	1365.62	12.64	0.07	15700.04
R&D, (EUR. mill.)	2379	14.95	160.37	0.70	0.00	3618.86
R&D capital stock, (EUR. mill.)	2379	57.58	514.93	3.44	0.00	13833.88
Employment	2379	1719.51	5503.24	229	3	60289
Non-R&D employment	1034	2232.46	6195.26	301.50	12	43882
R&D employment	1038	170.71	1418.64	7	0	20722

16 To control the potential bias caused by outliers, we employed the method of Hadi (1994) to identify and exclude outliers.

3 ECONOMETRIC SPECIFICATION

We consider the Cobb-Douglas production function following closely the model by Bond, Harhoff & Van Reenen (2002).

$$y_{it} = \beta_n n_{it} + \beta_k k_{it} + \beta_r r_{it} + (\eta_i + \upsilon_{it} + m_{it}) \quad (1)$$

$$\upsilon_{it} = \rho \upsilon_{i,t-1} + e_{it}$$

$$e_{it}, m_{it} \sim \text{MA}(0)$$

where y_{it} is log production of company i in year t, n_{it} log employment, k_{it} log capital stock, r_{it} log some measure of R&D inputs and α_t a year-specific intercept. η_i represents an unobserved firm-specific effect, υ_{it} a possibly autoregressive shock, e_{it} a productivity shock and m_{it} serially uncorrelated measurement error.

The model can be rewritten in the following dynamic representation:

$$y_{it} = \beta_n n_{it} + \rho\beta_n n_{i,t-1} + \beta_k k_{it} + \rho\beta_k k_{i,t-1} + \beta_r r_{it} + \rho\beta_r r_{i,t-1} + \rho y_{i,t-1} \quad (2)$$

$$+ (\alpha_t - \rho\alpha_{t-1}) + (\eta_i(1-\rho) + e_{it} + m_{it} - \rho m_{i,t-1})$$

or

$$y_{it} = \pi_1 n_{it} + \pi_2 n_{i,t-1} + \pi_3 k_{it} + \pi_4 k_{i,t-1} + \pi_5 r_{it} + \pi_6 r_{i,t-1} + \pi_7 y_{i,t-1} + \alpha_t + (\eta_i + w_{it}) \quad (3)$$

subject to three unlinear common factor restrictions $\pi_2 = -\pi_1\pi_7$, $\pi_4 = -\pi_3\pi_7$ and $\pi_6 = -\pi_5\pi_7$. These common factor restrictions can be imposed and tested using minimum distance techniques.

Our estimation strategy proceeds as follows. First, we estimate the unrestricted version of the equation and use a minimum distance estimator to obtain the structural parameters. If the restrictions are rejected by the data, we use the parameters of the unrestricted version and calculate the corresponding long run effects. Then we proceed by considering whether the impact of R&D differs between high tech and low tech industries. We also expand the basic model by adding more lagged R&D variables to the regression. Finally, we use alternative specifications and data to examine if our results are robust.

In addition to standard OLS, we estimate the model by a standard first differenced GMM estimator (DIF) proposed by Arellano and Bond (1991). However, this estimator is found to have poor finite sample properties when the marginal processes for input factors are highly persistent (Blundell and Bond 1998). In these cases, the lagged levels of series are only weakly correlated with subsequent first-differences. By exploiting the extended set of moment conditions, Blundell and Bond derived a linear estimator labelled the GMM system estimator (SYS).

3.1 The basic results

Our basic results are contained in Table 3.1. Following Bond *et al* (2002), we estimate equation (3) by OLS, Within groups, Difference GMM and System GMM estimators. In the upper part of the table, we report the results of the unrestricted version of the model. We tested common factor restrictions but these restrictions are rejected in all estimations except in the DIF3 estimation[17]. Hence, equation (3) is treated as an unrestricted model and consequently corresponding long-run effects and standard errors are computed and reported in the lower part of the table[18].

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[17] We imposed common factor restrictions with minimum distance estimation and tested these restrictions. In OLS, Within Groups, DIF2, SYS2 and SYS3 estimations restrictions were rejected at better than 0.01 level. The detailed p-values of these tests and structural parameters of restricted models can be found in Appendix (Table A.1).

[18] In order to consider longer-run effects, we used a non-linear combination of estimators. The point estimate of interest is obtained by:

$$\hat{\beta}_{RD(long.run)} = \frac{\sum_{k=0}^{n} \hat{\beta}_{RD(t-k)}}{(1-\hat{\beta}_{y(t-1)})}$$

Table 3.1. Basic results (Dependent variable=log (value added))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Value added (t-1)	.75***	.222***	.383***	.33***	.534***	.564***
	(.02)	(.035)	(.06)	(.124)	(.05)	(.076)
Capital (t)	.102***	.049	-.047	.015	.035	.29**
	(.03)	(.033)	(.128)	(.132)	(.124)	(.134)
Capital (t-1)	-.048	.003	.031	-.022	.019	-.139
	(.033)	(.035)	(.08)	(.099)	(.099)	(.11)
Employment (t)	.66***	.675***	.81***	.816***	.747***	.815***
	(.069)	(.068)	(.121)	(.131)	(.115)	(.107)
Employment (t-1)	-.496***	-.115*	-.25**	-.253*	-.382***	-.555***
	(.068)	(.066)	(.1)	(.15)	(.114)	(.124)
R&D (t)	.004	.002	-.04	-.019	-.015	-.022
	(.009)	(.010564)	(.031)	(.042)	(.031)	(.034)
R&D (t-1)	.02**	.005	.023	.031	.045*	.052**
	(.009)	(.01)	(.025)	(.028)	(.026)	(.026)
m1 (p-value)			<0.001	<0.001	<0.001	<0.001
m2 (p-value)			0.974	0.838	0.514	0.568
Sargan (p-value)			0.480	0.474	0.353	0.365
Difference Sargan (p-value)					0.261	0.307
Long run effects						
Capital	.222***	.067	-.025	-.011	.116	.346***
	(.025)	(.046)	(.103)	(.107)	(.0938)	(.0986)
Labour	.684***	.72***	.908***	.841***	.785***	.595***
	(.033)	(.053)	(.138)	(.164)	(.127)	(.132)
r&d	.108***	.008	-.021	.018	.064	.069
	(.017)	(.015)	(.049)	(.0741)	(.0465)	(.058)
Observations	2379	2379	2379	2379	2379	2379
Number of firms	434	434	434	434	434	434

Note: Heteroskedasticity corrected standard errors in parentheses. All regressions include time dummies for each year. In DIF2 (DIF3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in levels lagged 2 (3) periods or more (up to 6 periods). In SYS2 (SYS3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in differences lagged 1 (2) period as additional instruments for the levels equations. Difference Sargan is a test of the additional moment conditions used in the system GMM estimators relative to the corresponding first-differenced GMM estimators.

The first point worth noticing is that in terms of R&D the results of different estimations vary. In the OLS estimation, the long-run effect of R&D is positive and statistically significant. This impact, however, becomes statistically insignificant when we control for *permanent* differences across firms implying that the positive productivity impact of R&D is mostly driven by cross-sectional differences across firms. Similar results have also been found in some previous studies (see, e.g., Hall & Mairesse 1995).

The diagnostics in different estimations are satisfactory. We find no evidence of second order serial correlations and the Sargan tests do not reject the validity of instrument sets. To test the validity of different instrument sets, we use Difference

Sargan tests. The Difference Sargan tests (columns v and vi) suggest that additional instruments are valid favouring system estimators compared to difference estimators. Hence, we focus on the results of system estimations. The long run effect of capital in the SYS2 estimation seems implausible. The coefficient of capital is very low (0.11). Furthermore, this coefficient is statistically insignificant hence we cannot reject the hypothesis that the coefficient of capital differs from zero which, in turn, is implicitly unconvincing. In the SYS3 estimation, the long run coefficient of capital is 0.35 and statistically significant thus we treat SYS3 as our preferred estimator.

The existing literature indicates that the impact of R&D on productivity potentially varies between industries (see e.g. Harhoff 1998, Bönte 2003). In order to allow these differences, we split the sample into two groups namely higher technology (high-tech) industries and other industries (low-tech). To classify firms as high-tech and other firms, we follow the categorisation by OECD[19]. Since common factor restrictions were rejected in almost all columns (Table 3.1), we focus our further analysis on the long run effects derived from unrestricted versions of the model. The results of these estimations, as well as the corresponding long-run effects, are presented in Table 3.2.

[19] See STAN indicators documentation by OECD.

Table 3.2. "Industry effects"

	High Technology Firms	Other Firms
Value added (t-1)	.406***	.542***
	(.106)	(.082)
Capital (t)	.232	.341**
	(.149)	(.167)
Capital (t-1)	-.099	-.166
	(.12)	(.138)
Employment (t)	.879***	.59***
	(.104)	(.155)
Employment (t-1)	-.418**	-.36**
	(.172)	(.148)
R&D (t)	-.032	-.0127
	(.081)	(.027)
R&D (t-1)	.0429	.049**
	(.0687)	(.024)
m1 (p-value)	<0.001	<0.001
m2 (p-value)	0.936	0.697
Sargan (p-value)	0.163	0.707
long run effects		
Capital	.224**	.382***
	(.106)	(.101)
Labour	.776***	.501***
	(.143)	(.136)
r&d	.018	.078
	(.106)	(.055)
Observations	878	1499
Number of firms	158	277

Note: SYS3 estimators in all columns. Standard errors in parentheses. See also notes of Table 3.1

The results in Table 3.2 suggest that there are some differences in long run factor elasticities between high tech and other industries. These differences only relate to capital and labour elasticities while the long run elasticity of R&D remains statistically insignificant in both types of industry.

Until now our analyses have focused on a relatively short window of two years to consider the impact of R&D. However, it is possible that the effect of R&D on productivity occurs in the longer run than from *t-1* to *t*. To take into account these longer run effects, we expand the model by adding R&D dated *t-2* to *t-4* to the regression (Table 3.3).

Table 3.3. The model with more lagged R&D variables (Dependent variable=log (value added))

	(i)	(ii)	(iii)
Value added (t-1)	.55*** (.078)	.514*** (.075)	.431*** (.08)
Capital (t)	.269** (.136)	.355** (.149)	.187 (.172)
Capital (t-1)	-.116 (.112)	-.192 (.119)	-.04 (.149)
Employment (t)	.796*** (.116)	.735*** (.124)	.877*** (.109)
Employment (t-1)	-.525*** (.129)	-.446** (.135)	-.503*** (.14)
R&D (t)	-.0225 (.0327)	-.192 (.119)	-.054 (.037)
R&D (t-1)	.119*** (.043)	.116** (.049)	.149*** (.056)
R&D (t-2)	-.0617* (.035)	-.0756** (.036)	-.067 (.043)
R&D (t-3)		.008 (.013)	.012 (.014)
R&D (t-4)			.0378*** (.019)
m1 (p-value)	<0.001	<0.001	<0.001
m2 (p-value)	0.949	0.661	0.955
Sargan (p-value)	0.520	0.906	0.955
long run effects			
Capital	.339*** (.095)	.335*** (.093)	.259*** (.084)
Labour	.604*** (.128)	.595*** (.127)	.659*** (.122)
r&d	.077 (.059)	.073 (.058)	.138** (.063)
Observations	2379	1945	1511
Number of firms	434	434	434

Note: SYS3 estimators in all columns. Standard errors in parentheses. See also notes of Table 3.1

When R&D dated *t-2* (column *i* in Table 3.3) and *t-3* (column *ii*) are included in the model, the long run effect of R&D remains statistically insignificant. However, the long run effect of R&D becomes statistically significant when R&D dated *t-4* is included in the model (column *iii*) suggesting that there is a significant lag between R&D and its positive outcome for productivity. In other words, we do not observe a statistically significant improvement of productivity until four years after R&D.

3.2 *Robustness tests*

Next, we perform a number of robustness tests. To save space, we do not report completely the results of these new regressions.

Robustness test 1:

In the basic models (Table 3.1), we followed Bond *et al* (2002) and used the logarithm of R&D expenditure directly as an indicator of R&D activity. This method can be motivated as a steady state approximation to the stock (for details, see Bond *et al* 2002). However, our results might be biased, if the steady state approximation is not reliable. To take this into account, we re-ran the model (SYS3) by replacing log(R&D expenditure) with log(R&D-stock). The results of these regressions indicate the following: First, common factor restrictions were rejected at better than 0.001% level. Hence, we calculated the long-run effects using the unrestricted version of the model. Second, the regression echoes our previous result concerning the basic model (Table 3.1, column vi) that the impact of R&D is statistically insignificant (p-value 0.17).

Robustness test 2:

Nokia alone accounts for more than 40% of Finland's total private sector R&D thus our results are potentially driven by a single company (Ali-Yrkkö and Hermans 2002). To control this potential bias, we excluded Nokia from the sample and re-ran the basic model (SYS3) and the model with additional lags up to 4 years (column iii in Table 3.3). The results of these new regressions confirm our previous findings. *First*, in a basic model, the long run coefficient of R&D remains statistically insignificant (p-value 0.55). *Second*, this long run effect becomes statistically significant (coefficient 0.12 with p-value 0.07) when lagged R&D variables up to 4 years are included in the regression.

Robustness test 3:

Our results may be downward biased, because of double-counting, that is, R&D expenditure consists of R&D labour and investment in physical capital that are already included in the model. Schankerman (1981) argues that in order to estimate R&D elasticity correctly, the production factors capital and labour should be purified by subtracting the R&D share of these factors. Our data enables us to separate R&D labour and non-R&D labour, but we are unable to make the same distinction between R&D capital and non-R&D capital. To take into account the double-counting problem, we make two significant changes. First, instead of the total number of employees we define EMPLOYMENT so that it includes only non-R&D employees. Second, we use the number of R&D employees as an indicator of R&D. We again find that the long-run effect of the basic model is statistically insignificant (p-value=0.45). This long-run coefficient effect becomes statistically significant (coefficient 0.14 with p-value 0.07) when R&D lags up to 3 years are included in the regression.

Robustness test 4:

The result that the lag between R&D and productivity improvement lasts even 4 years (Table 3.3) is potentially biased because the sample differs in columns (i)-(iii) in Table 3.3. To eliminate this sample bias, we re-ran models (i) and (ii) by using exactly the same sample (1511 observations) as in column (iii). The results of these new estimations confirm our previous results. Hence, the long-run effects of R&D remain statistically insignificant when R&D dated from t to $t-2$ and from t to $t-3$ are included in the model.

3.3 Another robust check with alternative data

In order to obtain some further evidence on the robustness of our main findings for Finland we perform an additional analysis with an alternative data set. To this end we use the data of Statistics Finland.[20] The data are obtained by linking R&D survey and Financial Statements statistics data. The former is the source of R&D expenditures and the latter the source of labour, tangible capital input, output and industry group information. We use data over the period from 1995 to 2004. The sample is constructed by following the principles similar to those used in our main analysis above.

The results for this robustness check are reported in Table 3.4 which basically corresponds to Table 3.3 but is estimated using a different data set. The main differ-

[20] These data can be used only at the premises of the Research Laboratory of Statistics Finland following the terms and conditions of confidentiality. To obtain access to these data, please contact the Research Laboratory of the Business Structures Unit, Statistics Finland.

ence is that with these data we have also used a five-year lag for R&D in the final model (column iv).

Table 3.4. The results with the data of Statistics Finland

	(i)	(ii)	(iii)	(iv)
Value added (t-1)	.351***	.36***	.36***	.36***
	(.095)	(.09)	(.095)	(.0987)
Capital (t)	.06	.12	.119	.311
	(.188)	(.192)	(.191)	(.297)
Capital (t-1)	.132	.061	.059	-.116
	(.197)	(.204)	(.203)	(.318)
Employment (t)	.203*	.147	.148	.0976
	(.111)	(.118)	(.119)	(.163)
Employment (t-1)	.146	.174*	.168	.173
	(.096)	(.103)	(.102)	(.147)
R&D (t)	.125**	.085	.086	.047
	(.056)	(.059)	(.0586)	(.077)
R&D (t-1)	-.03	-.039	-.0446	.035
	(.046)	(.048)	(.048)	(.062)
R&D (t-2)	-.02	.0231	.0273	-.015
	(.037)	(.042)	(.042)	(.057)
R&D (t-3)		.046**	.0466**	.045*
		(.022)	(.0219)	(.026)
R&D (t-4)			.009	.002
			(.018)	(.024)
R&D (t-5)				.029
				(.027)
m1 (p-value)	<0.001	<0.001	<0.001	<0.001
m2 (p-value)	0.200	0.259	0.271	0.172
Sargan (p-value)	0.103	0.132	0.125	0.030
long run effects				
Capital	.296***	.282***	.279***	.305***
	(.09)	(.093)	(.094)	(.098)
Labour	.538****	.501***	.493***	.423***
	(.119)	(.123)	(.125)	(.138)
r&d	.111*	.181***	.194***	.224**
	(.062)	(.068)	(.074)	(.103)
Observations	1496	1496	1496	1496
Number of firms	558	558	558	558

Note: SYS3 estimators in all columns. Standard errors in parentheses.

Generally these estimations confirm our earlier main findings. R&D does have an economically and statistically significant effect. More specifically, we obtain further evidence that R&D investment does not become productive as soon as it is put in place. We find that a window of about 5 years backwards may be needed to capture the full impact. Compared to a short window of two years (i.e. when only current and one-year lagged R&D are included) where the coefficient for the long-run effect is 0.105 (standard error is 0.064), the long-run effect of R&D is about doubled to 0.224 (standard error is 0.103) when R&D is measured over a five- year period.

4 CONCLUSIONS

In this paper, we analysed the impact of R&D on firms' productivity using a large panel data of Finnish firms over a nine-year period from 1996 to 2004. As a robustness test, we also used another database of Finnish firms to confirm our results. We studied the productivity effect of R&D by employing a dynamic production function approach (Bond *et al* 2002).

Our results are two-fold. *First*, in the short run (in 1-2 years) we find no productivity impact of R&D that is statistically significant. This result was echoed when the model was estimated separately in high tech and low tech industries. *Second*, R&D does have an economically and statistically significant impact when we took into account R&D efforts made 3-5 years before. Hence, a window of almost 5 years was needed to capture the full impact of R&D.

For earlier Finnish results with firm data, Rouvinen (2002) has found evidence of lags between 4-5 years in the productivity effect of R&D investments. Further, in an analysis of micro-level sources of industry productivity growth, Maliranta (2005) found that R&D may also increase industry productivity through intra-industry restructuring between plants, indicating the role of creative destruction in innovative efforts. It was found that this mechanism involves lags of several years.

It is crucial to note that our results show the average effect of the R&D. In practice, there are likely to be considerable heterogeneity in the magnitudes of the effect between different firms. From the point of view of policy implications it would be important to distinguish such groups of firms where the effects of R&D inputs are highest or even positive, that is, which firms use R&D efficiently. For instance, Maliranta and Rouvinen (2004) found that the productivity effects of the use of ICT were considerably greater in the firms that have a relatively young establishment than in those firms whose establishments (and organisations) are old. The search of similar complementary factors of the R&D should have a high priority in future research. They might include such factors as intensity of competition in the product markets or human capital in the firm and in the region.

Our results have an important policy implication. The public sector in almost all industrial countries tries to foster technological change by using a variety of instruments, such as R&D loans and subsidies, national R&D laboratories and tax cuts. Our results suggest that there is a considerable lag between investment in R&D and its effects, implying that any type of policy to promote business R&D should have a long-term view lasting at least 5 years. As a consequence, evaluating technology policy requires taking into account these long lags between R&D activity and its impacts.

5 APPENDIX

Data appendix

The data related to financial reports came from Balance Consulting Ltd. and *Talouselämä* magazine's top 500 database.

R&D expenditure

R&D expenditure of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers. The variable was deflated using the GDP price index (2000=100).

Value added

Value added was computed directly from the income statement of the firm. It was calculated by summarising operating profit, personnel costs, depreciation and rent costs. The variable was deflated using the industry level price indices (2000=100).

Knowledge capital stock

Capital stock was calculated based on perpetual inventory calculations using a depreciation rate of 15 %, i.e., $G_t = (1-0.15)G_{t-1} + R_t$, where R_t is R&D expenditure. The variable was deflated using the GDP price index (2000=100).

Capital stock

Capital stock was calculated based on perpetual inventory calculations using a depreciation rate of 8 %, i.e., $K_t = (1-0.08)K_{t-1} + I_t$, where I_t is investment. The capital stock in the initial year was defined to be equal to capital assets in that year. The variable was deflated using the price index of capital goods (2000=100).

Employment

The total number of employees of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers or in the database of Balance Consulting Ltd.

Net Sales

Net sales came directly from the income statement of the firm. The variable was deflated using the industry level price indices (2000=100).

Table A.1. Basic results with common factor restrictions (Dependent variable=log (value added))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
Value added (t-1)	.75*** (.021)	.222*** (.035)	.383*** (.055)	.33*** (.124)	.534*** (.05)	.564*** (.076)
Capital (t)	.102*** (.034)	.049 (.033)	-.0469 (.128)	.0152 (.132)	.035 (.124)	.29** (.134)
Capital (t-1)	-.048 (.0335)	.003 (.035)	.031 (.085)	-.022 (.099)	.019 (.099)	-.139 (.11)
Employment (t)	.665*** (.068)	.675*** (.068)	.81*** (.121)	.816*** (.131)	.747*** (.115)	.815*** (.107)
Employment (t-1)	-.496*** (.068)	-.115* (.0659)	-.25** (.102)	-.253* (.15)	-.382*** (.114)	-.555*** (.124)
R&D (t)	.004 (.009)	0017 (.011)	-.036 (.031)	-.019 (.042)	-.015 (.031)	-.022 (.034)
R&D (t-1)	.0223** (.009)	.005 (.01)	.023 (.025)	.031 (.0279)	.045* (.026)	.05** (.026)
m1			<0.001	<0.001	<0.001	<0.001
m2			0.974	0.838	0.514	0.568
Sargan (p-value)			0.480	0.474	0.353	0.365
Difference Sargan (p-value)					0.261	0.307
COMFAC- Restrictions (p-value)	2.578e-48	.0026	.007	.1356	1.244e-11	1.347e-12
Structural parameters						
ρ	.816*** (.004)	.1744*** (.027)	.267*** (.039)	-.016 (.068)	.351*** (.026)	-.05 (.046)
β_K	-.0806*** (.003)	.0177* (.009)	-.075*** (.024)	-.041 (.042)	-.192*** (.015)	.048* (.026)
β_N	.644*** (.016)	.621*** (.05)	.665*** (.083)	.73*** (.122)	.702*** (.071)	.772*** (.068)
β_R	.054** (.021)	-.008 (.032)	-.026 (.0478)	.031 (.052)	.042 (.045)	.001 (.04)

Note: 434 companies, 2235 observations in all estimations. Standard errors in parentheses. All regressions include time dummies for each year. In DIF2 (DIF3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in levels lagged 2 (3) periods or more (up to 6 periods). In SYS2 (SYS3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in differences lagged 1 (2) period as additional instruments for the levels equations. Difference Sargan is a test of the additional moment conditions used in the system GMM estimators relative to the corresponding first-differenced GMM estimators. COMFAC is a test of common factor restrictions which is distributed under the null as a χ^2 with degrees of freedom equal to the number of restrictions (p-values in round brackets).

Table A.2. Basic results with COMFAC restrictions (Dependent variable=log (Net sales))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
Net sales (t-1)	.92***	.336***	.414***	.434***	.651***	.761
	(.011)	(.035)	(.117)	(.132)	(.077)	(.068)
Capital (t)	.12***	088***	.084	.044	.207**	.172
	(.037)	(.034)	(.108)	(.115)	(.104)	(.11)
Capital (t-1)	-.095***	-.025	-.104	081	-.107	-.059
	(036)	(.029)	(.067)	(.077)	(.077)	(.095)
Employment (t)	.628***	.655***	.859***	.849***	.655***	.822***
	(.091)	(.087)	(.121)	(.141)	(.123)	(.131)
Employment (t-1)	-.584***	-.19***	-.281**	-.338**	-.442***	-.699***
	(.092)	(.07)	(.129)	(.174)	(.139)	(.136)
R&D (t)	.007	.009	-.039	.004	-.0148	-.061*
	(.008)	(.009)	(.028)	(.0327)	(.029)	(.036)
R&D (t-1)	.01	.0001	-.01	.018	.029	073**
	(.008)	(.009)	(.022)	(.027)	(.024)	(.029)
m1			<0.001	<0.001	<0.001	<0.001
m2			0.623	0.663	0.824	0.800
Sargan (p-value)			0.158	0.066	0.428	0.127
Difference Sargan (p-value)					0.972	0.718
COMFAC- Restrictions (p-value)	8.765e-88	3.068e-15	.008	.022	3.951e-11	6.723e-20
Structural parameters						
ρ	1.08***	.224***	.06	-.049	.307***	.165***
	(.002)	(.026)	(.049)	(.071)	(.024)	(.035)
β_K	-.298***	-.013*	.004	-.03	-.148***	-.08***
	(.002)	(.007)	(.0226)	(.032)	(.012)	(.017)
β_N	.605***	.63***	.763***	.763***	.618***	.781***
	(.007)	(.046)	(.102)	(.132)	(.062)	(.067)
β_R	.003	-.01	.0557	.085	.105**	-.004
	(.01)	(.033)	(.055)	(.052)	(.051)	(.0497)
Observations	2379	2379	2379	2379	2379	2379

Note: See notes of Table A.1

Table A.3. Basic results without COMFAC restrictions (Dependent variable=log (Net sales))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
Net sales (t-1)	.92***	.336***	.414***	.434***	.651***	.761
	(.011)	(.035)	(.117)	(.132)	(.077)	(.068)
Capital (t)	.12***	.088***	.084	.044	.207**	.172
	(.037)	(.034)	(.108)	(.115)	(.104)	(.11)
Capital (t-1)	-.095***	-.025	-.104	.081	-.107	-.06
	(.036)	(.029)	(.067)	(.077)	(.077)	(.095)
Employment (t)	.628***	.655***	.859***	.849***	.655***	.822***
	(.091)	(.087)	(.121)	(.141)	(.123)	(.131)
Employment (t-1)	-.584***	-.19***	-.281**	-.338**	-.442***	-.699***
	(.092)	(.074)	(.129)	(.174)	(.139)	(.136)
R&D (t)	.007	.009	-.039	.004	-.015	-.061*
	(.008)	(.009)	(.028)	(.033)	(.029)	(.036)
R&D (t-1)	.01	.0001	-.01	.018	.029	.07**
	(.008)	(.009)	(.022)	(.027)	(.024)	(.029)
m1			<0.001	<0.001	<0.001	<0.001
m2			0.623	0.663	0.824	0.800
Sargan (p-value)			0.158	0.066	0.428	0.127
Difference Sargan (p-value)					0.972	0.718
Long run effects						
Capital	.303***	.095**	-.03	-.066	.288***	.474***
	(.06)	(.048)	(.106)	(.127)	(.103)	(.141)
Labour	.541***	.701***	.987***	.902***	.613***	0.516***
	(.081)	(.056)	(.155)	(.185)	.142	(.211)
r&d	.215***	.014	-.084**	.039	.04	.048
	(.046)	(.0141)	(.042)	(.07)	(.05)	(.083)

Note: See notes of Table A.1

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ESSAY 4: TECHNOLOGY SOURCING THROUGH ACQUISITIONS – DO HIGH QUALITY PATENTS ATTRACT ACQUIRERS?

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ABSTRACT: This study analyses how patent quality impacts the likelihood of acquisition. If a firm owns high quality or valuable patents, other firms may be interested in buying the firm to obtain the ownership of these patents. To proxy the quality of patents, we use both forward and backward citations. Moreover, our data enables us to distinguish between cross-border and domestic targets. Multinomial logit estimations show that owning patents correlates with becoming a target for a foreign firm. The same does not apply to targets for domestic firms. However, we do not find evidence that the quality of patents impacts the likelihood of becoming target for a domestic or a foreign firm.

KEY WORDS: Acquisition, M&A, patent, quality, value, target, likelihood.

1 INTRODUCTION

The recent empirical evidence indicates that technology-driven foreign direct investments have recently increased (e.g. Jungmittag, Meyer-Krahmer & Reger 1999). While the dominant purpose of overseas technology development is still to adapt products and production processes to suit the local market conditions (Patel and Vega 1999), multinational companies increasingly invest in foreign R&D in order to get access to technology or knowledge held by firms and people in a given country (Neven & Siotis 1996, Florida 1997)[21]. In addition to in-house foreign R&D, cross-border M&As offer an alternative route to get access to foreign knowledge. Similarly, also domestic deals offer firms a route to acquire external knowledge inside the national economy. Even though both domestic and cross-border M&As can be used for the same purposes, informational asymmetries (Gioia & Thomsen 2002) and different corporate governance systems (Rossi and Volpin 2004) can potentially explain why a firm is targeted either by a domestic or foreign acquirer.

The economic literature gives two broad rationales for the question: why firms buy other firms? The first suggests that the market for corporate control displaces the non-value-maximising practices of management of the target companies (see e.g Manne 1965). The second class suggests that mergers and acquisitions (M&As) are purposed to create synergist benefits achieved by combining two existing companies (Bradley, Desai and Kim 1983).

To our knowledge, only a few studies have analysed M&As as a means of acquiring technology. Granstrand and Sjölander (1990) elaborate on the economic effects of acquisitions of small technology-based firms and conclude that acquired firms grew faster than non-targets. Ali-Yrkkö, Hyytinen and Pajarinen (2005) analysed how patenting affects the probability of being acquired. They conclude that the number of patents owned by a firm is positively correlated with the probability that the firm is acquired by a foreign firm. Although patent counts are known to be an imperfect measure for the value of the patent (Hall, Jaffe and Trajtenberg 2001b

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[21] It is also possible that foreign firms use M&As as a means to obtain access to public R&D funding system in a given country.

and Gallini 2002), there are a number of reasons why patenting (in general) potentially increases the likelihood of being acquired. *First,* patent applications and grants disclose inventions to the public (Gallini 2002) and reveal the knowledge level of the inventor to competitors and other potential buyers. *Second*, the patents owned by a firm block other firms from using the patented technology without the patentholder's permission (O'Donoghue, Scotchmer and Thisse 1998). *Third*, new technologies can serve as a source of potential competition to the incumbent's internally developed products (Gans and Stern 2000).

In this study, we extend the existing literature by analysing the impact of patent quality on M&As. The specific purposes of this study are two-fold. The first purpose is to examine how the patent quality measured by patent citations impacts the likelihood of acquisition. Our second purpose is to investigate whether the impact of patent quality on the likelihood of becoming a target differs between domestic and cross-border deals. Our data is a unique firm-level dataset of more than 1350 firms covering the period from 1998 to 2004.

The remainder of this study is organised as follows. The next section outlines the model of takeover likelihood employed. In section 3 we describe our data. Section 4 provides the results of our empirical analyses and section 5 concludes.

2 LIKELIHOOD MODEL

This study employs a multinomial logit model to estimate the likelihood that a firm is acquired by another firm. Our model specifies the probability, P_{ij}, that firm i belongs to outcome j, where $j = 0$ if the firm is not acquired, $j = 1$ if it is acquired by a domestically owned firm, and $j = 2$ if it is acquired by a foreign-owned firm.

Following the previous analyses (see Powell 1997), the model is specified as follows:

$$P_{ij} = \frac{\exp(\beta_j' X_i)}{1 + \sum_j \exp(\beta_j' X_i)} \tag{1}$$

where β_j is a vector of parameters to be estimated and X_i a vector of target-specific explanatory variables. As usual, to identify the parameters of the model, the normalisation $\beta_0 = 0$ is imposed.

3 DESCRIPTION OF THE DATA

3.1 Sample construction

Our dataset is a combination of three different types of data: M&A-data, financial statements data and patent data. The M&A-data are originally collected by *Talouselämä* (Finnish financial magazine) which aims at reporting all M&As in Finland in which the net sales of the target company exceed EUR 0.5 million. The financial statements data are from the database of Balance Consulting Ltd. (a commercial vendor of financial statement data). Finally, our patent data are from the European Patent Office.

The data comprises a sample of targets and non-targets over the seven-year period from 1998 to 2004. The initial group of target firms consists of 1461 firms acquired during the period[22]. From this group of targets, 776 firms are excluded

[22] We focus on deals where the whole firm or subsidiary is acquired. Thus, we exclude the acquisitions of business units and divisions.

either because the lack of the required financial statements data (545 firms) or because they belong to the financial services sector or they are classified as outliers. Following the earlier literature (see Powell 1997), we construct a random sample of non-target firms as follows: From the population of non-target firms available to us, we draw a random (but industry-matched) sample in each year between 1998 and 2004[23]. The number of non-targets selected for each year equals the number of targets (with financial statements) for that year. Of these non-targets those with the required financial statement data and those that do not belong to the financial services sector, are included eventually as non-targets each year. As a result of this sample construction process[24], our final estimation sample includes 1375 observations (see Table 3.1 below)[25].

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[23] There are 10,368, 11,514, 12,759, 13,160, 12,995, 12,069 and 11,229 firms in 1998, 1999, 2000, 2001 and 2002, 2003 and 2004 respectively, in the "population" of non-targets available to us.

[24] Our sample includes all targets but only a random selection of non-targets. As Palepu (1986) has noted a sample like this is choice-based and not representative of the true population. However, the bias introduced by this choice-based sampling is not a serious concern, for in the logit model the bias is only limited to the parameter estimate of the constant term (Maddala 1983). The model is estimated in standard fashion using maximum likelihood methods.

[25] To control the potential bias caused by outliers, we used a method proposed by Hadi (1994) to identify and exclude outliers.

Table 3.1. Composition of the Estimation Sample

	Targets						Non-targets			Total
	Number identified	Financial statements	Sample excl. financials	Meet all criteria + outliers removed	Domestic	Cross-border	Population	Random sample	Meet all criteria (financials and outliers excl.)	
1998	183	126	125	100	71	29	10368	125	106	206
1999	233	178	177	143	103	40	11514	177	138	281
2000	317	228	222	191	134	57	12759	222	173	364
2001	234	105	103	77	49	28	13160	103	85	162
2002	206	137	136	78	56	22	12995	136	99	177
2003	176	91	91	60	39	21	12069	91	58	118
2004	112	51	50	36	29	7	11229	50	31	67
Total	1461	916	904	685	481	204	84094	904	690	1375

Note: Sources of data are *Talouselämä*, a major Finnish financial magazine, which aims at reporting all M&As in Finland in which the net sales of the target company exceed EUR 0.5 million. The financial statements data are from the database of Balance Consulting Ltd. The patent data are from the European patent office, EPO.

3.2 Definition of variables

Acquisition: Our dependent variable is TARGET equalling 0 if the firm is not acquired; 1 if it is acquired by a domestically owned company; and 2 if it is acquired by a foreign-owned company.

Patents and patent quality: We use two measures of patenting activity. First, *Patent* dummy variable is one if a firm has been granted patents, otherwise zero. Second, to proxy the quality of firms' patents (for firms with *Patent*=1), we follow the existing patent literature and use forward citations as an indicator of quality (see Harhoff, Scherer and Vopel 1999). As Hall, Jaffe and Trajtenberg (2001a) note, forward citations suffer truncation bias meaning that a patent granted for example in 1998 can receive citations in our data just from patents granted up to 2004. However, the patent will also be potentially cited by patents in later years, but we do not yet observe them. To take into account the truncation bias and variation by technological fields (Hall *et. al.* 2001a), we calculate forward citations by first taking the number of citations received by a given patent and dividing it by the corresponding year-field mean presented in the appendix (Table A1, for details, see Nikulainen, Palmberg and Pajarinen 2005), and then we add up forward citations (calculated in this way) of all patents owned by the firm. We expect that patent quality increases the likelihood that the firm will be acquired.

Inefficient management: Management discipline motive suggests that M&As serve as a mechanism where inefficient management is replaced with more efficient management. Even though several studies have suggested poor financial performance to be a characteristic of targets (e.g., Dickerson, Gibson and Tsakalotos 2002), some other studies have found profitability to be an insignificant determinant of targets (e.g, Palepu 1986, Powell 1997). To proxy managerial performance we use the return on capital employed. Jensen's (1986) free cash flow theory implies that firms with a high free cash flow tend to waste the money rather than distribute free cash to shareholders. In this paper, we use the ratio of cash flow to total assets to proxy the free cash flow.

Firm size: Earlier studies (e.g. Palepu 1986 and Powell 1997) suggest that the transaction costs of M&A increase with the firm size indicating that the likelihood of acquisition decreases with the firm size. In contrast to this result, Dickerson, Gibson and Tsakalotos (2002) report that the likelihood (non-linearly) increases with the size.

Thus, no conclusion can be drawn on the impact of firm size. In this study, we use the logarithm of total assets to measure firm size.

Ratio of tangible assets to total assets: The study by Stulz and Johnson (1985) suggest that the acquirer can use the target's assets as security for debt financing of the takeover. To control this effect we calculate the ratio of fixed assets to total assets.

Growth-resource imbalance: Previous literature suggests that high growth firms with low resources and low-growth firms with high resources are potential targets of companies with the opposite balance (Palepu 1986). To control this, we construct a dummy equalling one for the combinations high growth – low liquidity - high leverage and low growth – high liquidity – low leverage; and is zero otherwise. In this study, growth is measured as annual sales growth, leverage as ratio of long-term debt to total assets and liquidity as the ratio of marketable securities and cash to total assets. Each of the variables is defined as 'high' if its value for a firm exceeds the sample average, otherwise it is defined as 'low'.

4 EMPIRICAL RESULTS

4.1 Univariate analysis

First, we consider descriptive statistics by targets and non-targets (Table 4.1). The comparison suggests that targets are more frequently patent owners (*Patent*) than non-targets (t-value = -3.5). However, when we compare the quality of patents measured by the number of forward citations and backward citations of those firms that have patents, we do not find statistically significant differences between targets and non-targets. These differences potentially indicate that patenting, in general, increases the probability of being acquired but the impact of the patents' quality is uncertain. The comparison also suggests that non-targets are smaller than targets (t-value = -7.3) and in relative terms non-targets have more tangible assets than have targets (t-value = 1.72).

Table 4.1 Descriptive Statistics for Targets and Non-Targets, (two-tailed t-tests in means)

	Non-targets		Targets		*T*-test for means	
	Mean	S.D	Mean	S.D	*t* stat.	*p*-value
Return on capital employed	0.281	0.307	0.270	0.317	0.659	0.510
Firm size	0.888	1.547	1.538	1.753	-7.296	<0.001
Ratio of tangible assets to total assets	0.282	0.224	0.262	0.221	1.721	0.086
Free cash flow	0.119	0.118	0.110	0.117	1.470	0.142
Growth-resource imbalance	0.265	0.442	0.258	0.438	0.288	0.774
Patent (0=no, 1=yes)	0.019	0.136	0.054	0.226	-3.497	0.001
Forward citations	0.066	0.725	0.394	0.126	-2.561	0.011
Backward citations	0.044	0.614	0.395	3.218	-2.814	0.005
Firms with Patent=1						
Forward citations	3.490	4.148	6.755	12.087	-0.951	0.346
Backward citations	2.344	3.973	6.767	11.723	-1.328	0.190

Note: S.D. = standard deviation. Sources of data are *Talouselämä*, a major Finnish financial magazine, which aims at reporting all M&As in Finland in which the net sales of the target company exceed EUR 0.5 million. The financial statements data are from the database of Balance Consulting Ltd. The patent data are from the European patent office, EPO.

Next, we consider differences between domestic and cross-border targets (Table 4.2). In terms of patenting, the comparison indicates that domestic targets patent less frequently than cross-border targets (significant at better than 0.01% level). Even though the patents' quality of cross-border targets is, on average, higher than the patent's quality of domestic targets, for firms with *Patent*=1 the differences measured by *Forward citations* and *Backward citations* are not statistically significant (t-values 0.11 and 0.14). The table also indicates that compared to domestic targets, cross-border targets are bigger (p-value 0.001) and their financial performance better (p-value 0.08). Furthermore, the ratio of tangible assets is smaller in cross-border targets than in domestic counterparts. The remaining tests for the difference in means are statistically insignificant.

Table 4.2. Descriptive Statistics for Domestic (TARGET = 1) and Cross-Border (TARGET = 2) Targets

	TARGET=1		TARGET=2		*T*-test for means	
	Mean	S.D	Mean	S.D	*t* stat.	*p*-value
Return on capital employed	0.256	0.302	0.303	0.348	-1.772	0.077
Firm size	1.396	1.631	1.873	1.975	-3.278	0.001
Ratio of tangible assets to total assets	0.271	0.224	0.239	0.211	1.716	0.087
Free cash flow	0.111	0.116	0.108	0.119	0.234	0.815
Growth-resource imbalance	0.252	0.434	0.275	0.447	-0.627	0.531
Patent (0=no, 1=yes)	0.037	0.190	0.093	0.291	-2.965	0.003
Forward citations	0.027	0.162	0.083	0.277	-3.315	0.001
Backward citations	0.152	1.617	0.968	5.315	-3.051	0.002
Firms with Patent=1						
Forward citations	3.546	7.168	9.660	14.832	-1.631	0.111
Backward citations	3.857	7.392	9.401	14.265	-1.518	0.137

Note: S.D. = standard deviation. Sources of data are *Talouselämä*, a major Finnish financial magazine, which aims at reporting all M&As in Finland in which the net sales of the target company exceed EUR 0.5 million. The financial statements data are from the database of Balance Consulting Ltd. The patent data are from the European patent office, EPO.

4.2 Basic regressions

In Table 4.3, we present the results of the multinomial logit model. Our right-hand side (RHS) variables are those defined in section 3. To control the annual variations and industry-specific factors of the M&A-activity, yearly time dummies and industry dummies are included in the model.

In columns (a) and (b), we display the results for domestic targets (TARGET=1) and cross-border targets (TARGET=2), respectively. The numbers displayed are coefficients and associated robust standard errors[26]. A positive sign on a parameter indicates

[26] The Huber/White/sandwich estimator of variance is used in place of the traditional calculation.

that an increase of the variable increases the probability of takeover (domestic or cross-border).

Table 4.3. Multinomial Logit Estimates for TARGET

	(a)			(b)	
	Coef.	Std. err.		Coef.	Std. err.
Return on capital employed	-0.160	0.310		0.747	0.434*
Firm size	0.245	0.046***		0.472	0.062***
Ratio of tangible assets to total assets	-0.871	0.361**		-1.032	0.513**
Free cash flow	0.194	0.794		-1.106	1.120
Growth-resource imbalance	0.028	0.141		0.220	0.190
Patent (0=no, 1=yes)	0.480	0.417		0.941	0.472**
Forward citations	-0.016	0.038		0.033	0.030
Observations			1375		
Wald Chi^2			126.72		
significance			<0.001		
Log likelihood			-1291		
R^2_{Pseudo}			0.06		
Joint tests (df)					
INDUSTRY (p-value)	10.45	(0.88)		25.34	(0.08)
YEAR (p-value)	5.43	(0.49)		5.49	(0.48)
PATENTS (p-value)	1.33	(0.51)		7.58	(0.02)
Other controls (p-value)	33.97	(<0.001)		60.29	(<0.001)

Notes: Dependent variable: TARGET. *=significant at 10% level, **=significant at 5% level, ***=significant at 1% level. The dependent variable=0, if a firm is not a target, =1 if the firm is a target of domestic (Finnish) acquirer, =2 if the firm is a target of foreign acquirer. Joint tests (df) for the joint significance of the indicated variables: 'PATENTS' tests the joint significance of *Patent* and *Forward citations* 'Other controls' tests the joint significance of *Return on capital employed, Firm size, Ratio of tangible assets to total assets, Free cash flow*, and *Growth-resource imbalance.*

The estimation provides us with six main findings. First, patenting matters in foreign M&As. The coefficient of *Patent* (dummy variable) is positive and statistically significant (p-value= 0.046) in deals with a foreign acquirer. In domestic deals, *Patent* is not statistically significant. This finding means that owning patent(s) is correlated with cross-border deals. Even though we cannot be sure that a causal relationship exists, the results imply that foreign acquirers are particularly interested in targets with patents supporting the technology sourcing motive. Second, the coefficient of *Forward citations* is statistically insignificant in both domestic and foreign M&As (p-

values 0.67 and 0.28, respectively) suggesting that the quality of patents does not increase the probability of being acquired. Thus, the likelihood of a takeover is the same for firms with low quality patents and firms with high quality patents, other things being equal. The joint test for *Patent* and *Forward citations* indicates that the two variables are jointly different from zero (p-value=0.02) in the equation for cross-border targets, but jointly *not* significant (p-value=0.51) in the equation for domestic targets.

Third, the larger the firm, the more likely it is to be acquired. The size increases the likelihood of acquisition both in domestic and foreign deals. Fourth, *the ratio of tangible assets to total assets* has a negative impact on the probability of a takeover. This result is opposite to the view that firms with a high amount of tangible assets enabling greater debt capacity are more likely to be acquired. Fifth, financial performance matters in cross-border deals. The higher *the return of capital employed*, the more likely the company is to be acquired by a foreign-owned firm. Hence, our results concerning the financial performance of targets do not support the hypothesis that M&As are used to replace inefficient management with a more efficient management team. Sixth, insum our results provide evidence that the targets' characteristics of domestic firms differ from targets' characteristics of foreign firms. We tested (not reported in Table 4.3) the coefficients of all RHS variables (except industry and year dummies) in column (a) against the corresponding coefficients in column (b). The statistic of this joint test is statistically significant at better than 0.001% level.

4.3 Alternative specifications and robustness tests

Next, we perform a number of robustness tests. To save space we do not report these tests in detail.

Robustness test 1:

To test the sensitivity of our results to the using method of forward citations, we repeat the estimation using alternative using of forward citations. Following Trajtenberg (1990), we used forward citations weighted patent counts as an alternative measurement for the patents' quality. Each patent x is weighted by the number of year-field corrected forward citations (denoted by C_x). For a firm i an index of weighted patent counts (WPC_t^i) in a year t is calculated by: $WPC_t^i = \sum_{x=1}^{n}(1+C_x)$. The results of this estimation echoed our previous results. The coefficient of *Patent* for the targets of foreign firms is positive and statistically significant (p-value=0.05) and the coefficient of patent quality measured by citations weighted patent counts is *not* statistically significant (p-value 0.29). For the targets of domestic firms, both coefficients remained statistically insignificant.

Robustness test 2:

Are our results an artifact of the multinomial logit model? To test this, we ran a binomial logit model where the dependent variable equals one if the firm is acquired by a foreign firm and zero otherwise. The results of this new estimation show that our basic results hold. First, the coefficient of *Patent* is positive and statistically significant at better than 10% level. Second, the coefficient of *Forward citations* is not statistically significant (p-value=0.23).

Robustness test 3:

To test to what extent our results depend on the decision to use forward citations reflecting patent quality, we re-run the regressions in Table 4.3 by using an alternative measurement for patent quality. The results of Harhoff, Scherer and Vopel (1999) suggest that the number of backward citations correlates positively with the value of the patents. Following this line, we re-ran our model by using backward citations as an indicator of patent quality. The results of this estimation again echo our previous findings. For the targets of foreign firms, the coefficient of *Patent* remains statistically significant (p-value=0.06) and the coefficient of patent quality measured by backward citations does not deviate statistically significantly from zero. Moreover, both these coefficients were statistically insignificant for the targets of domestic firms.

Robustness test 4: One of the most serious assumptions within the multinomial logit framework is the assumption of the independent of irrelevant alternatives (IIA). Violating IIA makes multinomial logit potentially an invalid estimator. To test the IIA assumption, we conducted a test suggested by Hausman & McFadden (1984). The tests not reject the H_0 that IIA holds (p-values vary from 0.58 to 0.99).

5 DISCUSSION AND CONCLUSIONS

This study analysed the impact of patent quality on M&As using data on Finnish firms during 1998-2004. Our large dataset (1375 observations) consisted of firms that are mostly small and private. We contributed to the existing M&A literature by analysing how the patent quality impacts the likelihood of acquisition. Furthermore, we distinguished the targets acquired by a foreign firm and domestic firm.

To define patent quality, we have used the citations of the firms' patents registered in the European Patent Office. Our results show that the ownership of patents increases the likelihood that the firm is acquired by a foreign-owned firm, but the same does not hold for the probability that the firm is acquired by a domestic firm. However, we do not find evidence that owning high quality patents increases the likelihood of acquisition. This result remained in the targets of both domestic and foreign firms.

Our results have several implications. *First,* our findings imply that the characteristics of the targets of cross-border and domestic deals differ. It seems that foreign-owned firms are particularly interested in targets with patents supporting the hypothesis that some firms use M&As as a means of sourcing technology. There are at least two potential reasons for this. On the one hand, M&As can serve as a mechanism whereby the companies with inefficient intellectual property management are attractive acquisition targets. On the other, combining the intellectual properties of target and acquirer potentially creates synergist benefits. *Second,* our results provide evidence that patent quality does *not* increase the likelihood of becoming the target of domestic nor foreign firms. It is a bit difficult to interpret our finding that the ownership of patents increases the likelihood of becoming a target for a foreign firm, but that the quality of the owned patents does not matter. One potential reason for this is that citations are an imperfect proxy for the quality of patents because there are at least two reasons why patent B applicant cites patent A. First, citing potentially implies that patent A includes some crucial knowledge or technology related to patent B. Second, the firm applying for patent B may cite patent A in order to argue that patent A is not relevant in this field but that the applicant is aware that patent A exists. This controversial role of forward citations is worthy of further investigation in the future.

6 APPENDIX

Table A.1 Mean Citations Received by Grant Year and Technology Field

	Electrical engineering	Instruments	Chemicals	Process engineering	Mechanical engineering	Consumer goods and civil eng.
1991		10.60	4.14	3.77	2.28	0.83
1992	2.83	9.82	7.18	3.89	3.29	4.46
1993	2.18	5.42	7.10	2.90	2.37	3.11
1994	4.80	7.63	3.67	3.25	2.97	2.32
1995	5.04	2.82	7.66	3.34	2.42	2.78
1996	7.52	7.50	4.88	3.80	2.42	2.08
1997	5.97	6.13	5.90	3.31	2.03	3.03
1998	5.44	5.18	4.37	2.42	2.78	2.88
1999	5.67	4.32	6.51	3.16	2.44	1.87
2000	4.69	6.10	6.26	3.13	3.26	2.57
2001	6.08	9.06	5.40	2.74	1.49	1.25
2002	5.59	3.26	2.38	2.20	1.51	1.38
2003	5.08	1.97	3.47	1.48	1.03	1.02
2004	5.30	1.42	2.87	1.28	0.72	0.58

Source: Nikulainen, Pajarinen and Palmberg (2005)

Table A.2. Correlation matrix

	ROE	SIZE	TANGIBLE ASSETS	FREE CASH FLOW	IMBALANCE	PATENT DUMMY	FORWARD CITATIONS
ROE*	1						
SIZE	-0.285	1					
TANGIBLE ASSETS	-0.255	0.2696	1				
FREE CASH FLOW	0.6968	-0.1728	0.0962	1			
IMBALANCE	0.1146	-0.1464	-0.1069	0.0769	1		
PATENT DUMMY	-0.0562	0.2744	0.051	-0.0093	-0.0538	1	
FORWARD CITATIONS	-0.0118	0.2173	0.0143	0.0116	-0.0417	0.4956	1

* ROE= the return on capital employed

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