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Proceedings of the tip Workshop

Changing Strategies for Business R&D and their Implications for Science and Technology Policy

February 25th 2002 - Vienna, Austria

Editors: Nikolaus Gretzmacher (Joanneum Research)
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Gernot Hutschenreiter[*] and Wolfgang Polt[**]

1 Introduction and Summary

1.1 Introduction: The context of the workshop

The tip-workshop gathered researchers and evaluation practitioners from several countries (Austria, Belgium, Finland, Germany and Switzerland) in the context of the current OECD project on "Changing Strategies for Business R&D and their Implications for Science and Technology Policy". In all of these countries, the question of identifying means to raise the leverage effect of public funding is high on the political agenda and thus there is great interest in comparing methodologies to assess and compare these effects.

The aim of the workshop was to present, compare and discuss recent approaches and the outcomes of recent studies with a view to encourage mutual learning and to pave the ground for a common framework for future activities (surveys, case studies, econometric studies) in the field.

The presentations addressed the topic from two different angles: on the one hand they reviewed recent studies attempting to identify leverage effects of public support to private R&D, on the other hand they looked into the determinants of the patterns of private R&D. A brief summary of these presentations is given below. They are also available from the tip web site (http://www.tip.ac.at).

1.2 Summary of presentations

Gernot Hutschenreiter (Austrian Institute of Economic Research, WIFO) gave an overview of macro-level econometric studies of the impact of government support to R&D on private R&D expenditure. Experts in the field bemoan a lack of an adequate theoretical framework for macro-level analyses in terms of their micro foundations. In particular, there are problems of aggregation, i.e. to passing from a micro-economic setting to an explicit macro model. These difficulties are attributed to factors such as the heterogeneity of firms etc. However, it has to be noted that there appear to be serious shortcomings in the micro-theoretical framework, despite recent efforts in the field.

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Certainly, a macro-level approach is afflicted by serious econometric problems. At the same time, at the conceptual level there are distinctive advantages of conducting the analysis at the macro level. One of these advantages lies in the fact that firm-level studies do not capture important phenomena such as the impact of R&D aid on R&D worker's wages which, given the elasticity of the supply of qualified labour in the short run, is a channel for "crowding out" private R&D investment. Moreover, the extent to which "spillovers" (in this context the impact of public support for one firm's R&D on other firms' R&D investment decisions) are captured depends on the level of aggregation at which the analysis is conducted. Obviously, macro-level studies are able to capture such spillovers most comprehensively.

As compared to the firm-level relatively few studies have been conducted at the macro-level. A recent survey (David – Hall – Toole, 2000) lists just seven studies of that kind out of which five studies are based on US data and two on cross-country panel data. Studies based on cross-country panel data have the advantage that they are not subject to the endogeneity problems of time series analyses of individual economies.

Almost all macro-level studies find that public support to R&D complements (rather than substitutes) private R&D investment. This apparent uniformity of results (as compared to those of the much more frequent firm-level studies) may be due to the fact that macro-level studies capture spillovers more completely.

A recent and in some respects pioneering study not yet included in the survey cited above was performed at the OECD (Guellec – van Pottelsberghe, 2000) based on panel data for 17 OECD countries over the period 1981-1996. One salient feature of this study is that the impacts of various forms of public support to R&D expenditure performed and funded by the business enterprise sector are estimated simultaneously. This is a feature which would be rather difficult if not impossible to implement at the micro-level.

In the model (estimated in logarithmic differences) the independent variable is R&D expenditure performed and funded by the business enterprise sector. The dependend variables are: an autoregressive term, (direct) public support to business enterprise R&D, an index of generosity of tax incentives for R&D, government sector R&D expenditure, higher education sector R&D expenditure and value added.

Major results of this study are the following:

- Business sector R&D expenditure is stimulated by both direct support and tax incentives for R&D.
- Direct support has a longer-lasting impact on business sector R&D as compared to tax incentives.
- Direct support and tax incentives to R&D tend to be substitutes.
- Government and higher education sector R&D expenditures appear to "crowd out" business sector R&D expenditure.

An attempt along these lines was made at WIFO for Austria. Despite the differences in the econometric approach (time series versus cross-country panel econometric approach) etc., the results for Austria are broadly in line with those of the OECD study.

The presentation by **Nikolaus Gretzmacher** (Institute of Technology and Regional Policy, Joanneum Research) gave a survey on contemporary analytical firm-level studies and outlined the currently available microeconometric methods of measuring leverage effects of public R&D funding.

A comparison of 14 recent company-level studies indicates the difficulties of measuring leverage effects, as the results are inconclusive: roughly half of the studies indicate complemenarity and substitution between public and private funding respectively. It has to be noted, though, that these studies employ different methods and look at different sets of data at different periods of time, and thus are not strictly comparable. In addition, especially the earlier ones use relatively simple methods. In the light of this experience, it pays to look for further methodological advances in micro-econometric evaluation techniques.

To measure the leverage effect of a public R&D funding instrument, the typical econometric approach would be to regress some measure of private R&D on public R&D as well as some firm and time specific control variables. The sign of the regression coefficient of the public R&D measure shows whether there exists a complementary or substitution effect.

The known difficulties with this approach are that subsidies are not randomly assigned to firms. Different characteristics of subsidy instruments induce different firm behaviour. Hence it is important to pinpoint the induced interference in the firm's funding decision and to differentiate between general, indirect subsidies and selective, direct subsidies. We also have to consider that looking at only one subsidy instrument ignores the fact that there are usually multiple instruments in place simultaneously.

An analytical indication for the existence of *substitution effects* is the conjecture that public policy and funding agencies often select R&D projects with higher success probability, which would have been carried out anyway. The effect on the price of inputs is not negligible either. An inelastic supply of R&D personnel could lead to crowding out of public funding.

On the other hand there are a number of reasons to believe that there will be substantial *complementary effects*. Apart from the risk-sharing between public and private the upgrading of R&D facilities could lead to lower fixed costs for future projects and shorter development times could increase the success probability. Both of the latter scenarios would contribute to positive leverage effects (see Busom 1999, David 2000, Lach 2000).

In the end, it is an empirical question whether the complementarity effects outweigh the substitution effects or not. The identification of the net effect requires an assessment of what would have occurred in the absence of the measures, i.e. the identification of the "counterfactual". Trying to measure the *effect of the treatment on the treated* is known as the *fundamental evaluation problem*, because the counterfactual cannot be observed directly. If participating and non-participating firms would not differ systematically there would be no *sample selection bias* and the problem could be solved by simple comparison between the two groups (see Keilbach 2001). As this is not the case, we have to use more elaborate estimation methods to arrive at meaningful comparisons. Three different methods are presented here:

(i) the *Before-After estimator*,

(ii) the *Difference-in-Differences estimator* and

(iii) the *Cross-Section estimator*.

Using the *Before-After estimator* we assume that the expected mean of the counterfactual firms is equivalent to the expected mean of participants before implementation. The *Difference-in-Differences* (DID) estimator underlies the assumption of the existence of a comparison group for matching participation and non-participating firms after implementation of the programme. Finally the *Cross-Section estimator* takes as a fact that the target variable does not differ from the average of non-participants and the counterfactual.

Which estimator one applies depends on the data availability and the evaluative question. Especially data availability and the early design of data collection in the evaluation process are crucial for the feasibility applicability of the methods described above. But at least in principle, some advanced methods are available for identifying leverage effects on the firm level.

Andreas Fier (Zentrum für Europäische Wirtschaftsforschung/Joanneum Research) presented some results from recent studies in Germany which undertook to actually applying some of the microeconometric methods described by Gretzmacher. He added the observation on recent microeconometric studies that most of the studies carried out so far showing complementarity were European, while most of the studies showing substitution were from the US.

Based on studies of the effects of R&D subsidies using a 'matched-pairs' approach to a sample of more than 500 service companies one could on the one hand identify some variables which influence the propensity to participate in a public R&D programme (e.g. firm size, location, sectoral dynamics and technology intensity of the industry) and on the other hand demonstrate that the participants of policy schemes have significantly higher innovation intensity that their non-participating counterparts.

In an analysis of leverage effects (also for German service firms) one finds that one DM of subsidy induces the firms to spend 1.37 DM more on R&D. This effects is decreasing over time.

Tanja Tanayama and **Eija Ahola** (TEKES/VTT) in their presentation addressed the *selection problem* of a specific type of policy measure, namely the direct public R&D subsidies (grants, loans).

The underlying idea is: The selection mechanism consists of two interlinked decision problems.

1. Firms decide whether to apply for a subsidy or not, for which projects to apply and what to apply
2. Given the technology policy guidelines and budget constraints the public agency decides for which projects to give a subsidy, how large and what kind of a subsidy to give. Based on some criteria it ranks the application and funds the best.

The key point is that firms integrate their knowledge of the public agency's behaviour in their decision problem, i.e. there is a feedback from the public behaviour to the firm behaviour.

In the theoretical model they are aiming to develop both decision problems are dealt with simultaneously:

- Firms maximise expected profits by weighting the expected benefits of applying against the costs, having some information on the public agency's behaviour.
- Public agency maximises the objective function determined by technology policy guidelines given a budget constraint. By ex-ante screening the public agency ranks the application according to some criteria.

This model will be used in empirical analysis of how the selection mechanism functions in Finland. This analysis will address the following questions:

- Which are the key differences between potential applicants, applicants and those awarded a subsidy?
- What determines whether a firm will send an application?
- What determines whether a application will be accepted or rejected?

The ultimate of the study will be to identify how changes in the funding policy affect the likelihood of a firm to apply for a subsidy and the likelihood of getting a subsidy.

Sigrid Suetens and **Jan Larosse** (Universiteit Antwerpen and IWT respectively) reported results of a qualitative analysis of the efficiency of R&D subsidies in the Flamish region based on a survey involving R&D managers of innovative firms. A starting point of this work was the observation that econometric studies have their drawbacks. In particular it was argued that focus on the issue of "additionality" is too narrow. It does not account adequately for the fact that public support can lead to more efficient use of R&D funds, e.g. through the creation of innovation networks between firms. Additional information gained from interviews may complement econometric research and help to interpret results of econometric studies.

The Flemish survey was based on questionnaires and interviews involving managers of the 15 companies with the largest R&D expenditure in the Flemish region. In the first part of the questionnaire firms were asked to give indications on which parameters were important in determining their R&D investment decisions. These parameters are grouped into three sets:

- Company-related parameters
- Market-related parameters
- Government-related parameters

In the second part of the survey, government-related parameters were examined in more detail, e.g. by asking for an indication whether planned R&D investment would have been carried out without public support, or whether fiscal incentives have stimulated additional R&D expenditure.

Reinhold Hofer (Vienna University of Economics) presented an overview of theoretical considerations and empirical results concerning corporate finance and R&D. This overview dealt with questions such as: Why do firms underinvest in R&D? What determines R&D at the firm level? And finally: What is the role of corporate finance in this context? In particular, the econometric evidence concerning the following relationships was surveyed:

- Internal funds and R&D: The literature surveyed finds that internal funds are highly relevant for R&D performing firms. This holds true for both small and large firms. There are differences across countries.
- External funds and R&D: R&D performing firms tend to have lower debt than other firms. R&D performing firms tend to have long-term oriented financing. There are variations across countries.
- Ownership and R&D: The evidence points to be a positive influence of institutional ownership on R&D. Also, there seems to be some negative influence of owner control on R&D for large firms due to constraints on internal and external finance.
- Financial markets and R&D as a signal: R&D expenditure is strategically used on the capital market. Increases in R&D expenditure result in higher stock prices. A higher debt-ratio combined with R&D appears to be a signal for projects with high likelihood of success.

In their presentation on “Patterns of R&D in the Swiss Economy” **Spyros Arvanitis** and **Heinz Hollenstein** (ETH Zurich) presented both results from recent surveys into the patterns of R&D in the Swiss economy as well as a research plan for future analysis.

In Switzerland some surveys have been carried out which provide some data on the patterns of financing R&D.

- The Swiss Innovation Survey 1990, 1993, 1996, 1999 (since 1996 services included),
- A questionnaire on “Financing Innovation” as addendum to the Innovation Survey 1999,
- The Survey on the internationalisation of Swiss firms 1998 (services included),
- In addition, official R&D statistics (since mid-seventies every third or forth year). Most recent data 2000 are available (on meso-level data).

From theses surveys, some main messages come out regarding some major elements of the overarching question: With respect to *contract-R&D*, it can be seen that the share of contract R&D in total R&D has strongly increased during the nineties. With respect to *R&D co-operation*, also a strong increase of the share of firms co-operating in R&D (as a percentage of all firms doing R&D) can be noticed. The same holds true for *internationalisation of R&D*. Though Switzerland is not a country with large public subsidies to industry public support of R&D has been an increasingly popular instrument to fostering innovation in private enterprises.

Finally they outlined a research plan which consists of four fields of analysis of patterns of private R&D: (a) Contract R&D, (b) R&D co-operation, (c) Internationalisation of R&D and (d) Financing R&D-driven innovative activity.

The results would then be discussed in the light of their implications for Science and Technology Policy. The approach would be bottom-up: i.e. from the analysis of (emerging) patterns of R&D to Science and Technology Policy conclusions. It would rest on firm-level data (some industry data as well), and it would be descriptive as well as an econometric analysis of each topic mentioned above. The individual modules could be treated sequentially. To what extent the research plan can be realised depends on the time schedule of the project, the resources and the group’s (and our own) preferences.

Gernot Hutschenreiter*

2 The Impact of Public Support to R&D on Private R&D Investment - A Survey of Macro-level Studies

2.1 Introduction: Advantages and Disadvantages of the Macro-level Approach

Experts in the field bemoan the lack of an adequate theoretical framework for macro-level analyses in terms of their micro foundations. In particular, it is pointed out that there are problems of aggregation, i.e. to passing from a micro-economic setting to an explicit macro model. These difficulties are attributed to factors such as the heterogeneity of firms (see David – Hall – Toole, 2000). However, it has to be noted that, despite recent efforts in the field (see, e.g., David – Hall, 2000), the micro-theoretical framework is not flawless either. E.g., the explanatory framework used by David, Hall and Toole is not well suited to cover important phenomena in the area of public support to R&D such as targeted support for (lumpy) R&D projects etc.

Certainly, the criticism regarding the (lack of) "microfoundations" of the macro-level approach is valid. However, at the conceptual level there are also distinctive advantages of conducting the analysis at the macro level. One of these comparative advantages lies in the fact that firm-level studies do not capture important phenomena such as the impact of government support to R&D on the wages of R&D workers which, given a low short-run elasticity of the supply of qualified labour, is a channel for "crowding out" private R&D investment (see Goolsbee, 1998). Moreover, the extent to which "spillovers" (in this context the impact of public support for one firm's R&D on other firms' R&D investment decisions) are captured depends on the level of aggregation at which the analysis is conducted[1]. Obviously, macro-level studies are expected to capture such spillovers most comprehensively. From an econometric point of view, macro studies are less affected by problems posed by the endogeneity of variables than micro-level studies (Guellec – van Pottelsberghe, 2000).

These advantages at least mitigate some of the disadvantages of the macro-level approach such as the limited number of observations and its reliance on high levels of data aggregation (Levy – Terleckyj, 1983). It is obvious that a high level of aggregation implies heterogeneity of both the R&D and the function and design of government support programs involved.

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[1] On the significance of the level of aggregation in the study of a different type of spillovers ("R&D spillovers") see Griliches (1979, 1992).

2.2 Empirical Results

While there is an abundance of studies examining the impact of public support on private R&D investment at the firm level, relatively few studies have been conducted at the macro-level. A recent survey by David – Hall – Toole (2000) lists just seven studies of that kind (some of them are still in the limbo of "grey literature"). Out of this, five studies are based on US data while two draw on cross-country panel data. From an econometric point of view, studies based on cross-country panel data have the advantage that they are not subject to the endogeneity problems of time series analyses of individual economies.

Almost all macro-level studies find that public support to R&D complements (rather than substitutes) private R&D investment (with the exception of Lichtenberg, 1987). This is in contrast to the inconclusiveness of results of the much larger set of firm-level studies. This apparent uniformity of results may be due to the fact that macro-level studies are able to capture spillovers more completely than studies conducted at a disaggregate level. For a discussion of the studies covered by their survey see David – Hall – Toole (2000).

Let us just single out the study by Levy – Terleckyj (1983) which David – Hall – Toole (2000, p. 521) have labelled as "the most definitive of its kind". Based on NSF data for the United Sates for the period 1949-1981, Levy and Terleckyj examine the effect of contract R&D performed in industry and other government R&D on private R&D expenditure. They find that their results are consistent with the hypothesis that government contracts for R&D performed in industry stimulate additional private R&D expenditure (about $ .27 per dollar of R&D contracts). In contrast, the impact of overhead reimbursement of R&D turned out to be large and negative. The estimates were neither stable nor statistically significant. These results appeared to be quite robust with respect to variations in the period of observation and the estimation techniques applied.

A recent and in some respects pioneering study not yet included in the survey by David – Hall – Toole (2000) was performed at the OECD (Guellec – van Pottelsberghe, 2000) based on panel data for 17 OECD countries over the period 1981-1996. One salient feature of this study is that the impacts of various forms of public support to R&D expenditure performed and funded by the business enterprise sector are estimated simultaneously. This is a feature that would be rather difficult if not impossible to implement at the micro-level. Mostly, the factors determining private R&D expenditure are studied in isolation (e.g. influence of only the tax incentive or only the direct R&D subsidy on the R&D expenditures of the business sector).

Table 2.1: Macro-level studies

Author	Time period	Data type	Number of observations	Explained variable (private R&D)	Explanatory variable(s)	Controls	Method	"Net" findings (elasticity)
Levy – Terleckyj	1949-1981	Time-series	33	US$ Private R&D stock	US$ Government contracts to industry (stock)	Lag output, lag taxes, unemployment age R&D stock, US$ Government R&D, US$ reimbursement	GLS	Complementarity
Terleckyj (1985)	1964-1984	Time-series	21	US$ Private R&D expenditure	US$ Government contracts to industry	Output, government durables, lag R&D in Europe/Japan	GLS	Complementarity
Lichtenberg (1987)	1956-1983	Time-series	28	US$ Private R&D expenditure	US$ Government contracts to industry	Sales, sales to government	OLS	Insignificant (0.045)
Levy (1990)	1963-1984	Panel (cross-country)	9x21	US$ Private R&D expenditure	US$ Government contracts to industry	GDP, country dummies, pred. Europe and Japan private R&D	Pooled GLS	Complementarity
Robson (1993)	1955-1988	Time-series	33	Change in private basic research	Change in federal basic research	Level and chg private appl. *R*, Government appl. *R*, Government purchases, change in non-government purchases of goods and services	OLS – 1st-diff	Complementarity
Diamond (1998)	1953-1993	Time-series	41	US$ Private basic research	US$ Federal basic research	GDP. time trend	OLS – 1st diff Box-Cox	Complementarity (1.04)
von Tunzelmann – Martin (1998)	1969-1995	Panel (cross-country)	22x27	Change in private R&D	Change in public R&D	Levels of private and public-funded R&D, country dummies	Fixed effects	
Guellec – van Pottelberghe	1981-1996	Panel (cross-country)	17x16	Business enterprise R&D (log differences)	Government funding of business enterprise R&D, tax incentives for R&D, Government intramural expenditure on R&D, R&D performed by universities (in log diff.)	Autoregressive term, Value added (log differences), time dummies	3SLS, country fixed effects	Direct support for R&D: Complementarity (0.07)

Source: David-Hall-Toole (2000); own additions.

In the model (estimated in logarithmic differences) the independent variable is R&D expenditure performed and funded by the business enterprise sector. The dependent variables are: an autoregressive term, (direct) public support to business enterprise R&D, an index of generosity of tax incentives for R&D, government sector R&D expenditure, higher education sector R&D expenditure and value added.

The study attempts to quantify the influence on the self-financed R&D expenditures of the business sector of the following forms of public R&D expenditures:

- direct public support to R&D in the business sector,
- indirect support to R&D represented by an index of the "generosity" of the tax incentives,
- R&D expenditures of the public sector (public research institutions) and
- R&D expenditures in the higher education sector.

In addition, the model includes an autoregressive term (business sector R&D expenditure of the previous period) and value added as an additional (control) variable.

The main results of the study (for "the average" of the countries covered, not for any individual country) are as follows:

- Both direct government support and tax incentives to R&D stimulate internal R&D funded by the business sector. 1 EUR in direct subsidies raised the average R&D expenditure by around 1.61 EUR in total in the short term.
- Direct support has a longer-lasting impact on business sector R&D as compared to tax incentives.
- Direct support and tax incentives to R&D tend to be substitutes: an increase in the intensity of one decreases the effect of the other.
- Government and higher education sector R&D expenditures appear to "crowd out" business sector R&D expenditure. In this context, however, it should be noted that the time lags in the OECD model appear much too short to adequately represent the influence of university research (or more basic research in general).

The study implies important statements about the effectiveness of public support to R&D:

- Neither direct subsidies that are "too low" nor "too high" are optimal. Up to a subsidy intensity of 13%, the stimulating effect increases, beyond this threshold it declines. Beyond a 25% subsidy intensity, public subsidies appear to substitute for private financing. This implies that subsidy intensity cannot be arbitrarily increased without a decrease in efficiency. Therefore, there are limits to the ability to influence business-firm's R&D investment decisions in the short run.

- Industry's uncertainty as to future subsidy policy (e.g. due to frequent changes in the subsidy requirements, the subsidy intensities etc.) reduces its effectiveness. This result confirms the results of earlier studies. For this reason a long-term orientation or the stability of support policy is recommended.
- The effectiveness of an instrument depends on the use of the other components of public R&D expenditure.

The study offers a strong argument for smoothing and co-ordinating support policy. Short-term stop-and-go policies (resulting from budgetary restrictions) are inefficient. Reforms to individual instruments in the R&D support system should – for reasons of effectiveness – take the overall support system into account.

From a methodological perspective[2], the approach taken by Guellec and van Pottelsberghe has advantages with respect to the exogeneity of variables (when compared to firm-level analyses) and to accounting for the total impact of the independent variables (including spillovers) on business enterprise R&D expenditure. In addition, the analysis is not confined to one particular type of government support to R&D (e.g., to tax incentives or direct subsidies).

One can identify some weak points, too. Apart from the variables representing government (and lagged business enterprise) R&D expenditure, only value added is included as an independent variable. It would have been certainly helpful to explicitly draw on theoretical models (and available empirical evidence) concerning the factors driving the growth of business enterprise R&D expenditure (omitted variables). Another weakness is the modelling of the interactions between the components (substitution or complementarity) in connection with the functional form of the regression equation.

An additional problem may be posed by the orthogonality of variables (correlation matrix). Orthogonality is a precondition for the estimation; on the other hand, substitutive or complementary relations among explanatory variables are examined (which implies dependency). In particular, the specification, estimated in logs, implies a Cobb-Douglas form, which in turn implies an elasticity of substitution of 1. An exact definition of substitutive or complementary relations – best derived from a theoretical model – and a discussion of the empirical specification (Allen elasticities of substitution) is thus warranted.

An attempt along the lines of the Guellec – van Pottelsberghe study was made at WIFO for Austria. Despite the differences in the econometric approach (time series versus cross-country panel econometric approach) etc., the results for Austria are broadly in line with those of the OECD study. The WIFO study provides a first attempt to quantify the influence of various policy instruments on the R&D expenditures in Austria financed by the business sector (FUNT). In this study, an econometric approach was used (see Hutschenreiter – Polt – Gassler, 2001; Federal Ministry,

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[2] I am indebted to Michael Pfaffermayr (University of Innsbruck and WIFO) and Michael Wüger (WIFO) for sharing their views on these issues.

2001)[3]. Along with the business-sector R&D expenditures of the previous period, explanatory variables include:

- direct technology-related government support for the business enterprise sector - DIR (present values according to the FINKORD database and WIFO calculations),
- tax incentives to R&D measured by an index ("B-Index") of the generosity of the Austrian R&D allowance - B (WIFO calculations),
- higher education R&D expenditure - UNI (Statistics Austria),
- gross physical investment of industry (based on the WIFO investment survey).

The period of observation covers two decades (1980-1999). The econometric model was estimated in logarithmic differences (growth rates). Specifically, the estimated R&D investment model takes the following form:

$$\Delta FUNT_T = C + \lambda \Delta FUNT_{T-1} + \beta_{DIR} \Delta DIR_{T-1} + \beta_{UNI} \Delta UNI_{T-1} + \beta_B \Delta B_T + \beta_{INV} \Delta INV_T + \varepsilon_T \,,$$

where Delta (Δ) is the log-difference operator: $\Delta x_T = \log x_T - \log x_{T-1}$ and $\log$ the natural logarithm.

Analytical possibilities were limited by the rather long intervals between Austrian R&D surveys. The results of the econometric study for Austria are nevertheless consistent with the results derived by Guellec – van Pottelsberghe (2000) in several respects. However, the comparison of the estimated results with those of the OECD study should not be overstretched since the analyses not only differ with respect to data and period of observation but also in the econometric approach.

A major result is that direct technology-related support has a highly significant influence on the R&D expenditures financed by the business sector in Austria (at the 1%-level). The calculations provide an idea as to the magnitude of this effect.

The elasticity is defined by the number of percentage points by which the dependent variable (in this case the R&D expenditures financed by the business sector, FUNT) changes, when the value of the respective explanatory variable, e.g. direct technology-related subsidies (DIR), are increased by 1%. The marginal effect of an increase of the variable DIR on FUNT is yielded by multiplying the elasticity by the (average) relation FUNT/DIR.

In the basic variant, the result is that 1 additional EUR of direct technology-related subsidies induces 0.59 EUR of R&D expenditures financed by the business sector (Table 2.2). The effect of 1 EUR of subsidy on all R&D expenditures therefore amounts to 1.59 EUR. In comparison, the OECD study's basic variant reaches a short-term effect of 1.61 EUR on all R&D expenditures (long-term 1.70). If one considers that

[3] Jointly with Serguei Kaniovski (WIFO).

these calculations assume a somewhat broader definition of subsidies in Austria, these results can certainly be termed similar.

Table 2.2: Effect of an increase in direct subsidies by 1 Euro

	Austria	17 OECD countries
Elasticities	0.06	0.07
FUNT / DIR	9.82	8.71
Marginal effect on R&D expenditures financed by industry (FUNT)	0.59	0.61
Marginal effect on total R&D expenditures	1.59	1.61

Source: Austria: WIFO; OECD countries: Guellec – van Pottelsberghe (2000)

Tax incentives to R&D were represented by an index of the generosity of the R&D tax allowance. Within the observed period, the "generosity" of the R&D tax allowance changed three times: once directly due to the increase of the R&D tax allowance and twice due to changes to the corporate income tax rate. The coefficients are less robust than for direct support, but as a rule they have the correct sign. That means, according to our results, an increase in the generosity of the tax incentive for R&D (through an increase in the R&D tax allowance or the corporate income tax rates) leads, as expected, to an increase in the R&D expenditures financed by the business sector.

In empirical studies examining the effects of fiscal incentives to R&D, a cost/benefit ratio is often calculated. This ratio shows the relationship between the R&D expenditures induced in companies by the tax incentives and the corresponding loss of tax revenue (and is therefore approximately comparable to the total effect of the direct support on total R&D expenditure). The highest estimates published to date are in the range of 2. The majority of estimates performed in the 90s are in the range of 1.3 to 2.0 (see Hall – van Reenen, 2000).

The elasticity of R&D expenditures financed by the business sector in relation to higher education R&D expenditures is negative in all respects. In the basic variant, an increase in higher education research expenditures of 1 EUR leads to an increase in total R&D expenditures of 0.72 EUR. The OECD study (2000) showed similar results for this relationship. Here as well, the crowding-out-effect apparently dominates the stimulating effect. In both models, the time lags appear to be much too short to adequately represent the influence of university research.

In summary, based on the available results, the OECD findings with respect to the leverage effects of subsidies appear to be useful as working hypotheses. Expectations that an expansion of subsidies would, in the aggregate, entail additional R&D expenditures financed by the business sector of the same amount appear – at least in the short term – rather optimistic. All the more this is true for claims, sometimes circulating in the public sphere, of "leverage effects" of multiple size. This of course does not mean that individual instruments can not have a stronger effect on research financed by the business sector than the averages estimated here.

2.3 Conclusions

Relatively few studies have been conducted at the macro level. Although a lack of "microfoundations" of the macro approach is acknowledged, it is argued that the macro-level approach has distinctive advantages mitigating the drawbacks associated with it. Perhaps most important is the fact that this approach is able to cover spillovers most comprehensively. The results of available empirical studies are rather uniform pointing at a complementary relation between public (support for) R&D and private R&D expenditure.

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3 Measuring Leverage Effects of Public R&D Funding – An Overview of Contemporary Analytical Models

3.1 Introduction

This survey is an effort to compile contemporary models on measuring the leverage effects of public R&D funding. As our starting point we take the consensus amongst economists that leaving R&D performance only to private firms without government intervention will result in an underinvestment in R&D in terms of desired social returns (cf. Martin and Scott [2000:439]).

Various studies on the R&D spending behavior of firms raise the question whether government R&D funding has a complementary or substitution effect on private R&D investment. Does government funding crowd out private R&D funding completely, partially, or not at all? Are there in fact positive leverage effects observable? Many economists, based on the pioneer work of Blank and Stigler (1957) as well as Griliches (1958), have evaluated the firm behavior on different R&D funding policies. Hence, at the beginning it is necessary to point out our interest in this field.

The 'OECD Working Group on Innovation and Technology Policy' focuses on the new patterns of private and public financing of R&D. In recent publications they indicate considerable evidence of significantly changing business strategies for R&D:

> *"The growing levels of business R&D compared to publicly funded R&D imply that the private sector exerts greater influence over national innovation systems and that governments must better leverage their more limited resources to improve national innovative performance. The changing patterns of business R&D suggest that governments will need to adapt S&T policies to better complement private sector activities and address emergent market failures while avoiding government failures." (OECD [2001:2])*

The consequences of the changing environment are our main motivation in surveying analytical models and performing new studies on the efficiency of current public R&D policies. Two fields of research have been identified to analyze the linkage between private and public R&D investment. First, there are qualitative analyses, namely case studies, surveys, and peer reviews, which are very expensive if done on a large scale and not well suited for generalization. Furthermore the results are often exposed to critique over the expert's objectivity. Second, the group of quantitative research studies, which is organized by the degree of data aggregation. The structuring in line of

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business, firm level, industry level, and macroeconomic models are the commonly used classification of quantitative research studies (cf. David et al. [2000]).

Macroeconometric models on measuring leverage effects consider aggregate private and public R&D spending variables with limited possibilities to adjust for heterogeneities and asymmetries among firms or interdependence of enterprise behavior in imperfectly competitive markets (cf. David et al. [2000:525-26]). Thus we decided to focus mainly on the evaluation of microeconometric (line of business, firm level, and industry level) models where we can observe the more disaggregated effects, which are vital for adjusting public R&D funding policies.

To cope with the different approaches of recent models a brief outline of various public subsidy instruments and the anticipated firm behavior is given in part 3.2. In part 3.3 of this survey we are going to present and compare a number of different methods to estimate leverage effects of public R&D spending as well as the key results of these studies.

3.2 Public subsidy instruments and anticipated firm behavior

We have to bear in mind that different subsidy instruments induce different firm behavior. It is not necessary but seems to be very useful to introduce a classification of used subsidy instruments if we want to pursue with analyzing analytical evaluation models. Fölster (1991) proposes to summarize the instruments in two broad categories: General subsidies and selective subsidies where the latter can be subdivided into non-self-financing and self-financing subsidies. Table 3.1 presents a useful classification.

Table 3.1: Classification of subsidy instruments

General subsidies	Selective non-self-financing subsidies	Selective self-financing subsidies
Tax deduction for R&D expenses	Project grants	Fee-bases loan guarantees
Tax deduction for a rise in R&D expenses	Project loans at subsidized interest rates	Royalty grants. Royalty to the state is based on sales of the invention toward which the grant was applied
Personnel grant toward costs of R&D personnel	Conditional loans that are repaid only if R&D is successful	Stock option grants. In return for an R&D grant the state receives a stock option that can be exercised if the stock value rises significantly.
	Loan guarantees	Convertible loans. The state gives a loan that can be converted into stock if the project turns out to be a commercial success
	Prizes	Equity investment. The state invests in venture firms either directly or indirectly via private investment companies

Source: Fölster (1991:24)

Refering to Fölster (1991) the most common instruments are grants, loans, and tax deductions. However all subsidy instruments are in use somewhere and are not only theoretical applications.

Besides econometric evidence on the efficiency of subsidy instruments, which we are going to present later, there are several issues important to consider for policy makers. The main differences between the two broad categories of subsidies are discussed below.

General subsidies allow the firm to choose their R&D projects whereas with selective subsidies the government chooses the R&D project to support. Although the bureaucrats want to influence the decision on the performed R&D projects to maximize social returns they often lack market information and hence influence the decision on technological standards. The problem of asymmetric information can be partly reduced by letting the firms bid for the indirect subsidy in a competitive environment to ascertain the firm's internal valuation of a project (cf. Martin and Scott [2000]).

Furthermore the allocation process of general subsidies, like tax deductions or tax credits, is in most of the cases transparent and unbureaucratic. The entry barrier can be kept low which assures the participation of small and medium enterprises (cf. Hutschenreiter and Polt [2001]). A major disadvantage occurs with budgeting the general subsidies, because they can only be estimated through the tax expenses of previous years.

Remember that for each subsidy instrument there are arguments for potential positive as well as negative leverage effects on private R&D spending behavior. Lach (2000) argues for a tendency of complementary as well as substitution effects. He pointed out that on the one hand subsidized R&D can upgrade R&D facilities, which leads to lower fixed costs for future R&D projects and therefore to an increase in the probability of realizing the project. In addition knowledge spillovers from the funded project can increase the probability of success of future projects. On the other hand government bureaucrats are under pressure exhibiting short-term success in allocating public funds, which can lead to a funding of R&D projects with higher success probability. These are projects, which the firm would have undertaken anyway and private expenditures can be crowded out, if they are not invested in other, much riskier R&D projects. Another reason for crowding out could be the effect on the price of R&D inputs, especially the inelastic supply of R&D personnel.

Martin and Scott (2000) approach the problem of a reasonable use of a specific subsidy instrument by analyzing the main mode of innovation. They argue that

> *"Industries differ enough and in sufficiently important aspects that these differences must be taken into account in explaining market performance. This is true for technological performance as well as product market performance in a static sense. With respect to the appropriate institutional framework for public support to investment in innovation, factors to be taken into account are*

- *whether innovation is incremental in nature or takes the form of discrete, fundamental breakthroughs;*
- *the extend to which patents or other mechanisms allow innovators to appropriate a sufficient share of the profits that results from successful innovation;*
- *the degree of product-market rivalry;*
- *the importance of learning-by-doing (if present, R&D is a necessary ticket to enter the market)."*

(Martin and Scott [2000:445]).

Table 3.2: Innovation modes, sources of sectoral innovation failure, and policy responses

Main mode of innovation	Sources of sectoral innovation failure	Typical sectors	Policy instruments
Development of inputs for using industries	Financial market transactions costs facing SMEs; risk associated with standards for new technology; limited appropriability of generic technologies.	Software, equipment, instruments	Support for venture capital markets; bridging institutions to facilitate standards adoption
Application of inputs developed in supplying industries	Small firm size, large external benefits; limited appropriability	Agriculture, light industry	Low-tech bridging institutions (extension services) to facilitate technology transfer
Development of complex systems	High cost, risk, limited appropriability (particularly for infrastructure technology)	Aerospace, electrical and electronics technology, telecom/computer technologies, semiconductors	R&D cooperation, subsidies; bridging institutions to facilitate development of infrastructure technology
Applications of high-science-content technology	Knowledge base originates outside commercial sector; creators may not recognize potential applications or effectively communicate new developments to potential users	Biotechnology, chemistry, materials science, pharmaceuticals	High-tech bridging institutions to facilitate diffusion of advances in big reserach

Source: Martin and Scott (2000)

Table 3.2 summarizes innovation modes in four main categories and the respective sources of sectoral innovation failure. The policy instruments are designed in such a way that they overcome the private underinvestment in technology R&D.

3.3 Analytical Models & Results

Recent years have seen many analytical models on measuring the leverage effects of public R&D spending. The results couldn't be more heterogeneous. Wallsten (2000), for example, uses a three-stage least square firm-level model on SBIR funded companies and shows that public R&D subsidies lead to over 80% crowding out of private R&D spending. Lach (2000), who as well used an econometric model to analyze Israeli manufacturing firms, made the counter argument. He finds a complementary effect on public R&D spending of over 40%. Why do the results of empirical studies on the effects of public subsidies remain so ambiguous?

First we have to explain the major difficulties and obstacles in the model selection process to be able to draw conclusions on different modeling approaches and the yielding results. In designing an econometric framework one has to take account of the relevant risks:

- Public subsidies are not always randomly assigned to the private firms, which implies endogeneity of public funding. Including an endogenous variable in linear regression framework will cause biased estimators if there exits correlation with the regression's error term. It is not unrealistic to assume that for instance public and private expenditure are correlated because firms with an increase in private spending receives subsidies, not because public subsidies caused private R&D spending to increase.
- Neither from a negative nor a positive relationship of public to private R&D spending one can automatically conclude a crowding out or substitution effect. A consistent estimator of the firm's R&D spending performance in absence of a public subsidy is needed to draw reasonable conclusions (cf. Busom [1999]).
- It is important to build a framework on measuring not only a single subsidy instrument at one point in time. Public R&D policies are far-reaching (cf. subsidy instrument above) and proper econometric analyses have to measure the effects of all subsidy instruments simultaneously.
- Considering a static econometric approach, as researchers in this field often pursue it, leaves out the long-term effects of subsidies through the channel of learning-by-doing and spillover effects. The future success of private R&D projects can be affected by past-subsidized R&D projects.

Before we introduce some econometric approaches and results, we first want to point to an example of a qualitative study about leverage effects of different subsidy instruments. Fölster (1991) conducted a survey on 214 (135 from large firms, 79 from small firms) research projects or project proposals amongst Swedish high-level R&D managers to evaluate the leverage effects of a single subsidy (cf Table 3.1). They were asked both on R&D projects carried out and on those that were rejected. The efficiency of a subsidy is defined as the amount of additional private R&D expenditure generated for each invested unit of public R&D spending. The author simulated imperfect information, hence one half of the projects are selected on the criterion that they would not have been conducted or would have generated at least 50 percent of complementary private R&D spending. The other half is selected as though the subsidizing agency had no information about the project and all applying firms would receive the subsidy. Table 3.3 presents the ratio of additional private R&D spending generated by each single subsidy instrument.

General subsidies induce an increase of private R&D spending in large firms of only 16-19% percent, whereas this effect is only 7-8% for small firms. The most effective instruments are the self-financing subsidies. Stock option grants and royalty grants show the highest complementary effects amongst the groups of large and small firms. The reason might be that firms would not have conducted the projects in absence of these specific subsidy instruments, thus making carry-over effects very small. Overall it is observable that smaller firms generate more additional R&D expenditure through public subsidies than large firms. A crowding out effect, which would be indicated by a negative ratio, does not exist for any of the subsidy instruments.

Table 3.3: Ratio of R&D generated by the subsidy with imperfect project information

	Large firms	Small firms
1. Tax incentive	0.19 (0.06)	0.08 (0.07)
2. Grant to R&D personnel	0.16 (0.06)	0.07 (0.07)
3. Project grants	0.41 (0.06)	0.52 (0.07)
4. Project loans	0.40 (0.05)	0.59 (0.07)
5. Conditional loans	0.47 (0.06)	0.64 (0.08)
6. Fee-based loan guarantees	0.48 (0.01)	0.47 (0.02)
7. Royalty grants	0.56 (0.10)	0.74 (0.11)
8. Stock option grants	0.72 (0.09)	0.92 (0.10)

Standard errors are shown in parentheses

Source: Fölster (1991:84)

The results of the qualitative study doesn't only leave us with interesting questions but also gives as an impression on what econometric models should be able to achieve. In a next step we are going to summarize microeconometric models of Lach (2000), Czarnitzki and Fier (2001), Irwin and Klenow (1995), Klette et al. (2000), Wallsten (2000), and Busom (1999).

David et al. (2000) worded a very accurate explanation of what these models try to accomplish:

> *"The typical econometric approach is to regress some measure of private R&D on the government R&D, along with some 'control' variables. When a positive coefficient on the public R&D variable is found, this is interpreted as revealing the predominance of complimentary between private and public investments. On the flip-side, a negative coefficient is taken to imply that public R&D and private R&D are substitutes" (David et al. [2000:510]).*

Even stated as simple, we want to gain deeper insight by looking at different models.

3.3.1 Israeli manufacturing firms: Lach (2000)

Lach (2000) analyses the effect of an R&D subsidy on private R&D spending of Israeli manufacturing firms. The observation period from 1990 to 1995 includes approximately 180-190 firms per year. The used data set on R&D subsidies bases on the grant statistics of the Office of Chief Scientist (OCS) and some other smaller government agencies. Subsidies given by the OCS vary between 30 and 66 percent of the total R&D expenditures for a project (30% for improving an existing product, 50% for creating a new product or industrial process and 66% for projects of start-up companies). The OCS is obligated by law to subsidize all eligible projects. The data set contains firm level data but it is not possible to distinguish between firms whose proposal was rejected and firms that didn't apply for a subsidy.

Lach (2000) presents an analytical step-by-step approach to explore various channels through which a public subsidy affects the firm's decision process. We want to acknowledge the structured work by presenting the key steps and results of his work.

3.3.1.1 The Simple Difference Estimator

The framework of the model starts out with a straightforward approach of the simple difference estimator. The estimator $\hat{\alpha}$ is the difference of the mean private R&D expenditure ($\bar{y}_t^{D_{t-1},D_t}$) of two groups where the one group received a subsidy at time t ($\bar{y}_t^{01}$) and the other did not ($\bar{y}_t^{00}$), given that they were both not subsidized in $t-1$.

$$\hat{\alpha}^D = \bar{y}_t^{01} - \bar{y}_t^{00} \tag{1}$$

$$E\left(y_{it}^0 \middle| D_{it} = 1, D_{it-1} = 0\right) = E\left(y_{it}^0 \middle| D_{it} = 0, D_{it-1} = 0\right) \tag{2}$$

In accordance with equation (2) α is a consistent and unbiased estimator only if y_{it}^0 is independent of D_{it}. In the sample of Israeli firms the R&D subsidy appears to have no significant effect on private R&D expenditure, given that the estimator is unbiased. But it is further shown that α cannot be unbiased if the subsidies are not randomly assigned to the firms. This is only the case if *"there are no common or correlated factors determining the probability of receiving a subsidy and the level of R&D expenditure.* [The assumption] *is overly strong and is bound to fail in the data"* (Lach 2000:18).

3.3.1.2 The Simple Difference Estimator Conditional on Covariates

Accounting for the differences in private R&D expenditure by using all firm characteristics (x is a vector of covariates) extends the model to

$$E\left(y_{it}^0 \middle| x, D_{it} = 1, D_{it-1} = 0\right) = E\left(y_{it}^0 \middle| x, D_{it} = 0, D_{it-1} = 0\right) \tag{3}$$

where the inclusion of x leaves the question whether a firm is selected in the subsidy program or not independent of y_{it}^{0}. An OLS regression of the form

$$y_{it} = x_{it}'\beta + D_{it}\alpha + \varepsilon_{it} \tag{4}$$

makes the estimation of α possible.

Lach (2000) includes industry affiliation, employment size and sales as firm characteristics to correct for the possible bias in receiving public funding. His results, using the firm characteristics, get more precise but are still insignificantly different from zero. It is very likely that not all firm characteristics can be captured since it is almost impossible to know all factors correlated with the probability of receiving an R&D subsidy.

3.3.1.3 Difference in Differences (DID) estimator

Further, Lach (2000) suggest using a Difference in Differences (DID) estimator to overcome the above-quoted problem. The error term ε_{it} of equation (4) is, due to the potential correlation, decomposed into a firm-specific (θ_i) and a time-specific (λ_t) effect. That leaves η_{it} in equation (5) as an i.i.d. zero mean error term.

$$y_{it} = x_{it}'\beta + D_{it}\alpha + \theta_i + \lambda_t + \eta_{it} \tag{5}$$

Again consider only firms without subsidy in t-1 and taking the first differences results in,

$$\Delta y_{it} = \Delta x_{it}'\beta + D_{it}\alpha + \Delta\lambda_t + \Delta\eta_{it} \tag{6}$$

The model now allows for “firm specific unobserved effects and economy wide shocks to affect both the level of company-financed R&D expenditures and the support status of the firm.” (Lach 2000:21)

The Difference-in-Differences (DID) estimator with covariates in equation (7) may overcome the problem that the characteristics of a subsidy-receiving firm might be correlated with the firm’s changing R&D expenditure. Lach (2000) proceeded with explaining that the DID estimator accounts for common observed covariates and permanent differences between applicants, but cannot explain factors which affects both the level of R&D expenditure and the probability of receiving a subsidy simultaneously.

$$\hat{\alpha}^{DID} = \left(\bar{y}_t^{01}(x_t) - \bar{y}_{t-1}^{01}(x_{t-1})\right) - \left(\bar{y}_t^{00}(x_t) - \bar{y}_{t-1}^{00}(x_{t-1})\right) \tag{7}$$

To improve the precision of the estimator (the samples are otherwise getting too small) Lach pooled the data over the 5 years using only observations for which $D_{it-1} = 0$. He also accounts for the fact that subsidies are usually given to firms over a period longer than one year and hence one lag of D_{it} is added to the model. The results are presented in Table 3.4.

Table 3.4: Pooled DID Estimates of a, 1990-95, Equation (5)

Variable	Coefficient
$D_t = 1$	-0.299 ** (.168)
$D_{t-1} = 1$	0.378 * (.190)
Employment	-0.108 (.239)
Sales	0.285 (.208)
Within R^2	0.087
N (firms)	214 (103)

*Standard errors in parentheses. Year dummies included. */** indicates different from 0 at 5% /10% significance level. Firms only used with $D_{it-2} = 0$.*

Source: Lach (2000:24)

Public subsidies crowd out private expenditure by almost 30% but this effect is reversed if the firm is subsidized more than one year. A complementary effect of 38% percent is measured in the follow up year, which leaves a net complementary effect of only 8% (standard deviation of 75 percent). The parameters are still not significantly different from zero, thus Lach pursued with the development of the model framework.

3.3.1.4 Dynamics and the Effect of the Subsidy Level

Lach pursued his work by extending equation (5) using *q* lags of the log of the amount of subsidies (s_{it}). To capture the dynamic effects the subsidy level replaces the binary variable D. The author argues that a dynamic framework takes account of the effects on R&D expenditure, especially if a time lag in the impacts is observable.

$$y_{it} = x'_{it}\beta + \sum_{\tau=0}^{q} \alpha_\tau s_{it-\tau} + \theta_i + \lambda_t + \eta_{it} \qquad (8)$$

Table 3.5 presents the results for a GMM estimation with a lag of one period. The OLS coefficient of s_{t-1} is small but statistically significant. Factoring out the firm-specific effects using a within estimator leads to a smaller coefficient. Still, we can conclude that there is a small but significant positive effect on the lagged subsidy level.

"Although significantly positive, the subsidy effect is substantially lower what could havebeen expected a-priori given the dollar-by-dollar matching upon which most subsidies are based. The reasons for this "less than full" effect lie in that the subsidies are sometimes granted to projects that would have been undertaken even without the subsidy, and in that firms adjust their portfolio of R&D projects–closing or slowing down non-subsidized projects–after the subsidy is received." (Lach [2000:31])

Table 3.5: Estimates of the subsidy level effect, (q=1)

Coefficient of	OLS	Within	First Δ	First Δ
y_{t-1} (ρ_1)	0.779* (.035)	0.082 (.050)	-0.029 (.140)	-0.003 (.123)
s_t (δ_0)	-0.006 (.017)	-0.024 (.021)	-0.080 (.064)	-0.119** (.063)
s_{t-1} (δ_1)	0.054* (.016)	0.044* (.016)	-0.089 (.057)	-0.061 (.051)
Employment	0.139* (.053)	0.233** (.141)	0.202 (.321)	0.243 (.297)
Sales	0.053 (.044)	0.130* (.052)	-0.222 (.140)	-0.181 (.131)
m_1	-2.87	-3.96	-0.96	-1.29
m_2	0.75	-0.26	-0.75	-0.52
Instruments	–	–	A	B
Sargan test	–	–	0.80 (35)	0.91 (45)
N (firms)	766 (221)	545 (193)	545 (193)	545 (193)
Years	1991-1995	1992-1995	1992-1995	1992-1995

Industry and year dummies included. Asymptotic robust standard errors in parentheses.

Source: Lach (2000:28)

3.3.2 German service firms: Czarnitzki and Fier (2001)

Czarnitzki and Fier (2001) analyze whether public research funding sustainably enforce the innovative activity of German service firms. In addition they ask if future access to public R&D funding schemes is affected by current participation in a public R&D program. The used data set contains a sample of 2,541 observations of the German service sector, from which 137 are associated with an R&D subsidy. To keep with the international standards the authors use the definition of innovation expenditure of the OSLO-manual.

Innovation intensity (*InnoInt*) on the firm level is defined as the ratio of innovation expenditure and sales, whereas public funding intensity (*PFInt*) is the ratio of the sum of public subsidies over the past five years divided by the sales. The lags are included to account for the length of research projects. Hence subtracting public R&D funding intensity from innovation intensity composes a net innovation intensity indicator (*NetInnoInt*). The authors use this indicator to measure the correlation of past public R&D subsidies to current private R&D expenditure. In the case of a positive correlation past public R&D subsidies would have a positive impact on current private R&D spending. Czarnitzki and Fier (2001) estimate an OLS-model by regressing net innovation intensity on public funding intensity and several control variables

$$\begin{aligned} NetInnoInt_{it} &= \alpha_i + \beta_1 PFInt_{it} + \beta_2 EMP_{it} + \beta_3 EMP_{it}^{\;2} + \beta_4 EAST_i + \beta_5 AGE_i^{\;-1} \\ &\quad + \beta_6 EX_{it} + \beta_7 DIV_{it} + \beta_8 GRFF_{it} + IndustrieDummies + \varepsilon_{it} \end{aligned} \tag{9}$$

where EMP = Employment, $EAST$ = Dummy for firm location in Eastern Germany, AGE = Firm age, EX = Export to sales ratio, $GRFF$ = Sectoral dynamics indicator, DIV = Firm diversification index

Table 3.6: OLS regression on public funding intensity

	Dependent variable:	
Exogenous variables:	NetInnoInt	NetInnoInt
PFInt	1.37 ** (2.08)	
PFInt (lagged)		1.26 ** (2.00)
1/AGE	15.05 *** (3.53)	15.03 *** (3.52)
GRFF	9.37 *** (2.92)	9.48 *** (2.94)
Joint significance of EMP and EMP^2	13.46 ***	13.49 ***

*t-values are shown in parentheses, significance levels: ***/**/*=1/5/10%,*
estimation as in equation (9), coefficients only shown if statistical significant.

Source: Czarnitzki and Fier (2001:10)

Table 3.6 shows the results of the OLS regression. The public funding intensity coefficient is significant at the 5% level, whereas the degree of competition, measured by the sectoral dynamics, as well as the firm age coefficient are significant at the 1% level. Putting the numbers in words would lead to the following key results:

- They find that one unit of public R&D subsidies leads to an increase in private R&D funding of 1.37 units in the following time period.
- Conducting the regression with a time lag of one year on public funding intensity shows the effect over time. If the subsidy was granted a year ago the leverage factor decreases to 1.26.
- An increasing competition leads to an increase in private R&D spending.
- Younger firms are more innovative than old firms. *"We confirm this hypothesis of innovative start-ups in the service sector"* (Czarnitzki and Fier [2001:9]).
- The two employment variables are insignificant individually, but jointly significant at the 1% level. *"Large companies invest relatively less in innovative activity than smaller ones"* (Czarnitzki and Fier [2001:9]).
- All other firm specific variables have no statistically significant effect on innovation intensity.

3.3.3 US-Sematech funded high-tech firms: Irwin and Klenow (1995)

In 1987 the US government initiated Sematech with the primary goal to improve the US semiconductor production technology. The consortium was founded by 14 high-technology firms and they received annually ARPA funding of up to $100 million in matching funds since 1997.

Irwin and Klenow (1996) used annual firm-level data for the period 1970-93 to evaluate the US research consortium Sematech. They compared the research effort of Sematech members with non-member firms controlling for firm fixed effects, time effects, firm age effects, and past R&D intensity.

$$\left(R\ \&\ D/Sales\right)_{it} = \beta_1 Sematech + \beta_2 \left(R\ \&\ D/Sales\right)_{it-1} + Dummies + \varepsilon_{it} \qquad (10)$$

They present results for two time periods (1970-1993, 1980-1993) with OLS and WLS estimates. The chosen weights for the WLS estimation were firm-year assets. Sematech is a dummy variable for participation in the project, all other dummies are mentioned above. The estimated coefficients are given in Table 3.7.

Table 3.7: Sematech membership and R&D expenditure

Exogenous variables:	Dependent variable: R&D/Sales			
	OLS (1970-93)	WLS (1970-93)	OLS (1980-93)	WLS (1980-93)
Sematech	-1.30 (0.49)	-1.02 (0.33)	-1.83 (0.60)	-1.84 (0.49)
Lagged R&D/Sales	0.43 (0.06)	0.57 (0.05)	0.20 (0.07)	0.34 (0.06)
Age≤2	7.0 (2.4)	3.6 (2.4)	5.3 (1.2)	2.8 (2.2)
3≤Age≤5	9.8 (2.3)	5.8 (1.9)	7.8 (1.4)	6.1 (1.4)
Age≥6	10.5 (2.2)	6.5 (1.9)	8.6 (1.4)	6.3 (1.2)
Unweighted R^2	0.78	0.75	0.77	0.75

Standard errors in parantheses, results in percentage terms, firm and year effects included

Source: Irwin and Klenow (1996:334)

As the results are given in percentage terms the interpretation is straightforward. Sematech member firms' R&D intensity decreased by 1.3 and 1.0 percentage points for the period 1970-93 and by 1.8 percentage points for the shorter period 1980-93. In terms of overall private R&D spending 9Irwin and Klenow (1996) estimated a reduction of $300 million per year amongst Sematech members.

Klette et al. (2000) point out that the validity of the control group is rather problematic:

> *"Comparing the list of Sematech member firms to the non-member US firms, it is clear that the Sematech-members are the leading US manufacturers in the electronic components industry, and this was true also when Sematech started." (Klette et al. [2000:74]).*

Beside the well know sample selection bias another drawback was pointed out. The public subsidy program Sematech, designed for a small number of high-technology firms, may have increased or decreased the R&D effort of competitors which were non-members. Comparing therefore the relative R&D spending of members and non-members can lead to bias results.

3.3.4 The problem of the counter factual: Klette et. al (2000)

Klette et al. (2000) did not estimate an econometric R&D-model, but rather approached the problem from a theoretical point of view. Many economists have identified a potential selection bias and the problem of the counterfactual but eventually only few have incorporated these problems in their models. Hence, we think it is very important to present the work of Klette et al. (2000) in a detailed form. The performance of a firm i in period t is represented by

$$Y_{i,t} = \alpha_i + \lambda_t + \beta_i D_i + u_{i,t} \tag{11}$$

where D_i is a dummy variable (one if firm received R&D funding, zero otherwise), α_i a firm fixed effect, λ_t are shocks common across firms, and u_{it} temporary fluctuations in unobservables.

The difference-in-differences estimator, given that firm-level data exist for the ex-ante and ex-post case, enables us to measure the average impact of R&D funding on the firm.

$$\hat{\beta}_{did} = \left(\overline{Y}_{t_1}^{s} - \overline{Y}_{t_0}^{s}\right) - \left(\overline{Y}_{t_1}^{n} - \overline{Y}_{t_0}^{n}\right) = \Delta\overline{Y}^{s} - \Delta\overline{Y}^{n} \tag{12}$$

The estimator is the difference between the average change of the firm performance in the supported and the non-supported case. If we take the assumption that D_i and u_{it} are uncorrelated we get

$$p\lim_{n\to\infty} \hat{\beta}_{did} = E\left(\beta_i \middle| D_i = 1\right) \equiv \beta^S \tag{13}$$

which is the mean impact of the treatment on the treated. As many economists have argued there remains the problem of a correlation between the shocks u_{it} and the probability of being selected in a subsidy program. Klette et al. proceed suggesting to implement variables, which correct the DID-estimator for the pre-program performance as well as variable to control for anticipated temporary shocks that influence the probability of being selected in a subsidy program.

In addition, Klette et al. suggest taking account of spillover effects from subsidized to non-subsidized firms. It is very unlikely that the performance of the non-subsidized firms is independent of the public R&D programs, particularly as most programs are designed to generate maximum spill over effects. To describe the situation best Klette et al. refer to the Catch-22[4] problem: *“If the program is successful in creating innovations that spill over to technologically related firms, it will be very difficult to find similar non-supported firms that can identify the counter factual outcome for the supported firms.”* (Klette et al. [2000:481])

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[4] Catch-22:

“In Joseph Heller's novel Catch 22, published in 1961, the catch in question was that airmen could be excused from flying missions only if they were of unsound mind, but a request to be excused from flying missions was a sign of a concern for personal safety in the face of danger and therefore evidence of a rational mind, so it was impossible to escape flying missions. A catch-22 situation is any such circular dilemma or predicament from which there is no escape, and is often extended to any situation or problem where the victim feels that it is impossible to gain a personal benefit or make the right decision.”

Source: Bloomsbury Good Word Guide, Bloomsbury 1997

Since we are trying to evaluate post-program performance or research intensity of firms who have been subsidized to overcome the problem of the counter factual by matching firms with the same 'fundamentals' the problem gets even worse. Klette et al. indicate that *"[...] the better a firm seems to satisfy the conditions required to identify the counter factual outcome in the absence of spillovers, the worse might this spillover problem be."* (Klette et al. [2000:482])

To conclude, the authors stress that even if an evaluation study finds little difference between subsidized and non-subsidized firms either be because the public R&D program was unsuccessful, or because it was successful in generating very high spillover effects to the non-subsidized firms.

3.3.5 US-SBIR funded technology-intensive firms: Wallsten (2000)

The Small Business Innovation Research (SBIR) program consists of three phases to which firms can apply. Phase one awards a maximum of $100,000 and only if the firm wins this award it can apply for phase 2 with a maximum subsidy of $750,000. In phase 3 the resulting product should be commercialised and no funding is distributed. Wallsten (2000) assembled a data set with firms who received awards (367 firms), firms who were rejected (90 firms) and firms who didn't apply but were eligible (22 firms). The selected industry was a group of small technology intensive companies. The observation period was from 1990 to 1993. Due to data restraints, the author observed only short- and medium term effects.

Wallsten (2000) points out the importance of controlling for endogeneity of awards. The standard OLS regression shows a significant correlation between e.g. employment and receiving an award. His solution provided is to simultaneously estimate a system of equations using the instrument variable approach. As the instrument variable, Wallsten used the SBIR total budget. Besides the results on the effects of SBIR funding on firm performance, he also estimated the relationship between firm-financed R&D and public financed R&D. The results are shown in Table 3.8.

Table 3.8: 3-SLS Estimates: Effect of SBIR-$ on firm-financed R&D spending

Dependent variable	Total $-value of SBIR awards	R&D spending in 1992
Constant	69,432 (0.23)	2,733,110 (2.02)
Total $-value of SBIR awards		-0.82 (2.31)
SBIR budget instrument	2.96 (11.58)	
Age	-12.78 (1.58)	
$Employment_{1991}$	736.70 (0.37)	-2,195.79 (0.25)
$Patents_{1988-1989}$	111,128 (2.00)	381,841 (1.62)
R&D $spending_{1990}$	-0.14 (3.25)	1.01 (4.90)
Never applied		-1,806,970 (2.38)
R^2 (81 observations)	0.80	0.71

Absolute t-statistics in parentheses

Source: Wallsten (2000:98)

The private R&D spending coefficient of the three-stage least-square estimation, with the total dollar value of SBIR awards as endogenous variable, is estimated at -0.82. This can be interpreted as a decrease of 0.82 units in private R&D spending for each unit of public R&D subsidy. Wallstein (2000) points out how important it is to control for endogeneity and to use an instrument variable approach.

> *"One interpretation of the empirical results is that the awards have no impact on firm R&D activities. They simply crowd out firm-financed R&D expenditures […]. This is not the only interpretation, however. Another possibility is that while the grants did not allow firms to increase R&D activity, they instead allowed firms to continue their R&D at a constant rate rather than cutting back. That is, while the grants may not have funded additional projects, they may have allowed firms to avoid eliminating ongoing projects." (Wallsten [2000:98])*

One last caveat: It may be possible that the effect of SBIR awards could materialize in the future, which, due to data constraint, can not be explored.

3.3.6 Effects of R&D Subsidies in Spain: Busom (1999)

Busom (1999) analyzes firm data of 154 Spanish firms conducting R&D activities in 1988. Almost half of the firms in the sample received public subsidies by the Spanish authorities. The selected firms were then asked a set of questions to complement the data of the Spanish Ministry of Industry. Table 3.9 shows the definitions of the binary and continuous variables for the forthcoming regression analysis.

Busom (1999) then constructs a framework to measure the leverage effects of public subsidies in Spain. First a firm has to decide whether to apply for a subsidy or not, second the public agency decides whether to grant the subsidy or not. These "demand and supply functions" are shown in equation (13) and (14). Equation (15) and (16) describe the effort decision of the firm, dependent on the participation status.

Busom's Analytical Framework:

Variables in capital letters are vectors of explanatory variables. Those in lower case letters are error terms with possible unobservable characteristics of the firm. A^* represents the expected profitability of an R&D subsidy, G^* is the variable of the funding decision of the public agency. $y_{1,2}$ is the R&D effort measured in R&D investment or R&D personnel, which is observed both for participating or non-participating firms. A^* and G^* are unobservable for the researcher.

$$A^* = f_a(Z, u), \qquad (14)$$

where the explanatory variables for the probability of applying are defined as firm size, capital ownership, importance given to R&D in the short run, pricing strategy, share of exports in total sales, R&D process indicators, and industry dummies.

Table 3.9: Definitions of the variables constructed from the survey

Binary Variables	*Definition*
Subsidies	
Cdti	=1 if a firm received a subsidy from CDTI; 0 otherwise.
European	=1 if a firm was a partner in EUREKA or any EC R&D program.
Ownership	
Public	=1 if firm was partly publicly owned
Foreign	=1 if firm was participated by foreign capital
Strategic Variables	
Price	=1 if firm declared to set prices and then adjust production to sales
Quantity	=1 if firm declared to make production plans and then adjust prices
Regulated	=1 if firm declared prices to be regulated
Other	=1 if none of the above
Monopoly	=1 if firm declared behaving as such
Frival	=1 if firm declared it would increase own R&D in response to a rival's
Shortrun	=1 if firm declared R&D to be important in the short run
R&D Process	
Ideariv	=1 if firm looked into competitor's products for ideas for own R&D
Ideapt	=1 if firm used own patents as sources of ideas
Ideaext	=1 if firm declared scientific and technical publications to be important
Cooperate	=1 if firm cooperated with others in R&D activities
Basic	=1 if firm does basic or applied research
Development	=1 if firm does development
Process	=1 if R&D activities are oriented towards process innovation
Product	=1 if R&D activities are oriented towards product innovation
Industry	
Dchemical	=1 if firm is in chemical or pharmaceutical industry
Detronics	=1 if firm is in electrical o electronics industry
Dequipmt	=1 if firm is in machinery or transportation equipment industry
Denergy	=1 if firm is in the energy sector
Dtraditional	=1 if firm is in textile, food, metal industries
Dservices	=1 if firm provides services to other industries
DotherI	=1 if firm is in other industries
Continuous Variables	
Patents	Number of patents obtained by firm during the previous 10 years
R&D expenditure	Total R&D expenditure in 1987, in Million pesetas
R&D personnel	Number of employees involved in R&D activities
Age	Number of years since firm was created
Employment	Total number of employees
Exportshare	Exports/total Sales

Source: Busom (1999:12)

$$G^* = f_g(W, v), \quad (15)$$

where the explanatory variables for a selection criterion are defined as number of patents, age of the firm, firm size, presence of public of foreign capital, and industry dummies.

$$y_1^* = h_1(X_1, w_1) \quad (16)$$

$$y_0^* = h_2(X_0, w_0) \quad (17)$$

where the explanatory variables for the effort decision are defined as total employment, strategy and ownership indicators, share of export over total sales, and industry dummies.

Additionally the participation in the program can be observed:

$$I = g(Z, W, u, v) \text{ where } I = 1 \text{ if } A^* > 0 \text{ and } G^* > 0 \text{ and } I = 0 \text{ otherwise.} \quad (18)$$

In a first step, Busom (1999) estimates a discrete choice model of participation solved with a simple univariate probit regression.

Table 3.10 shows the results for a model with all explanatory variables (Model 1), with only statistically significant explanatory variables (Model 2), and with an additional variable of the short run importance of R&D whilst industry dummies were dropped (Model 3). Columns 4 and 6 show the marginal effect of each variable on the probability of being a participant.

Busom's (1999) models 3 and 4 correctly predict 80% of participants and 70% of non-participants. The author found only six factors, which had a significant effect on the probability of having a public subsidy. The positive effects found to be public participation in the ownership, being in the chemical or pharmaceutical sector, age of the firm, and number of previous patents. Large firms size and foreign capital decrease the probability of having a subsidy.

In a next step Busom (1999) asks two questions:

- *"does participation induce a higher R&D effort than would have been made otherwise?"*
- *"does participation make the firm's choice of R&D effort less conditioned by factors such as firm size?" (Busom [1999:21])*

Table 3.10: Probability of the participation in the national R&D subsidy program

	Model 1	Model 2	Marginal Effects	Model 3	Marginal Effects
Constant	-0.61 (-1.2)	-0.39 (-0.9)		-0.67 (-1.4)	
Employment	-0.29 (-3.2)	-0.30 (-3.3)	-0.12	-0.30 (-3.3)	-0.12
Age	0.52 (2.7)	0.54 (2.9)	0.21	0.57 (3.1)	0.23
Exportsh	-0.01 (-0.1)				
Patents	0.44 (3.7)	0.46 (4.0)	0.18	0.45 (3.9)	0.18
Public	0.64 (1.7)	0.55 (1.5)	0.22	0.67 (1.8)	0.27
Foreign	-0.91 (-2.9)	-0.76 (-2.7)	-0.30	-0.79 (-2.8)	-0.32
Price	0.31 (1.1)				
Regul	-0.10 (-0.2)				
FRival	0.26 (0.3)				
Dchemical	0.50 (1.4)	0.50 (1.6)	0.20		
Detronics	0.51 (1.5)	0.51 (1.5)	0.20		
Dequipment	-0.09 (-0.4)				
Denergy	0.24 (0.4)				
Shortrun				0.54 (2.0)	0.22
LogLikelihood	-75.5	-76.9		-76.9	
Restricted L	-101.8	-101.8		-101.8	
X^2	52.5	49.6		49.7	
Pseudo R^2	0.26	0.24		0.24	
N	147	147		147	

t-values are shown in parentheses

Quelle: Busom (1999:31)

As dependent variables R&D expenditure, R&D expenditure per employee, R&D personnel, and R&D personnel per employee are selected to measure firm's R&D effort. R&D expenditure includes the subsidy itself, but information about the subsidy is limited to the binary variable (either subsidy received or not received). Busom (1999) estimates each of the four equations by four different econometric methods:

1. An OLS regression for the whole sample, assuming the group of participants and non-participants can be described by the same coefficients and no subsidy selection/participation bias exists,
2. An OLS regression with a split sample, which allows different coefficients for the two groups but exogeneity of selection/participation is still assumed,
3. A Heckman two step procedure, to correct for the subsidy selection/participation bias, and a
4. Maximum likelihood estimation.

Table 3.11 shows the results for the four procedures where R&D expenditure is used as dependent variable, omitting other measures of R&D effort (see above) because the results vary only slightly (cf. Busom 1999).

Table 3.11: Estimation results for absolute R&D expenditure

	Ordinary Least Squares			Sample Selection		Maximum Likelihood	
	Participants	Non-Participants	All	Participants	Non-Participants	Participants	Non-Participants
Constant	0.69 (0.43)	0.04 (0.64)	-0.18 (0.39)	0.70 (0.47)	-0.11 (0.84)	0.95 (0.57)	-0.39 (1.03)
European	-0.17 (0.30)	-0.17 (0.42)	-0.14 (0.25)	-0.17 (0.26)	-0.18 (0.38)	-0.20 (0.40)	-0.22 (0.51)
Employmt	0.62** (0.07)	0.53** (0.10)	0.61** (0.06)	0.62** (0.07)	0.54** (0.09)	0.65** (0.08)	0.56** (0.10)
Exportsh	-0.02* (0.006)	0.01 (0.009)	-0.003 (0.005)	-0.02** (0.005)	0.01 (0.008)	-0.02** (0.006)	0.01 (0.009)
Patent	0.22** (0.08)	0.26 (0.20)	0.20** (0.08)	0.22* (0.12)	0.22 (0.26)	0.13 (0.14)	0.13 (0.33)
Public	0.03 (0.28)	0.70 (0.50)	0.27 (0.27)	0.03 (0.25)	0.66 (0.46)	-0.03 (0.35)	0.63 (0.65)
Foreign	0.38 (0.30)	0.06 (0.38)	0.03 (0.24)	0.39 (0.33)	0.13 (0.43)	0.56 (0.41)	0.25 (0.52)
Quantity	-0.37 (0.25)	-0.20 (0.37)	-0.30 (0.22)	-0.37* (0.22)	-0.18 (0.34)	-0.38 (0.27)	-0.11 (0.49)
Frival	0.22 (0.24)	-0.12 (0.39)	0.12 (0.22)	0.22 (0.22)	-0.17 (0.40)	0.13 (0.26)	-0.27 (0.49)
IdeaRiv	-0.02 (0.22)	-0.21 (0.34)	-0.11 (0.22)	-0.02 (0.20)	-0.21 (0.30)	-0.04 (0.25)	-0.18 (0.41)
Dchemical	0.41 (0.30)	0.86* (0.46)	0.71** (0.28)	0.41 (0.23)	0.85** (0.41)	0.37 (0.30)	0.88 (0.57)
Detronics	0.45 (0.33)	1.85** (0.47)	1.17** (0.29)	0.45 (0.30)	1.84** (0.42)	0.47 (0.30)	1.82** (0.49)
Dequipmt	0.89** (0.42)	0.61 (0.54)	0.74** (0.35)	0.89** (0.37)	0.58 (0.49)	0.86 (0.71)	0.55 (0.51)
Denergy	0.10 (0.40)	0.83 (0.64)	0.62** (0.36)	0.11 (0.35)	0.83 (0.53)	0.13 (0.42)	0.89 (0.84)
Dservice	1.74* (0.47)	0.47 (0.55)	0.90** (0.37)	1.74** (0.42)	0.46 (0.50)	1.79** (0.47)	0.49 (0.59)
Lambdab				-0.01 (0.43)	-0.19 (0.79)		
CDTI			0.61** (0.22)				
R^2 Adjust	0.80	0.49	0.61	0.79	0.48		
Log Likel.						-265.8	
N	70	73	143	70	73	143	

Standard errors are shown in parentheses, significance levels: ***/**/*=1/5/10%, Lambda is the inverse of the Mill's ratio, the term included to correct for selection. Its coefficient is $b_{lambda} = \sigma_i \rho_i$. Testing for b_{lambda}=0 is equivalent to testing for selection.

Quelle: Busom (1999:32)

Using a chow test to test for equality of slopes between the group of participants and non-participants leads to a rejection according to Busom (1999). The OLS regression for the full sample shows similar results as Heckman's two step procedure. A firm's R&D expenditure, given that the firm does not receive public subsidies, is positively explained by firm size and by either being in the chemical/pharmaceutical or electrical/electronic industry. All other variables have no significant effect on the level of R&D expenditure. For the group of participants positive effects on R&D expenditure are being in the equipment/service industry, having a history of patenting, and an orientation to the domestic markets.

In the last part of her paper Busom (1999) test the presence of crowding out effects of public R&D subsidies. A counterfactual for subsidized firms is constructed by using the estimated effort of non-particpants. The results for individual firms can be summarized as follows:

- 29 firms would have spend at least as much as in the case of no subsidy
- 41 firms spend more than they would have without the subsidy

One caveat remains. Due to the fact that the level of the subsidy is unknown a more exact estimate of crowding out or complementary effects of public subsidies can not be made.

3.4 Conclusions

The survey on contemporary analytical firm-level studies outlined the currently available microeconometric methods of measuring leverage effects of public R&D funding. A comparison of recent company-level studies indicates the difficulties of measuring leverage effects, as the results are inconclusive: roughly half of the studies indicate complemenarity and substitution between public and private funding respectively. It has to be noted, though, that these studies employ different methods and look at different sets of data at different periods of time, and thus are not strictly comparable. In addition, especially the earlier ones use relatively simple methods. In the light of this experience, it pays to look for further methodological advances in micro-econometric evaluation techniques.

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4 Corporate Finance and R&D - Theoretical Considerations and Empirical Results: A Survey

4.1 Introduction

There is a broad consensus among economists that innovations are a main source of economic growth and structural change. One of the upcoming questions tackles the relations between the allocation of resources for innovations and the outcome of the innovation process, the funding of R&D activities and the innovative outcomes. A long lasting discussion in literature, starting e.g. with Schumpeter (1912), deals with this topic and the difficulties given in financing R&D activities in freely competitive markets.

Recently undertaken empirical explorations have drawn a picture, which shows quite different patterns of funding across countries, especially in respect to shares of public or business funds for R&D activities. There is in fact rapidly growing business funded R&D and the stagnation of government financing of R&D in OECD countries (Chesbrough 2001). A recently published report also shows (OECD 2001a) that there has been a sharp increase of R&D conducted and funded by business sector. Indeed this pattern of R&D funding differs sharply between the three main regions (Europe, Japan, US). While in all regions the business funding of R&D is becoming more important, measured in terms of shares of total R&D financing, in Europe the level is lowest (55%).

From these changing patterns of the innovation process the relationship between corporate finance and R&D investments becomes more importance and should be analysed in more detail. This survey is an attempt to review the primarily theoretical considerations and to give an overview of empirical evidence on questions like: What are determinants of financing R&D on firm-level? What are the relationships between corporate finance and R&D investments? In this respect theoretical and empirical work point to some constraints in financing R&D activities on firm level, which leads to cut backs in growth because of underinvestment in R&D from the social planners point of view and constitutes the application of technology policy tools.

This paper will address questions and problems of financing R&D investments on firm-level. After some theoretical considerations about the relationships of corporate finance and R&D investments in the first part of the paper, the second part will give an overview of some econometric evidence on these relations. Some short conclusions will finish the paper.

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4.2 Theoretical Considerations

The review here will be based on the firms context. Firstly, R&D activities are interpreted as a special type of investment which incorporates problems in project evaluation and appropriation of returns on investment and hence reductions of R&D. Secondly, the corporate finance of R&D projects is analysed. Mentionable are information problems in this context as much as cost of capital arguments and capitalstructure considerations. From this theoretical thoughts a policy oriented (pragmatic) classification scheme for looking at empirical evidence is derived. The background of the reviewed literature is mainly based on "mainstream" equilibrium approaches rather than on "neo-schumpeterian" ones, also having in mind the consequential problems.

Firms have to allocate financial resources for investments which generate highest returns: *"The price of the company`s shares at any time is determined by the perception of the market about the size and riskiness of the return which they will produce as investments."* (Budworth 1996, p. 15) R&D expenditures can be considered as a special form of investment to build knowledge capital, and literature lists a number of reasons why investments in physical equipment and investment in knowledge capital building have to be treated separately. All these arguments are known since the seminal papers of Arrow (1962) and Nelson (1959). The typical characterisation is given by the following features:

1. The process of R&D incorporates high risks and types of uncertainty which means that for R&D projects costs and benefits cannot be estimated exactly. The valuation process for decision making is becoming even more complex if one think of the different methods for valuation. The calculated values are "method-sensitive" (e.g. NPV vs. IRR or valuing R&D projects as "real options" - which can also incorporate strategic expectations) and therefore financing R&D will have difficulties and constraints.

2. The output of R&D activities, typically a form of knowledge, has characteristics of a "public good". This means that other firms cannot be excluded from use as far as knowledge cannot be kept secret, and that the produced knowledge is nonrival, which means that use by one firm does not exclude any other one from use. Although having made some modifications to this perception due to survey evidence, which measured substantial costs for imitation (Mansfield et al. 1981), the reduced incentives to undertake R&D investments still holds.

3. Furthermore the knowledge typically produces externalities which cannot be appropriated by the investing firm (Griliches 1992). This means that social returns to R&D investments are higher than private levels and again produce an underinvestment effect.

Up to this point investors and financiers are treated as one entity. But these arguments do not take into account the already in Schumpeters` (1912, 1942) as well as in Arrows` (1962) work addressed problem: the gap of private rate of return and the cost of capital when the investor and financier are different entities. Hence the typical empirical observation arises:

> *"Even the lower levels of uncertainty ... are such that only a very small proportion of R&D is financed directly by the capital market."* (Freemann and Soete 1997, p. 244)

The central focus therefore have to include considerations about financial market conditions in relation to the speciality of R&D investment. One can *distinguish "... between those factors that arise from various kinds of market failures ... and the purely financial considerations that affect the cost of different sources of funds."* (Hall 2002, p. 6)

In case of R&D investment following reasons are covering these areas of difficulties and the derived ordering of internal and external finance (Goodacre and Tonks 1995):

1. Asymmetric information problems on financial markets

   This problem is twofold: first, managers have pay-off relevant information which is not known by financiers ("hidden information"), therefore an adverse selection phenomenon is resulting based on the fact of a pooled interest rate as the sole observable one. Consequently, R&D investments are reduced.

   Second, financiers cannot observe managers actions. From that follows a moral hazard effect which let managers decide not in consistency with the shareholder. Manager tend to spend for activities that benefit them and have high risk averse behaviour. In combination with limits for leveraging (increasing debt) R&D is therefore heavily constrained.

   Both processes produce credit rationing for firms undertaking R&D, which on the other hand fosters the strategically use of management instruments to overcome the information problem ("signalling").

2. Cost of capital

   Typically an investment is sensitive to the calculation of the discount rate, which should show the opportunity costs of capital. For standard projects the opportunity costs are usually derived from a capital asset pricing model and include a riskfree discount rate and a risk premium. In case of R&D discount rate will be highly speculative. This requires a high risk premium for capital which results in a credit rationing effect.

3. Capital structure

   The Modigliani-Miller theorem (1958) would imply the irrelevance of capital structure for financing R&D. The external finance can be new equity and new debt. From the investors point of view the difference between them is that the income stream of equity is more risky. Therefore the expected return on holding equity will be higher than that of debt. Hence debt is a cheaper source of finance than equity for the firm. So several reasons are shown why the theorem fails in practice. In the context of R&D the following arguments are relevant:

- possible bankruptcy or liquidation costs (in case of bankruptcy there may be no possibility to get a fair price for R&D assets, because of their specificity);
- asymmetric information, agency costs (agency costs mean, that managers invest in projects others than owners would) and signalling (managers will use capitalstructure - e.g. high debt - as a signalling instrument for high quality).

From these strangs of considerations the most critical factor is information. Therefore R&D also can be used for "strategic" communication between firms (management) and financial market (lenders and shareholders).

As result emerges a form of "pecking order" which means that firms try to finance firstly with internal funds (cash flow, retention and accumulation of profits) and then external funds by preferring debt to equity. This produces rationing effects for R&D investments and a high preference for internal funds.

Beside this reflections another line of arguments can be developed along the growth path of firms, from very small and new ones to large and mature ones (Berger and Udell 1998). Depending on age and size, firms have different property status and collaterals for borrowing as much as track records for showing experience and competence. Both build limits to credit availability and foster instruments like angel financing and venture capital. But these strand of studies, which deal with start-up and venture capital are not discussed here. The focus here is on established firms and their relationships between R&D investments and corporate finance.

For the chosen focus one can summarise the arguments for financing R&D investments and derive a classification scheme for a more "pragmatic" look on empirical evidence as follows:

1. R&D is heavily depending on internal sources of funding which requires research for R&D and internal finance;
2. R&D claims for risk-carrying funding which means equity is preferred to debt, what requires a closer look for the relationship between R&D and external finance;
3. For the information problems communication structures and therefore R&D and ownership structure is relevant;
4. Further on, in case of strategic behaviour R&D as signal for financial markets and the consequences for R&D have to be looked at.

4.3 Empirical evidence

What does the empirical evidence for financing R&D show? Starting with this question the paper will proceed by presenting results of empirical studies, focusing on econometric results. In particular, having the theoretical considerations as a guideline, four categories of studies are built, depending on their main results: (1) Studies dealing with the relation between R&D and internal finance; (2) studies dealing with R&D and external finance; (3) studies dealing with R&D and the ownership structures and (4) studies dealing with R&D used as strategic signalling.

Table 4.1: R&D and internal finance

Author(s)	Main results	Sample
Hall (1992)	R&D pos. correlated to Cash-flow R&D neg. correlated to debt	Sample of US manufacturing firms (appr. 1500, 1973-1987)
Himmelberg, Petersen (1994)	R&D pos. correlated to Cash-flow	Sample of small US firms (179, 1983-1987)
Harhoff (1998)	R&D pos. correlated to Cash-flow	Sample of manufacturing firms from Germany (appr. 200, 1987-1994)
Bond, Harhoff, VanReenen (1999)	UK: R&D performing firms have less impact of Cash-flow on investment than non-R&D firms, but R&D is pos. correlated to Cash-flow Germany: Cash-flow insignificant	Sample of manufacturing firms from UK and Germany (appr. 200 per country, 1987-1994)
Hall, Mairesse, Branstetter, Crepon (1999)	R&D is more sensitive to Cash-flow in US than in France and Japan.	Sample of manufacturing firms from US, France and Japan (appr. 200 per country, 1978-1989)
Mulkay, Hall, Mairesse (2001)	R&D is more affected by Cash-flow in US than in France (with insignificant differences in R&D behaviour)	Sample of large manufacturing firms from US and France (appr. 500 firms per country, 1979-1993)

Source: own compilation

Table 4.1 shows the results in case of R&D activities and internal finance. All chosen studies look for differences between capital investments and R&D investments and their relations to internal funds expressed by cash flow and typically measured by ratios (e.g. cash flow to capital stock). Beyond that a few studies (Bond et al. 1999, Hall et al. 1999 and Mulkay et al. 2001) also look for differences between countries in this relationships. Due to data problems the mostly neglected part of industries - small firms - is only investigated by Himmelberg and Petersen (1994). But small firms for them mean sizes under $10 million in capital stock.

The overall result gives support to the hypothesised positive correlation between R&D and internal funds. A possible restriction of the results might be, that effects of firms cash flow on current R&D expenditure may reflect positive expectations of future profits rather than current liquidity constraints. Nevertheless there is a good reason for positive cash flow being more important for R&D investments than for ordinary investments. A second quite interesting result is given by the differences between countries mentioned by some of the studies. This points to some form of influences of different national systems in financing R&D systems (Bagella and Becchetti 1997, Christensen 1992, Tylecote 1994). For the Anglo-Saxon region (US and UK) internal funds are more important than in other regions under comparison. But for a more detailed answer one would have to take into account the different industrial structures and be more cautious about the sample structure.

To round off these results a recently conducted survey research for the UK Technology Strategy Forum is shown which also stress the increasing importance of internal funds. From a policy point of view it is interesting that just one company (NOKIA) has "officially" public funding for R&D while all the others seem to have only internal funding (see Table 4.2). While there exists a mix of funding sources within the companies the largest amounts are spend by decentral organisation units (as divisions or businesses). An interpretation could be found in restructuring of firms towards more market linked R&D activities to overcome market risks and to improve returns from R&D investments (OECD 2001b).

Table 4.2: Research funding of large firms

Issue	Internationalisation of the Organisation	Funding sources	Detailed comments
Company			
HP	Research employs 750 people on six site 450 Palo Alto 250 UK	Predominantly corporately funded, with business sponsorship	Research works on technology advancement
3M	14 Technology Centres including on "Science" based unit	20% Research portion of R&D is corporately funded	3M produce 600 patents per year (100 from Japan)
IBM	8 Labs: 3 in US, China, Switzerland, Israel, India, Japan	65% corporate, 25% divisions 10% miscellaneous	25% of the corporate funding is used to match the divisions to create joint programmes
Corning	Historically centralised R&D now moving closer to the business. 5 US sites, 4 international	Corporately funded	10% of this research on breaking out of current business boundaries
Nokia	52 R&D Centres in 14 countries. Research largely in central laboratory	24% corporate 70% business 6% public funds	Corporate funding is also discussed with businesses
Philips	6 laboratories in different countries (incl. US and China)	33% corporate 66% product divisions	Research employs 3000 people (1700 bench scientists)
Johnson Matthey	Centralised Research and devolved Development	Most funds are supplied by the businesses. Some corporate money to support a university and innovation programme	Single research laboratory in the UK. Small amount of pharmaceutical research in US

Source: Coombs et al. 2001

To sum up, the relevance of internal funds for R&D activities seems to be quite high, even being different by countries.

If one looks for relations in case of external financing, firstly it is to state, that there is not too much econometric evidence available. In Table 4.3 studies are noted which deal with relations between external funds and R&D. These studies have slightly different approaches in respect to the chosen samples for comparisons.

The study of Long and Ravenscraft shows the problems of a high share of debt in capitalstructure for R&D investments. This typically can be seen in case of LBOs. After leveraged buyouts accompanied by increasing debt shares the result clearly indicates the reduction of R&D investments. Also a preference for equity can be found interpreting the smaller declines of R&D investments of large compared to small firms in case of LBOs.

The study of Guiso (1998) shows the problems of getting funds for high-tech firms. They have more credit constraints than low-tech firms. This points to the risks involved in R&D investments and therefore the special form of finance.

Also mentionable are the results of Bah and Dumontier (2001) which show the different financial policies of R&D performing firms in several countries. There cross-section analysis by comparison of R&D intensive and non-R&D firms in Europe, Japan, UK and US produce a pattern of significant different financial policies of R&D performing firms. They have lower debt and lower debt maturity as well as lower dividend payments and higher cash levels. With the exception of Japan the financial policies are homogeneous for all other observed countries.

Table 4.3: R&D and external finance

Author(s)	Main results	Sample
Long , Ravenscraft (1993)	R&D is reduced after LBO due to debt increase Large firms have smaller declines	Sample from US firms (72 R&D LBOs and 3329 non-R&D LBOs, 1981-1987)
Bhagat, Welch (1995)	R&D is correlated to debt, stock returns, tax payment and Cash-flow but all variables differ between countries.	Sample of firms from US (5559), UK (697), Canada (239), Europe (France, Germany, NL, 221), Japan (589) for years (1985-1990)
Guiso (1998)	R&D performing firms (High-tech firms) are more credit constrained	Sample of manufacturing firms from Italy (appr. 1000, 1993)
Bah, Dumontier (2001)	R&D performing firms have different financial policy: - lower debt - lower dividend payment levels, - longer debt maturity - higher cash levels Exception Japan - there short term debt and dividend payments are the same for R&D- intensive and non-R&D.	Sample of firms from US (2887), UK (1111), Japan (2056) and Europe (France, Germany, NL, 950) for year 1996

Source: own compilation

One of the recent and most extended studies is from Bhagat and Welch (1995). This study gives quite interesting impressions about possible "institutional" influences of the financial system for R&D on firm-level (see Table 4.4) expressed by the comparison of several countries. A closer look to the measured relations shows the striking and opposite results with regard to above shown insights that cash flow (thus lower cost of funds) has no positive influence on R&D, while stock returns (signalling future opportunities and lower cost of capital) have positive effects on R&D. In case of Europe and Japan this should not be too surprising with a look to the financial system. The negative correlation in level of operating cash flow in US may represent a kind of inefficient management behaviour (risk-averse behaviour) once there are too much free internal funds. The Japan result in turn may point to an other level of willingness to take risks and therefore to finance R&D by debt. But other studies (Guerard and Bean 1998) have found more convergence in results between these countries. In any case, these results ask for further research regarding the interplay of financial systems and R&D investments in different national systems (Bagella and Becchetti 1997, Christensen 1992, Tylecote 1994).

Table 4.4: Correlation between R&D and the following variables

	US	Canada	UK	Europe	Japan
Lagged R&D	pos	pos	pos	pos	pos
debt	Negative, especially among small firms	insignificant	insignificant	insignificant	Positive
Stock returns	Mostly positive	insignificant	Positive for large firms, otherwise insignificant	positive	Positive, except in robust regressions
Operating cash flow	Negative in level, positive in differences and in robust regressions	Occasionally negative, mostly insignificant	inconsistent	insignificant	Insignificant
Tax liability	Negative or insignificant	Positive in robust regressions, otherwise insignificant	insignificant	insignificant	Positive

Source: Bhagat and Welch 1995, p. 467

So the overall conclusion from this part of empirical studies may be that R&D performing firms indeed prefer internal funds and equity to debt. R&D intensive firms have different financial policies compared to non-R&D intensive firms. This may represent the long term orientation of R&D investments as much as there influence on growth opportunities. Again the differences between countries ask for a more detailed analysis.

As mentioned above the third part of empirical evidence will deal with ownership structures. The question here is, if there is any necessity of an ownership concentration for more innovativeness, e.g. to overcome agency costs and information asymmetries between managers and shareholders in making managers more efficient.

Table 4.5 presents the sample of studies and their results. To start with the study of Francis and Smith (1995) negative relations between diffusely held firms and their R&D investments are shown. Firms are less innovative and R&D investments are more sensitive in timing when there is no concentration in ownership. A possible explanation may be that myopic behaviour of shareholders and missing long-term interests are directly transferred into myopic behaviour of managers.

Table 4.5: R&D and ownership

Author	Main results	Sample
Francis, Smith (1995)	Diffusely held firms have fewer patents, focus more on growth by acquisition and are more sensitive in timing of R&D	Sample from US (262, 1982-1990)
Love, Ashcroft, Dunlop (1996)	Foreign ownership raises Innovation	Sample from Scotland (417, 1992)
Majumdar and Nagarajan (1997)	Institutional ownership does not cut R&D	Sample from US
Pugh, Jahera, Oswald (1999)	Employee stock ownership plans increase long-term investment like R&D	Sample from US (183, 1990-1995)
Weigand, Audretsch (1999)	Small owner-controlled science-based firms have less liquidity constraints than small manager-controlled science and non-science-based firms.	Sample from German manufacturing firms (344, 1991-1996)
Samuel (2000)	Institutional ownership has negative effect on R&D	Sample from US manufacturing firms (603, 1972-1990)
Eng, Shackell (2001)	Institutional ownership and higher R&D	Sample from US
David, Hitt, Gimeno (2001)	Active institutional investors increase R&D inputs (short and long term)	Sample from US (73 largest industrial corporations) for years 1987-1993
Heid,Weigand (2001)	Owner-controlled firms are constrained in R&D by availability of internal and external funds.	Sample from German manufacturing firms (106, 1987-1993)

Source: own compilation

Institutional ownership and myopic behaviour is also at the core for the studies of Majumdar and Nagarajan (1997), Samuel (2000), Eng and Shackell (2001) and David et al. (2001). Results are mixed and not always coherent. Institutional ownership seems to be positive as well as negative for R&D depending on structures of interest. Central is the question in as far shareholders have myopic behaviour and no long-term interests and if there is a direct connection to managerial (myopic) behaviour. This will address again relationships between financial systems and innovation (Bagella and Becchetti 1997, Christensen 1992, Tylecote 1994) beside the intensity of influences other than ownership on R&D investments. For large firms in US the recent study of David et al. (2001) indicates that quite active institutional owners may have a reasonable influence on R&D investments in short term as much as in long term perspective.

Results for Germany are given by Weigand and Audretsch (1999) and Heid and Weigand (2001). Comparing science-based and non-science-based firms they show that governance structures have a reasonable influence on investments. Due to institutional factors this is not too much surprising. There is some positive signalling given by growth opportunities from science-based small firms which make them not credit constrained. But larger owner-controlled firms, which means they have owners in management, may have a owner dependent financial barrier. Often manager-owners do not want to give up shares or control of the firm and hence reduce their financing opportunities.

In Love et al. (1996) the interesting result of positive effects of foreign ownership on innovation may give the tentative idea of the importance of financial, technical and managerial endowment of multinational firms and their effect on R&D investment.

The study of Pugh et al. (1999) raises the question of the effects of participation and shareholding of employees on R&D. Being firstly an instrument to prevent take-overs, employment stock ownership plans also seem to create support for R&D. These anti-take-over amendments increase security for managers and therefore a willingness to take risk.

Even there is no unique position for positive relations between ownership and R&D investments, at least one could argue, that a form of long-term and innovation based growth orientation is a necessary part for positive correlation due to willingness for risk taking. This can occur in different forms of "concentrated" ownership which may be institutional ownership as much as participation of employees. Manager-owners on the other hand may be an obstacle for R&D, especially in large firms.

The fourth part of empirical evidence will address strategic considerations in context of corporate finance and R&D investments. Investments here will be interpreted as an instrument of signalling to overcome some theoretically explained communication problems affiliated with financial markets and R&D. In this context firms have to present their growth opportunities for influencing stock market prices by creating positive expectations. Usually R&D investments include high asymmetric information situations. Therefore the announcement of an increase in R&D investment will engender expectations on financial markets, that the firm will need supplementary finance to realise the growth opportunities. Respectively the studies try to get some insight in these reaction patterns.

As shown in Table 4.6 empirical results are given only for US samples. Almost all studies show that there seem to be a consequentially positive expectation about growth opportunities on the stock market with R&D announcements. Szewczyk et al. (1996) underpin this interpretation with their result of positive correlation between R&D increase and stock price for high-tech firms. But Chung and Wright (1998) make the point, that this may also depend on the actual situation of over- or underinvestment. If there are market situations of overinvestments then will R&D announcements be negatively rated by financial markets. A similar effect can also be seen by reductions of competitors stock market prices if a firm announces R&D increases (Sundaram et al.

1996, Wu and Wie 1998). Implicitly financial market actors seem to weigh the growth opportunities interpreting them almost as a zero-sum game between firms.

Another results are given by the combination of R&D and debt-ratio as a signal for a higher likelihood of success (Alam and Walton 1995, Zantout 1997). Expectations about R&D associated abnormal higher returns can gain this effect by highly leveraging implying a higher rate of return for debt finance in equilibrium.

A quite similar situation of using a broader spectrum of financial sources is reached with joint R&D investments announced through collaborations. These have also a positive effect on stock price (Wu and Wie 1998).

Table 4.6: R&D and strategic decisions of firms concerning corporate finance

Author	Main results	Sample
Alam and Walton (1995)	Firms with substantial R&D expenses and registration of straight debt have increase in stock price	Sample from US firms (316, 1978-1988)
Sundaram, John, John (1996)	Announcing R&D increases announcing firm`s stock price - and reduces that of competitor	Sample from US firms announcing R&D increase (125, 1985-1991)
Szewczyk, Tsetsekos, Zantout (1996)	Announcing R&D increases announcing firm`s q and stock price if high-tech firm	Sample from US firms announcing R&D increase (121, 1979-1992)
Zantout (1997)	Announcing R&D increases announcing firm`s stock price if debt ratio higher.	Sample from US firms announcing increasing R&D (156, 1979-1992)
Bange, DeBondt (1998)	R&D budget adjustments reduce gap between reported and analysts earning predictions	Sample from large US firms (100, 1977-1986)
Chung and Wright (1998)	R&D are positively related to market value of high q firms (growth opportunities but not overinvesting!) Financial market react differently on R&D whether there is over- or underinvesting	Sample from US manufacturing firms (appr. 900, 1983-1987)
Wu and Wie (1998)	Announcing R&D collaboration increases stock price of participating firm - stock price of rival firms is reduced	Sample from US firms announcing R&D cooperations (104, 1985-1992)
Aboody, Lev (2000)	Insider gains in R&D-intensive firms larger than in other firms. Insider time their transactions to direction of R&D expenditure changes	Sample from US firms (10013, 1985-1997)

Source: own compilation

The problems of asymmetric information situations in context of R&D are also fixed by Aboody and Lev (2000). They state higher insider gains in trading equities of R&D intensive firms than in others. Insiders like corporate managers or owners with more than 10 percent of equity use their information advantage to time the equity transactions dependent on R&D expenditure changes.

Similarly executives use information asymmetries in R&D budgets (Bange and DeBondt 1998). Managers adjust R&D budgets for closing gaps between predictions of earnings derived by financial market analysts and the reported earnings by the company.

From the mentioned evidence it should be quite clear that R&D can also be used strategically on financial markets. In general the announcements of increases in R&D create positive expectations about growth opportunities by shareholders. Having that in mind, managers use it as an instrument either to influence stock prices or to adapt to financial market expectations. In any case this will be combined with the given incentives of managers.

4.4 Conclusions

The aim of paper is to give an overview of theoretical considerations and empirical results concerning corporate finance and R&D investments, whereby the focus is on established firms and their relationships between R&D and finance rather than on start-ups. The empirical evidence is mainly represented by econometric studies.

From theoretical considerations liquidity constraints for R&D investments occur because of the nature of R&D investments and through information asymmetries between financiers and managers. These insights lead to preference structures in finance, preferring internal to external funding for R&D. Another result is mentioning the information problems in this case and leads to considerations about ownership and use of R&D as signal on financial markets.

Even having limited econometric evidence some tentative conclusions are derived for the relationships of (1) R&D and internal finance; (2) R&D and external finance; (3) R&D and ownership and (4) R&D and management behaviour. While the first two mainly deal with cost of capital and capital structure the second two have asymmetric information and agency costs at core.

The central results are:

1. For R&D investments internal funds seem to be of high relevance, but one also has to take into account differences between countries.
2. In case of R&D investments equity is preferred to debt as external fund. Some source of long-term orientation in this respect has a better fit for financing R&D. Again there exist some differences between countries which point to different financial systems.
3. If one is observing the information problems between management and investors, i.e. asymmetrical information and agency costs, a partly positive influence of institutional ownership on R&D is measurable. There seems to be negative influence of manager-owners on R&D for large firms.
4. Lastly R&D investments are strategically used in financial markets. Because of expectations about growth opportunities, announcing higher R&D expenditures typically increase stock prices of announcing firms and decreases that of

competitors. Furthermore debt-ratio combined with R&D seems to be a signal for projects with a high likelihood of success.

All these results have to be taken very cautious for several reasons. Firstly the data of the studies have a lot of shortcomings. The restrained availability of data produce results with biases towards the situation of large firms and therefore excludes a lot of others. The quite prominent observation of the US and the low representation of other countries may generate some biases in the overall conclusions. Secondly the quite low number of empirical studies dealing with these relations is another shortcoming. Therefore the results must not be reliable and robust. Thirdly most of the used approaches deal with quite short observation periods and sometimes small samples which again reproduces results of more "static" pictures.

Future research therefore will have to extend the empirical work on a broader set of countries and in a more dynamic setting. Institutional conditions as much as behavioural trends have to be explored in more detail.

Finally policy recommendations which have to be treated with caution may be derived from this survey: For supporting R&D investments by firms elements like opportunities for higher cash flows and more long-term oriented external finance as much as forms of institutional ownership will have to be developed. Obstacles to overcome may be found in short term orientation of financing and for large firms in manager-owners. Nevertheless there is more empirical evidence needed to get clearer results.

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5 Technology Policy and Business Innovation Activities - The case of Germany

5.1 R&D expenditure and public funding

In 2000 the German business enterprise sector invested more than € 30 billion in research and development (R&D) with the aim of producing innovations. The federal government and the German states spent another € 15 billion in order to support this process via education, science and subsidies to private business. For governmental and private investors there is no doubt that investments in research are necessary to secure technology progress, wealth and future. Research activities generate and cumulate knowledge, which lends itself into new products and provides competitive advantages. Governments as much as private business have a keen interest in these advantages.

On the other hand any innovation is preceded by numerous imponderables since it is hardly possible to predict over which period of time or whether at all a pioneering new technology can be generated. In the private sector decisions on investments in favour of research activities are always accompanied by management questions. The expenditures and costs, the behaviour of competitors, chances for implementation, market potential and possible yields are central issues. Innovations require extensive expenditures for systems and equipment as well as for know-how. R&D-efforts are inseparable linked with creativity and qualification of employees. The desired successful development is the result of a long process, not seldom influenced by pure chance. Is the innovation finally achieved, it is still open whether it will be recognized by the market. In contrast to alternative investment opportunities the returns on a R&D-investment are almost impossible to calculate.

Because of these risks it is assumed that investors reserved from investing their capital in research and development activities. Banks and often even the firms' top-management are cautious because no collaterals secure the risks or because the high costs put excessive financial demands on the firm. From an overall economic perspective of the state too little is invested in innovative activities, because often the gains from innovations for society as a whole are larger than those privately realized. Thus it is to be assumed that innovation projects are socially profitable due to positive externalities, while privately they are not (see Arrow 1962). In economic theory the result is market failure, in which case public promotion of research plays an important

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role. In the best case private costs can be reduced through public subsidies in such a way, that R&D-projects become profitable for many firms.

Many controversies hinge on subsidies for private R&D-activities because these are connected with a high degree of selectivity and repercussions on competition. Uncertainty and scepticism about the success of support in the case of subsidies to the private sector stem from the experience that profit maximizing firms have incentives to finance even those projects with public money that would have been carried out anyway. Privately unprofitable innovation projects would not be initialized despite promotion – the effect of public R&D-expenditures would be reduced. In these cases even no stimulating effect on private R&D-activities comes from public financial help and it falls flat without effect.

This study focus on the question, whether public subsidies generate a sustainable effect on firms' R&D activities. While in Germany more than 3,600 R&D-projects in over 2,000 firms are funded every year, a comprehensive analysis of recipients and effects is appropriated.

5.2 Literature review

In the 1950s, the US R&D budget was significantly raised and Blank and Stigler (1957) were among the first scientist to examine the relationship between publicly funded and private R&D. With a large sample of firms they tried to test for a complementary or substitutive relationship between public and private R&D investment. In case of a complementary relationship, firms extend their innovation activities due to public funding. If full crowding-out effects between public and private funds occur, the private innovation activities remain constant. The implications of such studies are still significant for today's R&D politics because a complementary relationship justify public funding whereas substitution is regarded as misallocation.

Over time and along with improved scientific methods it became clear that definite statements regarding the effect of public R&D funding cannot be made. Meanwhile, two main fields of research can be identified which are used to analyse the relationship between public and private R&D investment: qualitative and quantitative research studies. Qualitative data is frequently based on interviews or case-studies within a selected number of firms, whereas quantitative studies count for macro- and microeconomic information on a broad number of companies. David et al. (2000) surveyed macro- and microeconomic studies, focusing on their "net impacts". Only two out of fourteen of these empirical studies indicated substitutive effects on the aggregate level. On the firm-level the results are less clear, i.e. nine out of nineteen find substitutional effects. In summary, macroeconomic studies usually identify a complementary and "good-natured" relationship between public and private R&D expenditure, whereas micro-studies on the firm-level are not able to confirm this effect.

In contrast to macroeconomic studies, the advantage of a microeconomic analysis is that it controls for detailed influences among several determinants that may have an impact on private R&D activities. Recent microeconometric studies approach the above question with firm level or business data provided by ministerial offices, business publishers, statistical offices or own surveys. On this data, the impact of the available determinants on private R&D activities is tested by panel or cross-sectional econometric analysis (cf. Klette et al., 2000). Nevertheless, micro firm-level analyses require detailed databases and careful considerations to eliminate misspecifications (cf. Lichtenberg, 1984). In the 1990‘s Busom (2000) und Wallsten (2000) address other serious problems: selectivity, endogeneity and causality. The former, which is also described by Lichtenberg (1987) and Klette/Møen (1997), is linked to the public funding decision. The difficulty of this aspect lies within potential selection bias of the public institution that – depending on the applying firm and the relevant R&D project – is the only decider in the public funding process. Furthermore, the public institution might support only those firms and R&D projects that are expected to generate extensive economic spillover effects. The recipient firm would most likely not have increased its investment in these basic knowledge R&D projects. In order to separate these two processes, it is no longer sufficient to take only supported firms into account. Using a control group of firms that have not received public funding, the real effects of public subsidies should be analysed. Busom (2000) explores this problem by applying a selection model. While she applies a participation dummy for the R&D activity, Lach (2000) is able to test the impact of the R&D programme on the amount of investment with or without public support.

The literature review shows a non-uniform picture: While macro-economic analyses predominantly find a complementary relationship between R&D-promotion and private R&D-expenditures, the majority of micro-economic studies state substitutive effects (USA). The few European studies at the firm level diagnose again rather complementary effects of promotion. Methodical (data sources, methods of estimation etc.) differences might account for this lack of sharpness. In the USA contracts that are 100 per cent financed by the state are assigned to a larger extend than in Europe, where usually a cost-sharing approach is practiced for the financing of R&D-projects. Recent studies state the "control-group approach" as a crucial criterion for the choice of method which includes not only promoted but also non-promoted companies in the analysis.

5.3 German Data

In this study, data of the "Mannheim Innovation Panel" (MIP) is used, which is conducted by the Centre of European Economic Research (ZEW) on behalf of the German Ministry of Education and Research (BMBF). It is a survey which contains data from 1992 to 1998. In the last years, the MIP represented the German part of the second Community Innovation Survey (CIS2) of the European Commission. The data used in this analysis just includes the manufacturing sector. In order to examine the effects of direct project promotion as an influencing factor of private business R&D-expenditures in Germany extensive enterprise data, separately collected innovation data and detailed information on governmental R&D-subsidies were combined. The subsequent matching approach is based on the idea that one can compare a treated individual with a non-treated individual, which has the same characteristics like the treated-one, i.e. one is looking for "perfect twins". However, larger firms, e.g. the ones with more than 3,000 employees, are really unique and it would not be meaningful to look for twins for companies like these. Therefore, the study is restricted to firms with 3,000 employees at most. The sample includes 3,136 observations at the firm level. Out of those, 297 firms participated in at least one public innovation programme.

5.4 Empirical Considerations

The main question is whether the R&D activities of firms are stimulated by public funding. Is there a complementary relationship between private investment and public subsidies or do crowding-out effects occur?

The R&D expenditure is measured as the expenditure on R&D projects at the firm level. As a potential outcome variable of the matching procedure, the R&D intensity (*R&D_INT*) of firm *i* as the dependent variable is used in the regressions, i.e. the R&D expenditure (*R&D*) divided by sales:

$$R\&D\_INT_{it} = \frac{R\&D_{it}}{SALES_{it}} \times 100. \quad (1)$$

For sure, the increase of R&D intensity is not the only aim of public innovation policies but it is an important question whether public funding is complementary to private investment or whether crowding-out effects between public and private funds occur.

The participation in at least one public innovation scheme is captured by the dummy variable PFO_i which takes the value 1 if firm *i* is a participant and 0 otherwise. With this dummy variable, the recipients of public funding and non-recipients are differentiated exactly. However, different policy schemes which have had different aims, concepts and impacts are not separated. Therefore, the results of the empirical analysis is an average effect of various policy programmes. Some programmes might have performed better, while others failed.

For the subsequent analysis, it is necessary to estimate the probability of receiving public grants for innovation activities. Therefore, several control variables are used, to explain the probability of participation in public innovation programmes. The number of employees (divided by one thousand) *EMP* takes account of size effects. To distinguish firms which are located in the old or in new states of Germany, a dummy variable *EAST* is generated. Since the German reunification in 1990 the government maintains innovation schemes especially for firms located in eastern Germany in order to foster innovation activities in this underdeveloped region and to improve its technological performance. Thus, it is expected that the probability to participate in public policy schemes is larger for firms from eastern Germany than for those from the old states in western Germany. Moreover, the firms‘ age is added to the regression equations because some policy schemes are directly addressed to younger firms or new firm foundations. I use an inverse relationship (1/*AGE*) because some firms are quite old and a linear specification may not fit this circumstance very well. Moreover, the variables *EXPORT, IMPORT,* the market-share (*MSHARE*) and the market-concentration (*MCON*) control for competition. The export ratio with respect to sales measures the degree of international competition which the firm already experiences. Exporting firms demonstrate competitiveness and, hence, for their innovation activities high spill-over effects may be expected. The product diversity ratio (*DIVERS*) is a measure for companies with a single product or a broad diversity. This variable controls for a firms' possibility to use R&D results in just one or in different products resp. manufacturing processes. The variable *CAPITAL* is used to take different physical assets into account. *BONDX* is a credit-rating index, which is used by banks and which controls for capital raising and equity. Some firms belong to big companies, which have central R&D laboratories, other firms are independend. The variable *CSHARE* controls for investments from other firms, because firms within a affiliated group of companies might realise extra R&D-spillovers. Finally, the model contains a legal form dummy variable *LFD* which takes the value one for joint-stock companies or firms with limited liability; *LFD = 0* otherwise. The legal forms with limited liability indicate more reliable receipt of public funds. Joint-stock companies and firms with limited liability are officially registered and fulfil important preconditions for participation in public innovation programmes. Moreover, using legal forms with limited liability owners can minimize their risk up to a certain amount and thus have higher incentives to pursue more risky projects (cf. Stiglitz and Weiss 1981). Hence, they are more likely to enter public innovation schemes. Ten industry dummies (*INDUSTRY*) adjust for cross-sectional effects.

Table 5.1: Means of company characteristics of subsidized and non-subsidized companies before the matching

Variablen	Non-subsidized companies N=2.839 Mean	Subsidized companies N=297 Mean	Differences t-Test/pr-Test
SALES [Mio. DM]	106.7	296.4	-189.7**
EMP [TSD]	0.379	0.828	-0.4**
AGE [years]	40.6	55.7	-15.1**
EXPQ [%]	26.9	37.9	-11.0**
IMPQ [%]	18.9	20.6	-1.7**
MSHARE [%]	0.4	1.2	-0.8**
CAPITAL [Mio. DM]	0.07	0.09	-0.02**
DIVERS [%]	60.2	56.6	3.6**
BONDX [Index]	199.4	190.8	8.6**
MCON [%]	0.4	-0.2	0.6*
EAST [%]	0.13	0.15	-0.02
CSHARE [%]	0.72	0.84	-0.12**
LFD[%]	0.98	0.98	0.00
INDUSTRY1 [%]	0.03	0.03	0.00
INDUSTRY2 [%]	0.04	0.01	0.03*
INDUSTRY3 [%]	0.06	0.04	0.02
INDUSTRY4 [%]	0.11	0.12	-0.01
INDUSTRY5 [%]	0.10	0.03	0.07**
INDUSTRY6 [%]	0.14	0.09	0.05**
INDUSTRY7 [%]	0.28	0.26	0.02
INDUSTRY8 [%]	0.11	0.15	-0.04*
INDUSTRY9 [%]	0.08	0.18	-0.10**
INDUSTRY10 [%]	0.04	0.10	-0.06**

Source: BMBF Database PROFI und ZEW Database MIP

Note: Significant different from zero in a two-tailed t-test on the 1%-level (**), 10%-level (*)

5.5 Construction of matching samples

To address the evaluation question, the average programme effect for the participants θ^1 can be written as

$$E\left(\theta^1\right) = E\left(Y^1 \mid I = 1\right) - E\left(Y^0 \mid I = 1\right), \quad (1)$$

where $I = 1$ indicates the participant group, Y^1 denotes the value of the outcome variable in case of participation and Y^0 of non-participation, respectively. However, Y^1 and Y^0 cannot be simultaneously observed for same individuals. The situation $E\left(Y^0 \mid I = 1\right)$ is not observable by construction and has to be estimated. In the econometric literature it is usually called the counterfactual situation (cf. e.g. Heckman et al., 1998 and Heckman et al., 1999 for an overview on econometrics of evaluation).

To apply the matching approach it is necessary to make the conditional independence assumption (CIA) which was introduced by Rubin (1974):

$$Y^1, Y^0 \perp I \mid x, \quad (2)$$

i.e. conditional on observable characteristics, the participation and the potential outcome variable are statistically independent. Given this assumption, one can build a control group of non-participants, which strongly resembles the participant group in important characteristics, then

$$E\left(Y^0 \mid I=1,x\right) = E\left(Y^0 \mid I=0,x\right) \quad (3)$$

and thus the effect of participating in public policy schemes can be estimated as

$$E\left(\theta^1\right) = E\left(Y^1 \mid I=1,x\right) - E\left(Y^0 \mid I=0,x\right). \quad (4)$$

In the literature on the matching samples construction one can find several approaches to construct the control group. Supposing *x* contains only one variable, it would be intuitive to look for an individual as control observation that has exactly the same value in *x* as the corresponding participant. However, if the number of matching criteria is large, it would hardly be possible to find any control observation. Therefore, Rosenbaum and Rubin (1983) developed the propensity score matching. The idea is to estimate the propensity score of participation for the whole sample and find pairs of participants and non-participants that have the same probability value of participation. Usually, one does not perform an exact matching but the popular "nearest neighbor" matching, i.e. after the estimation of a (probit) regression model of the participation dummy on important criteria, one selects the control observation with the closest estimated probability value to the participant. Using this propensity score, one reduces the multidimensional problem of several matching criteria to one single measure of distance. However, as we are matching firms it is appealing to use not only the propensity score but also other firm characteristics like size and industry classification. This ensures that we compare participants only with controls of similar size and same industry. Otherwise the matching would possibly not be meaningful. For a better understanding of the matching algorithm, we briefly summarize the procedure applied:

1. Estimation of a probit regression model $I_i = x_i^{'}\beta + \varepsilon_i$ to calculate the (unbounded) propensity score of participation $x_i\beta$ for each firm. x_i is a vector of important factors that determine the participation, β is the parameter vector to be estimated and ε_i is the error term.
2. The sample of size *N* is divided into the two groups of participating (N^1) and non-participating (N^0) firms. Then the first participant is selected.
3. The vector is calculated
   $$d_{ij} = \left(x_i^{'}\hat{\beta}, z_i\right)^{'} - \left(x_j^{'}\hat{\beta}, z_j\right) \quad \forall \quad j = 1, \ldots, N^0,$$
   where z_i is a vector which contains important matching criteria additional to the

propensity score. In this case, this is firm size measured as the number of employees (*EMP*).

4. For the *i*-th participant, we use the vector of N^0 differences calculated in the preceding step to calculate a one dimensional measure called Mahalanobis distance:

$$MD_{ij} = d_{ij}^{'}\Omega^{-1}d_{ij} \quad \forall \quad j = 1,\ldots,N^0 .$$

   Ω denotes the covariance matrix of the propensity score and the included additional important matching criteria based on the potential control observations.

5. It is required that the potential twin which will be selected belongs to the same industry as the *i*-th participant and hence observations on non-participants of other industry classifications are dropped.

6. The control observation with the smallest value of the Mahalanobis distance is selected as nearest neighbor for the *i*-th participant. If more than one observation has the same Mahalanobis distance, one is randomly drawn.

7. The selected twin is returned into the pool of potential control observation, i.e. the sample is generated with replacement and steps 1 to 6 are repeated for all remaining participants.

8. Finally, the outcome variable, i.e. the innovation intensity, of the participant group and the selected control group are compared. A t-test on mean differences between both groups is carried out. If there is a difference being larger than zero, it is concluded that the public innovation subsidies stimulate private investment.

5.6 Empirical results

At first, a probit regression model on participation in public innovation schemes is estimated. The results are given in Table 5.2.

The participation probability increases with firm size. Larger firms often maintain R&D laboratories or departments, employ more qualified personnel and are, thus, more competent to meet the requirements demanded by government. As expected, the eastern Germany dummy has a positive estimated coefficient which reflects the intense support for the new states of Germany. Another important factor in explaining the probability of participation in public policy programmes is the industries' dynamics. The variables *EXPORT, IMPORT* and *CAPITAL* have a positive effect, i.e. governmental officials are more likely to support business sectors which have high standards of physical assets and international experiences. One explanation for this selectivity are higher spillover-effects, which are expected from established and well equipped companies.

Table 5.2: Probit estimation

	PFO-dummy (0/1)	
Variable	Coefficient	t-Value
EMP	1.510	7.95***
EMP2	-0.389	-5.04***
1/AGE	-4.068	-6.01***
EXPQ	0.006	4.22***
IMPQ	0.023	3.59***
MSHARE	0.032	1.60
CAPITAL	1.634	4.79***
DIVERS	-0.004	-2.11**
BONDX	-0.001	-0.94
DCON	0.003	0.33
EAST	1.381	8.15***
CSHARE	0.084	0.89
LFD	0.028	0.10
INDUSTRY2	-0.561	-1.62
INDUSTRY3	-0.092	-0.34
INDUSTRY4	0.186	0.77
INDUSTRY5	-0.263	-0.94
INDUSTRY6	0.084	0.35
INDUSTRY7	0.125	0.53
INDUSTRY8	0.361	1.49
INDUSTRY9	0.817	3.42***
INDUSTRY10	0.727	2.84***
CONST.	-2.552	-6.30***
Observations	N=3.136	
Pseudo R-Quadrat	0.21	

Note: Significant on the 1%-level (***), 5%-level (**), 10%-level (*)

Figure 5.1: Distribution of the propensity score before the matching

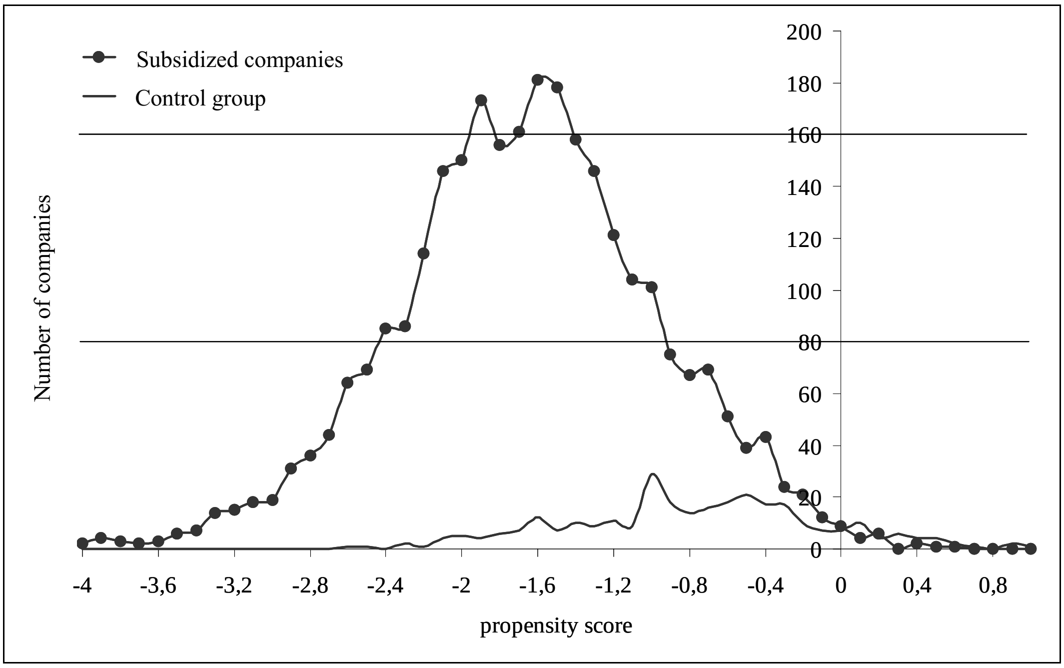


Figure 5.1 illustrates the difference between the participant group and the potential control group prior to the matching procedure. A t-test reports that the groups differ in the distribution over eastern and western Gemany and, more important, in the propensity scores.

Table 5.3: Means of company characteristics of subsidized and non-subsidized firms after the matching

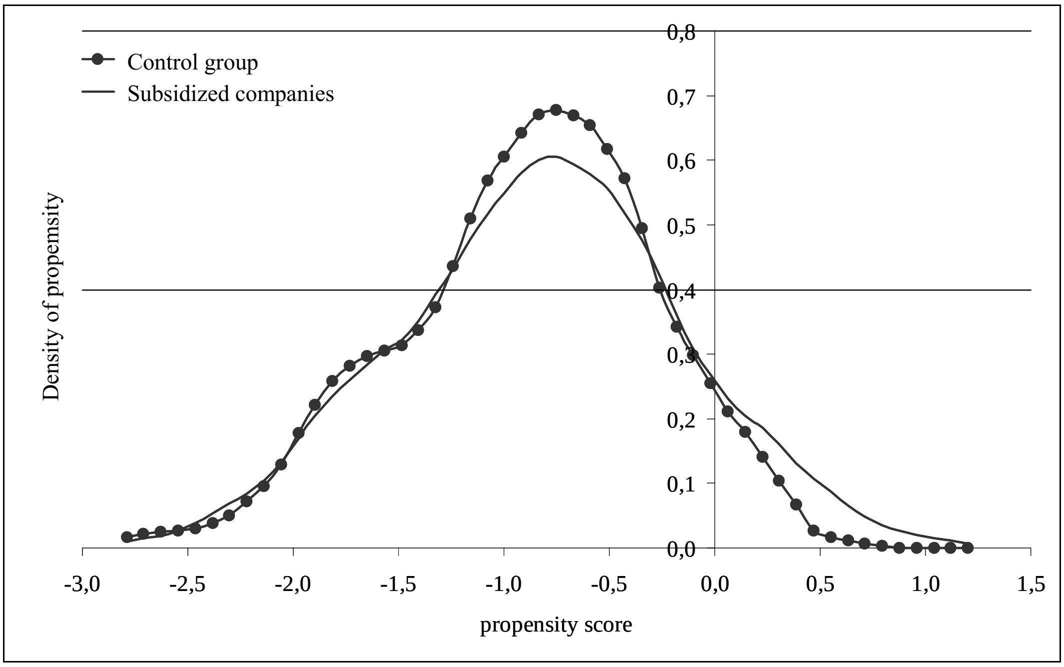
	Means before the matching		Means after the matching		
	Non-subs. companies	Subsidized companies	Non-subs.. companies	Subsidized companies	Difference*
Observations	N=2.839	N=297	N=297	N=297	
Variable					
SALES [Mio. DM]	106.7	296.4	243.96	296.4	-52.44
EMP [TSD]	0.379	0.828	0.801	0.828	-0.027
AGE [years]	40.6	55.7	54.1	55.7	-1.6
EXPQ [%]	26.9	37.9	37.9	37.9	0
IMPQ [%]	18.9	20.6	20.2	20.6	-0.4
MSHARE [%]	0.4	1.2	1.1	1.2	-0.1
CAPITAL [Mio. DM]	0.07	0.09	0.08	0.09	-0.01
DIVERS [%]	60.2	56.6	58.4	56.6	1.8
BONDX [Index]	199.4	190.8	195.6	190.8	4.8
MCON [%]	0.4	-0.2	0.02	-0.2	0.22
EAST [%]	0.13	0.15	0.15	0.15	0
CSHARE [%]	0.72	0.84	0.83	0.84	-0.01
LFD[%]	0.98	0.98	0.99	0.98	0.01
INDUSTRY1 [%]	0.03	0.03	0.03	0.03	0
INDUSTRY2 [%]	0.04	0.01	0.01	0.01	0
INDUSTRY3 [%]	0.06	0.04	0.04	0.04	0
INDUSTRY4 [%]	0.11	0.12	0.12	0.12	0
INDUSTRY5 [%]	0.10	0.03	0.03	0.03	0
INDUSTRY6 [%]	0.14	0.09	0.09	0.09	0
INDUSTRY7 [%]	0.28	0.26	0.26	0.26	0
INDUSTRY8 [%]	0.11	0.15	0.15	0.15	0
INDUSTRY9 [%]	0.08	0.18	0.18	0.18	0
INDUSTRY10 [%]	0.04	0.10	0.10	0.10	0

Source: BMBF Database PROFI und ZEW Database MIP

Note: * t-Test/pr-Tests values are not different from zero.

The matching algorithm picks one observation of the potential control group as nearest neighbor for every participant. The matching function includes the estimated propensity score and the number of employees. After the calculation of the Mahalanobis distance, we require that every potential neighbor belongs to the same industry classification as the corresponding participant. Out of these potential neighbors, the one with the smallest Mahalanobis distance is chosen as twin. After the matching procedure, we have a properly constructed control group, because the t-statistics on mean differences do not suggest any rejection of the hypothesis that the means of both groups are equal (Table 5.3). For example, the difference in propensity scores of participants and the potential controls prior to the matching was about .455 on average. After the matching procedure this difference has shrunk to -.040 which is statistically not different from zero (Figure 5.2).

Figure 5.2: Kernel-based estimation of the propensity score after the matching



On the basis of the successful matched sample construction it is possible to estimate the causal effect of innovations policies for the recipients of public funding. The average effect is the difference of the outcome variable, i.e. in this study the innovation intensity, between both groups:

$$\overline{\hat{\theta}} = \frac{1}{N^1}\left(\sum_{i=1}^{N^1} Y_i^1 - \sum_{i=1}^{N^1} Y_i^0 \right). \qquad (2)$$

Table 5.4 presents the estimates of the average policy effects $\overline{\hat{\theta}}$ for the sampled firms.

Table 5.4: Causal Effects - means of R&D intensity

Dependend variable: PFO		N	%	Non-subs. companies R&D-Intensity (%)	Subsidized companies R&D-Intensity (%)	Causal Effects %-Points	t-value
Total		297	100	3.58	6.87	3.29	4.422***
Size							
20-249	employees	54	18	4.79	16.84	12.05	3.581***
250-499	employees	68	23	3.68	4.83	1.15	1.588
509-999	employees	84	28	3.01	4.35	1.34	2.034**
> 1000	employees	91	31	3.33	4.80	1.47	2.123**

Note: Significant on the 1%-level (***), 5%-level (**), 10%-level (*)

The mean innovation intensity of subsidized firms is 6.87 % while the mean of the selected controls is only 3.58 %. Thus an innovation intensity of 3.29 %-points can be observed due to the participation in public innovation programmes. The hypothesis of full crowding out effects between public and private innovation funds can clearly be ruled out. This result shows that if firms are considered in public innovation policy schemes, it can be expected that these firms raise their R&D efforts, i.e. they increase the R&D expenditure in relation to their sales.

5.7 Conclusions

The present study aims at analyzing the effects of direct project support to firms carrying out R&D by the german federal ministry of education and research (BMBF) at the end of 1990's: Do public R&D appropriations *stimulate* private business R&D-activities? The objective of the empirical analysis was to measure the effects of the direct project promotion on private R&D-investment using an evaluation technique, which takes a selection bias into account.

The significantly positive coefficients of the R&D-models shows that project promotion has a stimulating effect on private R&D-expenditures in Germany. For the firms supported between 1992 and 1998 significantly higher R&D-expenditures than for non-supported firms can be observed. As it is to be expected, several firm characteristics of subsidized and not-subsidized firms do not reflect the true relationship due to high selectivity of the recipients. To correct this bias, a new evaluation method, the so-called "matching" was applied. The matching procedure consists of a selection correction by which for each promoted firm one twin firm from the control group is selected that has not been promoted. After a successful matching, this twin has the same promoting-probability and approximatly the same firm characteristics as the promoted firm itself. Consequently these mirror-image companies differ statistically only by the R&D-subsidy and permit an estimation of the causal effect of the R&D promotion on the amount of the R&D expenditures. The differences in the dependent variable "R&D expenditures" confirm that the project promotion has a complementary effect on private

R&D expenditures, even with the selection bias taken into account: the average R&D intensities of promoted firms differ from those of non-promoted firms by 3.29 percentage points. The promotion probabilities taken into account, promoted firms invest twice as much in R&D as non-promoted, even after the application of this procedure. The largest effect is achieved by the state for those firms with less than 249 employees. Materials research as well as physical and chemical technologies with their research in network projects have the largest positive effect on private R&D-investment.

The results imply that project promotion as a means to stimulate private R&D-expenditures has an important effect on companies R&D investments. Although the causal chain does not permit conclusions on the exact causes of the positive effects, it gives reference points of the characteristics of successfully promoted companies: With a view on promotion success a firm’s size, its age, the competition environment, the industry, and its location are as important as the amount of the promotion appropriations and the fields of technology it operates in.

However, the surprising scale of the effect arises doubts. Although the matching procedure controls for selectivity it has flaws of its own. For example it is based on the assumption that for identical values of the exogenous variables the propensity to invest in R&D and the promotion probability are statistically independent. A weakness of this approach is the impossible task to establish a sufficiently exact match, since the number of determinants of the R&D-expenditures is very large but the number of non-promoted firms is limited. As there is no test – and cannot be – which accepts or rejects the conditional independence assumption (CIA) it is possible that fundamental matching parameters remain unconsidered. Despite the advantages of the matching procedure when it comes to studying a greater number of firms, it is useful to rely on complementary case studies and in-depth interviews in order to get an intuition whether the operationalized features contribute considerably to the explanation of the observed effects. Another limitation of this analysis based on the overall effects of project promotion. In this line, the areas of promotion are not analysed separately and it constitutes only a analysis of means of all areas of promotion. Therefore in such a summarized analysis no difference is made whether the federal government is especially successful at stimulating R&D-investments in some fields of technology while in other areas it does not achieve any or only very small effects.

Despite the positive results of this study that make a point in favour of the instrument of direct project promotion in order to stimulate private R&D-expenditures, some crucial questions remain unanswered. It is unsettled how and for what the additional R&D-investments are used within the firm. Likewise the effect of promotion on spillovers, the utilization of R&D-results and of the related economic and social profit has to be evaluated in further research.

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6 Selective Public R&D Funding and Strategic Firm Behavior – Research Plan

6.1 Introduction

Since the seminal papers of Nelson (1959) and Arrow (1962) there has been a growing consensus that market failure related to research and development (R&D) activities calls for government intervention. Due to uncertainty, imperfect monitoring and imperfect property rights related to R&D activities competitive markets are unlikely to result in the socially optimal level of R&D investment (Gans and Stern, 2000). As a result public subsidies to private R&D activities have become an increasingly important technology policy tool in most OECD countries. Nowadays they constitute the second largest category of industrial support and they have been growing both in absolute terms and relative to other forms of support (Toivanen and Niininen, 2000).

The allocation of public subsidies to private R&D activities can be understood as a selection mechanism. Based on certain criteria this selection mechanism picks the projects to be funded. The existence of this selection mechanism has important implications for technology policy. Given the significance of public R&D subsidies as a source of R&D financing the selection mechanism has an essential role in shaping the innovative activities both within and between firms. We elaborate on these effects below. Secondly, it complicates the evaluation of the effects of public R&D subsidies on private R&D activities.

As mentioned above, public R&D financing nowadays constitutes an important source of financing to firms. As a result, it also for its part influences firms' innovative activities. A potentially important channel through which these effects materialize is that firms take the subsidy rules into account when deciding on what type of projects to initiate. This is the broad topic to which this research project will contribute to. Issues related to the interplay of firms' strategic behavior and public allocation rules are essential for analyzing and developing technology policy. However, such analyses seem to be missing from the economic literature and a proper understanding of the allocation mechanism is needed.

The rest of the research plan is organized as follows. In section two we discuss the broad economic framework which we plan to adopt. In particular, in this section we concentrate on how to theoretically and econometrically model the R&D subsidy

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process. We then discuss the policy relevance of our expected results and shortly highlight the so-called sample selection problem and its relevance in this environment. Shortly, our results will further our understanding of how the application process works, and also enable us to ask counterfactual questions that are central to (re)designing policy.

6.2 Allocation of public R&D subsidies

Public support to R&D can be broadly divided into production in public facilities and promotion of private R&D activity. Main policy tools for the latter are tax incentives and direct subsidies. Direct subsidies can be further divided into public procurement of R&D and public grants. One important difference between procurement and grant is that unlike public procurement, a grant does not involve any commitment to purchase in the future. In this research project the focus is on public grants. We are interested in how public R&D grants are allocated to firms. Therefore the concepts public R&D subsidy and public R&D funding refer here mainly to R&D grants.

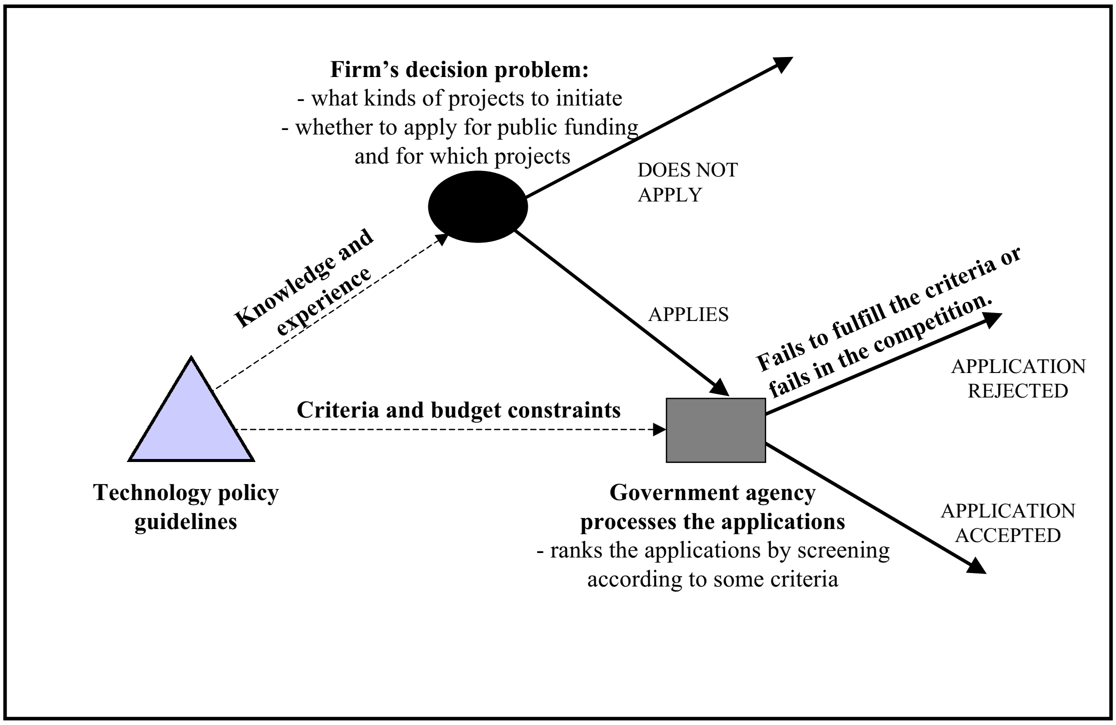
The allocation of public R&D grants can be understood as a two stage selection mechanism consisting of two interlinked decision problems.

- Firms decide whether to apply for a subsidy or not, for which projects to apply and what to apply.
- Given the technology policy guidelines and budget constraints the public agency decides for which projects to give a subsidy, how large and what kind of a subsidy to give. Based on some criteria it ranks the applications and funds the best.

Central feature in this description is that firms integrate their knowledge of the public agency's behaviour in their decision problem, i.e. there is a feedback from the public behaviour to the firm behaviour. Figure 6.1 below gives a simplified description of the selection mechanism.

Firms have to decide what kind of R&D projects to initiate, whether to apply for public funding and for which projects. In making these decisions firms take into account the behavior of the government agency. Firms have some knowledge about the technology policy guidelines that direct the functioning of the government agency. They may also have applied for public funding before and have that way gained experience about the functioning of the government agency and its application procedure. Based on this knowledge and experience firms assess the likelihood of their R&D project to get public funding. Since the application process is not costless, firms apply for a subsidy for only those projects that are expected to have a high acceptance probability.

Figure 6.1: Firm's decision problem



The government agency in turn does not know the true quality of the applications it receives. In order to be able to assess the applications it screens them and then ranks the applications according to some predefined criteria. The criteria are either directly or indirectly determined by the technology policy guidelines. Also the budget constraint is determined by the technology policy guidelines. Once the applications are ranked the government agency funds the best projects within the limits of the budget constraint. As a result an application can be rejected either because it fails to fulfill the criteria or because it fails in the competition. The above is of course a highly simplified description of the real phenomena, but it attempts to highlight the central features of the mechanism determining the allocation of public R&D funding.

Both the firm's and the public agency's decision problems are based on specific criteria, which can be described in the form of a decision rule. Firms that are awarded a public grant are the outcome of this selection mechanism. In order to understand the functioning of the selection mechanism the structure of the decision rules must be known. In practice this means answering two underlying questions: *What determines whether a firm will send on application?* and *How does the selection mechanism allocate grants to applicants?*

In answering these questions, our first task is to construct a theoretical framework describing the two decision. Theoretical models provide a useful tool in understanding complex real world phenomena. By focusing on the key structures they make it easier to understand the complicated interrelationships of the real world. The model to be developed will build on previous literature on two theoretical topics of the industrial organization literature: one related to corporate governance and the other to screening. The corporate governance literature can be applied to describe the firms' decision whether to apply for a grant or not while the screening literature can be related to the public agency's decision problem.

According to empirical evidence (Lehtoranta, 2000), the majority of firms that are applying for a public R&D subsidy in Finland are also awarded one. This may indicate that firms have some information on the criteria on which the allocation of subsidies is based. The application procedure is not costless to firms and as a result firms apply for a subsidy for only those projects that are expected to fulfil the criteria. This type of decision problem can be formalized applying the framework provided by the corporate governance literature (see Tirole, 2001 and Holmström and Tirole, 1997).

The basic idea is that when deciding whether to apply for a grant, the firm is weighting expected benefits of the project against the costs of applying, having some information on the public agency's decision rule. In this decision problem the firm has to take into account that a public grant may impose some restrictions on the control of the project as well as on the property rights of the outcome; these are part of the application costs. On the other hand a public grant may serve as a signal to other financial institutions and that way increase the possibilities of getting financing from other sources.

The public agency's decision problem can be related to the screening literature (Riley, 2001 and Hyytiäinen, 2000 provide surveys of the screening literature). The public agency allocating the grants can be understood as a screener, the main task of which is the ex-ante assessment of applications. Since the outcome of R&D activities are highly uncertain, the public agency faces an information problem while evaluating the applications. It cannot be known ex-ante, which projects will generate the desired outcome. Therefore the role of a public agency is twofold. First of all it has to acquire available information about the projects and secondly, it has to process that information following a specific decision rule. The structure of that decision rule determines what the outcome will look like.

Elaboration of these theoretical ideas will result in a structural model in which both decision rules are described in detail. This model will provide a systematic description of the phenomena in question and thus provide the necessary theoretical framework for the empirical part of the research project.

In the empirical analysis we plan to analyze how the selection mechanism functions in Finland. Our first task is to find out which are the key differences between potential applicants, actual applicants and those awarded a grant in Finland. However, for a thorough understanding of the Finnish selection mechanism this is just a necessary starting point. Instead of simply answering *how* potential applicants, applicants and those awarded a grant differ the main issue is *why* they differ the way they do.

Key questions in this respect are: *What determines whether a firm will send an application? Which are the key factors determining whether an application will be accepted or rejected?* and *How are these two interlinked?* Reliable answers to the above questions would enable us to consider how changes in the public allocation mechanism would affect a) the likelihood of a firm to apply for a grant and b) the likelihood of a firm to be awarded a grant.

The empirical analysis will be based on data from the Finnish National Technology Agency (Tekes), on financial data of the relevant firms (Asiakastieto Ltd.) and on survey data. The econometric analysis will be done in the framework of probability models using appropriate econometric techniques.

6.3 Relevance of expected results

Successful implementation of the research project will provide results, which are of central importance to two relevant technology policy issues. First of all the research project provides a systematic description of how the public selection mechanism and firms' application behavior are interlinked. A formal theoretical description combined with statistical hypothesis testing filters the essence of a complex real world system and thus makes it easier to understand the key interdependencies present in the allocation mechanism. Since a proper understanding of the existing mechanisms is essential for further development, the research project will potentially generate ideas about how the system could be improved further. Moreover the research project enables us to study questions like what type of firms would apply for public R&D subsidies if the public agency's attitude towards the expected risk of the projects is changed.

Secondly the need for a thorough understanding of the selection mechanism is further highlighted by the difficulties related to the microeconometric evaluation of the effects of public R&D subsidies on private R&D activities. Despite the increasing role of subsidies, the evidence on the effects of this policy tool remains rather limited (Klette et al., 2000; Busom, 2000). There is a growing literature on quantitative evaluation studies, but results of the analysis are contradictory.

The confusing empirical findings have raised the question whether the econometric setups have been adequately specified (David et al., 2000; Klette et al., 2000). One of the major drawbacks of these studies has been that the endogeneity of public funding has rarely been taken into account. This endogeneity may be due to selection bias in the funding process.

Selection bias reflects the fact that R&D subsidies are not randomly allocated to firms / projects. In order to get a subsidy firms / projects have to fulfil specific criteria. These criteria are likely to be based on factors which are correlated with the R&D output of the firm like R&D intensity of the firm, knowledge base of the firm, previous R&D activities, sector in which the firm operates etc.. If, for example, firms that are awarded an R&D

grant are more R&D intensive than other firms at the outset, it will be difficult to judge to which extent the differences in the R&D performance between firms with a grant and other firms are due to public subsidies. This selection bias makes it difficult to differentiate the effect of a public subsidy.

In order to get reliable findings possible endogeneities should be taken into account in the specification of econometric evaluation studies. A precondition for this is a thorough understanding of the mechanisms creating the endogeneity in the system. This research project will contribute to this end by analyzing the selection mechanism underlying the allocation of R&D grants. Therefore it will provide basis for more reliable econometric evaluations of the effects of R&D subsidies.

From an academic point of view the research project deals with issues of high scientific relevance. Moreover the research project is likely to provide results which are novel even in the international context.

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7 Evaluation of R&D subsidy policy in Flanders

7.1 Introduction

The importance of technological innovations as a determinant of economic growth and competitiveness of a country has been recognized since several years. Investment in research and development (R&D), knowledge and new technologies indeed seems an important condition for firms to remain competitive at an international level. On the other hand it is generally accepted that R&D and knowledge have public good characteristics that cause firms to invest less in R&D than socially desired. According to neoclassical tradition, government intervention in the technological domain should be aimed at bridging the gap between private and socially optimal R&D efforts. Whether government intervention, e.g. R&D subsidy policy, is efficient in the sense that additional private R&D expenditures are elicited, is a question that has been examined extensively in the econometric literature (for a clear overview see David et al., 2000).

In section 2 we continue arguing that examining the efficiency of R&D subsidies and policy in general should be done in a broader way that merely in terms of estimating the complementary or additionality effects of public R&D funds. In the rest of the paper an overview of recent analyses of the efficiency of R&D subsidies in Flanders is given. Section 3 focuses on the micro-econometric analysis of Meeusen and Janssens (2001) and section 4 on the qualitative analysis of Janssens and Suetens (2001). Section 5 concludes.

7.2 Efficiency of R&D subsidies and Flemish policy

The Flemish Innovation System has emerged as an autonomous innovation system in the nineties from the decentralisation of the Belgian Innovation System through successive waves of institutional change and transfer of policy competencies. Although innovation policy has become a regional competence, fiscal instruments are still a federal matter such that direct grants are still the only *financial* instrument of Flemish R&D and innovation policy. IWT[5] has been established in 1992 as the sole agency to support industrial R&D. The main financial support scheme is a bottom up support mechanism of project funding that has grown to more than 100 million euro a year

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[5] Institute for the Promotion of Innovation by Science and Technology.

(grants), directly distributed to Flemish companies. These characteristics --- the exclusive and broad usage of subsidies as a financial instrument that is increasingly used to stimulate industrial R&D --- urge for an assessment instrument to evaluate the effectivity of this instrument.

Econometric analyses of the efficiency of R&D subsidy policy are often attempts to answer the question ‘To what degree do R&D subsidies replace or enhance private R&D expenditures?’ and thus based on the assumption ‘the more R&D, the better’. David and Hall (2000) argue that it is not necessarily true that social rates of return on R&D investment exceed private rates of return. The authors consider the existence of patent races, imitation, ‘excess correlation’ among R&D projects of different firms, etc. that possibly result in a waste of R&D funds in some industries or domains such that the social rate of return is eventually lower than the private one. It is obvious that in such situation government subsidies aimed at raising private R&D in general elicit even more waste of funds. A restricted R&D subsidy policy, with only those technological domains in which no waste of private funds occurs, receiving support, is according to the authors hard to implement because of difficulties for government to evaluate the situation correctly. A first-best policy would be to restructure the (expected) pay-off structure of R&D projects, as the source of the excessive R&D investment lies within this structure. As such a policy is probably not feasible, the authors suggest implementing a policy of diminishing marginal tax credits for R&D investment.

Another factor that influences private and thus social rates of return on R&D is the productivity of private R&D. If private R&D expenditures are not productive in the strict sense that they do not lead to reductions in production costs, new products or services and/or higher innovation output in general, private and social returns --- which contain private returns --- are low. Thus, when evaluating R&D subsidies, R&D productivity should be taken into account such that the (implicit) assumption of a positive and constant relation between innovation input and output is dropped. It has to noted, though, that even when ‘strict’ R&D productivity is low, it is possible that social returns remain high because of the possible existence of inter-firm R&D spillovers and (basic) knowledge diffusion.

It is obvious that the way of assessing R&D (subsidy) policy should depend on the goals of the relevant policy measures. If a policy measure is aimed at raising private R&D expenditures of firms, government assumes that these firms under-invest in R&D, and a way of assessing the measure would be e.g. estimating the leverage effects of the R&D subsidies on private R&D (or ‘input additionality’). But often R&D subsidy policy is a part of innovation policy in general, such that assessment of R&D subsidy policy measures cannot be done without considering the interaction with innovation policy measures in general. Indeed, the role of subsidies as an incentive for changing business behaviour is different in a context of the linear innovation process than in the context of a nonlinear model where it is an element of a broader policy mix. Therefore we need a broader representation of additionality and additionality assessment. Table 7.1 represents an additionality policy matrix in which different kinds of policies are situated.

Table 7.1: Additionality policy matrix

Types of additionality	**Process / Actor-based**	**Structure / Institutional set-up**
Static spillovers ***Linear innovation model***	Individual innovation *Firm-based incentives* Behavioural additionality	Knowledge infrastructure *Science-based policies* Infrastructural additionality
Dynamic spillovers ***Non-linear innovation model***	Collective innovation *Network-based incentives* Interaction additionality	Systemic Composition *Cluster-based policies* Systemic additionality

The construction of this matrix reflects the broadening of the additionality concept from the context of (direct) impact of policy on the knowledge creation process within the individual firm to the context of the (indirect) impact on the knowledge flows between the collectivism of innovation actors. The rows of the matrix refer to the types of 'spillovers' (non-traded knowledge flows) that are addressed by policy. Static spillovers are linked to a linear model of innovation: the comparative static effect of one-time allocation decisions. Dynamic spillovers are part of a non-linear model, because they are one of the most important channels of diffusion, cumulative development and productivity of knowledge. The columns point to the level of systemic impact of policy actions. The process level is the locus of actor-based incentives. On the structural level we consider the institutional set-up and patterns of specialisation. Each quadrant represents a specific rationale for specific policy actions.

In the first quadrant, traditional policies based on 'market failures' are located --- such as e.g. R&D-subsidies to compensate private under-investment in R&D --- that affect individual firm behaviour. A typical method to assess these policies is the econometric analysis of the additionality effects of R&D subsidies on (long term) R&D investment behaviour, which comes down to comparing private R&D investment with and without incentives, ceteris paribus. Since it is more and more accepted that not one-way but 'several-ways' relations exist between public and private R&D decisions and other economic variables, the typical method of assessment is becoming insufficient. Although subsidies still are used as a lubricant for change in R&D behaviour, results should not be attributed to one policy incentive alone, which might hamper the measurement of the effects in a classical econometric approach.

In the second quadrant, the traditional stimulation policy is extended to the establishment of new knowledge infrastructures that have a strategic impact on the system. They can be implemented as 'exogenous' initiatives that should 'automatically' generate an economic return for society. Experience shows that only with the help of specific technology transfer programmes industrial benefits can be harvested. The linear innovation model has proven to be limited. The presence of 'absorption capacity' in industry will determine the productivity of (tradable) knowledge transfer and (nontradable) knowledge spillovers for knowledge creation and usage in industry and for a subsequent higher propensity to invest in R&D. A better 'matching' of science and industry often is an objective on itself in granting support to projects that involve university partners.

In the third quadrant, the impediments to technology diffusion are central because knowledge flows are acknowledged to be the motor for capitalising on dynamic spillovers. In any dynamic context, incentives to networking and technological communication between different actors can make an important contribution to good performance of the system. Subsidies are an element in creating better conditions for interaction. They can compensate for the coordination costs and the uncertainties that can be a barrier to engage in these interactions. Their return is per definition measured on the level of collective productivity.

In the fourth quadrant, we find policies aimed at using knowledge spillovers in a structural sense: to change the system in the direction of increased knowledge intensity. Cluster policies can strengthen specialisation patterns, or may change them according to strategic choices. The types of structural dynamic externalities also extend to social externalities, because knowledge affects the social and ecological characteristics of society. These cluster policies are particularly well suited for the implementation of policies for sustainable development, because they span larger parts of the value chain. Subsidies are than more targeted to specific actors, domains and thematics as to act upon the specific bottlenecks that inhibit the self-organisation process. The evaluation of their impact is difficult on the output level; it is their process impacts that act as indirect success measures.

The problem of assessment of the additionality of public incentives (subsidies in particular) is linked to the measurement problem of the externalities that are targeted. In a static context the subsidy is mainly a compensation for the individual entrepreneur as to stimulate him to do more R&D and become more innovative. But the level of 'underinvestment' cannot be empirically detected. In a dynamic context the subsidy is mainly a leverage to create additional spillovers that --- either internalised or not --- have a much more important impact on social productivity than the direct effects on the innovation capability of the firm which is subsidised. But the investment in R&D is not only to be considered as an investment in a (self-standing) creative capacity but also in a (collaborative) absorptive capacity that is linked with learning and able to capture knowledge as a public good. The inclusion of spillovers in effectivity measurement is therefore of prime importance. But again the extent of these spillovers is very difficult to establish.

The broadening of the scope of additionality of government in a systemic perspective pushes the assessment tools to new limits. The typical analyses of additionality of public incentives for private R&D in neoclassical tradition follow the linear approach and are restricted to the measurement of allocation effects in the narrow quantitative sense. There is a need to enlarge these models to the richer behavioural nature of additionality and to the interaction effects within a non-linear approach (interaction with other actors, interaction with other policies). The usage of other empirical assessment methods, such as e.g. interviews and questionnaires with R&D managers, can complement these efforts to construct evaluation instruments based on newer theories of industrial dynamics such as evolutionary economics and systems of innovation theory. On the other hand we also believe that characteristics of these newer theories can and should be integrated in an econometric framework (e.g. by modelling systems of equations with endogenous variables).

7.3 Microeconometric estimation of the effects of R&D subsidies on R&D expenditures of firms in the Flemish region

The traditional way of evaluating R&D subsidy policy is by econometrically estimating whether R&D subsidies are or have been efficient in stimulating private R&D behaviour. In David et al. (2000) a complete overview is given of papers that deal with this topic and it seems that no unambiguous conclusions can be made regarding the complementarity issue. Some studies provide evidence for complementarity of public R&D, while others find that public R&D substitutes for private R&D. Different kinds of policy measures used in analyses, different kinds of aggregation level, of econometric specification, of period, of country, etc. make it difficult to compare results though. Next to this, in many analyses some typical econometric estimation problems are not dealt with:

- simultaneity between private and public R&D decisions,
- the problem of omitted latent variables, such as technological opportunities,
- selectivity bias due to non-random sampling.

The first two problems have as a consequence that also public R&D decisions are endogenous. IV or GMM estimation methods can be used as an attempt to solve this problem.

In Meeusen and Janssens (2001) results are reported on a microeconometric analysis of the effects of R&D subsidies, provided by IWT, on private R&D expenditures of firms in the Flemish region. The firms in the sample are firms that answered the biannual R&D surveys that serve as a basis of OECD BERD and ANBERD statistics, in the period 1992-1997.

The authors have estimated the following equation:

$$RDI_{it} = \alpha_0 + \sum_{k=1}^{K} X_{kit} + \beta_0 SUBI_{it} + \beta_1 SUBI_{it-1} + \gamma RDI_{it-1} + \rho u_{it-1} + \varepsilon_{it} .$$

The dependent variable RD_{it} represents R&D intensity, i.e. intramural private R&D expenditures, irrespective of the source of financing, divided by turnover. The right-hand-side of the equation contains a lagged dependent variable, variables representing R&D subsidies, other control variables summarized in X and an autoregressive residual process of order one (last two terms of the equation). $SUBI_{it}$ and $SUBI_{it-1}$ are current and lagged intensities of R&D subsidies with turnover as nominator. X contains firm size measured by the logarithm of turnover, real growth of turnover as a proxy for expected future demand, the number of previously subsidised IWT projects, the number of EU projects, industry dummies and the technological level as defined by OECD[6].

As the dependent private R&D variable contains the amount of external financing, and thus the amount of received R&D subsidies, the long-term effect of the subsidies on privately financed R&D should be calculated as follows:

$$\beta_L^{'} = \frac{\beta_0 + \beta_1}{1-\gamma} - 1.$$

Using a general-to-specific approach, in which insignificant variables are left out of the model step by step (with a significance level of 95%), and maximum likelihood estimation of all parameters, the authors find that lagged R&D intensity, firm size, and current and lagged R&D subsidy intensities are significant, as is the autoregressive coefficient. The long-term effects of R&D subsidies on privately financed R&D and the elasticity of private R&D with respect to R&D subsidies are presented in Table 7.2. As Table 7.2 shows, 1 euro of government support would yield an additional amount of about 3.7 euro of privately financed intramural R&D expenditures, implying a strong complementary effect of R&D subsidies. The authors recognize that this estimate is too large to be realistic for the whole economy. Indeed, only firms that are expected to be R&D spenders are included in the sample (cfr. problem of selectivity bias).

Table 7.2: Econometric estimates

$\hat{\beta}_L^{'}$ (s.e. $\hat{\beta}_L^{'}$)	P-value	elasticity e	nobs
3.673 (0.941)	0.000	0.318	280

Apparently, the econometric results suffer from the typical econometric problems related to these kinds of analyses. That is, omitted latent variables and simultaneity of public and private R&D decisions. It seems that neither the sectorial, nor the technological dummies suffice to represent technological opportunities for firms. It is known that the sectorial or industry codes often lag behind on the real activities of firms and as the technological level definitions of OECD are nothing more than the grouping of some industries into high-tech, medium-tech and low-tech, this variable neither represents real technological opportunities.

[6] The OECD definition divides (mostly 2-digit ISIC revision 3) sectors in low-tech, medium-tech and high-tech.

A future econometric analysis of the effects of R&D subsidies on private R&D of firms in the Flemish regions, should take into account appropriate measures of technological opportunities, such as e.g. technological classifications of the government institutions (IWT) and expected future market demand. Another variable missing is a measure of internal funding such as cash flow. Further, it is necessary to do some robustness tests with respect to estimation methods and econometric specifications. Another step further would be the estimation of a simultaneous system of equations with output equations and R&D equations. Obvious examples of output equations are production equations to examine the productivity effects of mainly process R&D and innovation output equations with new products as a dependent variable to examine the output effects of mainly product R&D. Finally, different measures of government support should be taken into account, and dependent on the goals of the measures, effects can be estimated.

7.4 Usefulness of R&D subsidies in Flanders: a qualitative approach

In Janssens and Suetens (2001) questionnaires and interviews with the in 1997 15 largest R&D spenders in the Flemish region, of which 14 have received government support of IWT in the form of direct subsidies for specific R&D projects. The aim of the analysis was to serve as a complement to the previous microeconometric analysis and to give more information on R&D behaviour of large firms. Although the examined sample is quite small, the firms interviewed, represented 43% of intramural R&D and 58% of R&D subsidies in 1997.

In a first part of the questionnaire questions were asked on firm, market and government related parameters in general that influence R&D decisions, while a second part concentrated on government support in R&D and the IWT subsidy system as it existed at that time. Among the parameters related to company characteristics, R&D activity in previous periods and the strategic long-term aspect appeared to be most influential when taking R&D decisions. Being part of an international group was another factor that is of importance for some companies when making R&D decisions. In some firms the market knowledge of the mother company constituted a positive impulse in the sense that the R&D budget is better distributed. In other firms market knowledge of the mother company is rather interpreted as a negative factor though, as part of the autonomy of the daughter company disappears.

The R&D managers generally agreed that parameters related to market characteristics are the most important determinants of R&D decisions. Improving competitiveness and specific market prospects in particular seemed to be crucial factors. Obviously, generating new products and processes increases a firm’s competitiveness in a direct way. However, the magnitude and direction of R&D investments also seem to depend on R&D investments of competitors. Indeed, it is possible that own R&D efforts are raised in order to catch up with other firms such that the same or a higher level is eventually attained. Other firms hope to take advantage of the knowledge acquired by its competitors through technological spillovers and postpone their R&D investment. Other important factors that influence R&D decisions, according to the interviewed R&D managers, are the possibility to engage in cooperation agreements and network formation and accidental shocks in the economy. An example would be the Belgian dioxin crisis in the meat industry that has created incentives for some firms to start research on harmful substances or to develop new, improved products and processes.

Among the government-related parameters, IWT subsidies and European support measures are considered to be the most important factors influencing R&D decisions. Fiscal support measures did not seem to be important. The degree to which planned R&D investment would be carried out without IWT subsidies was closer to in any case than to totally not on a seven-points Likert scale, though, which indicates that subsidies rather substitute for own R&D. The most significant consequences of government R&D support on firms' R&D behaviour were the creations of possibilities to take higher risks, the stimulation of new research, the continuing and deepening of existing R&D activities and the establishing of new cooperative agreements.

The main negative aspects of the system of financing as it existed at the time of interviewing, i.e. in 2000, were the following:

- The application procedure was found to be too complex which lead to high costs of formulating project proposals.
- The evaluation committee lacks industrial feeling.
- The time period between the submission of the project proposal and the granting of the subsidies is too long.
- Intellectual property rights were not guaranteed as project proposal were to contain technical details.

It is clear that these aspects are all related to the flexibility of the subsidy system. Meanwhile, more specifically at the end of 2001, Flemish government has changed the subsidy system to make it more simple and transparent.

Positive aspects were the following:

- Cooperative agreements and networking have been stimulated within the private sector and between the private and the public sector.
- The system of granting funds through projects leads to clear agreements and expectations for all parties.

On the basis of the interviews it can be concluded that the IWT R&D subsidies did not lead to additional private R&D expenditures in the `strict' sense, on the contrary, most R&D projects would be carried out even without government support. But if the efficiency of R&D subsidies is interpreted in a broader way than merely in terms of `to how many additional private R&D efforts R&D subsidies have lead?', we could say that Flemish policy probably has `made a difference'. Indeed, through interaction between firms and between firms and the public sector, knowledge and technological spillovers are increased.

Finally, we want to remark that this study is very tentative and experimental. The intention was not to provide policy makers and other interested with clear and final conclusions, let alone statistically significant results, but to do a first step in the directions of qualitative research. Obviously, there is need for further, more thorough and statistically interpretable qualitative research.

7.5 Conclusion

A first evaluation of R&D subsidy policy in the Flemish region has been done by means of an econometric estimation of the effects of industrial R&D subsidies and a tentative qualitative study reporting on questionnaires and interviews with R&D managers of 15 large R&D spenders. The econometric part intended to give an indication of the `strict' leverage effects by attempting to provide an answer to the question `to how many additional private R&D efforts R&D subsidies have lead?', while in the qualitative part efficiency of R&D support was interpreted in a broader way. The need for more analyses on efficiency of R&D subsidies in the broad sense, is a consequence of the increasing acceptance of the systems approach in economics, and of leaving the traditional linear view of innovation and R&D. A consequence of this is that R&D (subsidy) policy measures and their evaluation should be situated in a general innovation policy, in which technology diffusion and productive and innovative output are also important objectives. Future empirical analyses should be an attempt to incorporate these needs. Conditions for firms to take the largest possible advantage of knowledge and technological spillovers, which are closely related to technological opportunities, should be identified. Therefore, further qualitative research with e.g. in-depth interviews is needed. This does not imply that quantitative research is not necessary any more, on the contrary, it should be maintained and improved, e.g. by endogenising as many R&D related variables as possible, by looking for appropriate measures of technological opportunities, by estimating systems of equations, by taking into account the different goals of policy measures.

7.6 References

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8 Emerging Patterns of R&D in the Swiss Economy

8.1 Introduction

Switzerland belongs to the most R&D-intensive economies, although it has lost some positions on the international ladder of R&D intensity at country level in recent years being superseded by some OECD countries which increased their R&D spending very much in this time (e.g. Finland and Korea).[7] The R&D/GNP ratio is of about 2¾ %, slightly less than in the eighties (3%). Three quarter of R&D is financed by the private sector, with some increase of public financing during the last two decades; nevertheless, the public share still belongs to the lowest among the OECD-countries. Although most R&D is done by large multinationals, Swiss SME's are more R&D-intensive than those of most other highly developed countries. R&D is thus a pervasive phenomenon in the Swiss economy.

Public R&D is very much oriented towards basic research (primarily at universities). As a percentage of GNP, basic research is by far the highest among all OECD countries. In the last decade, applied research became somewhat more important, since Switzerland a) increased its participation at the EU research programmes (EUREKA, Framework programmes, etc.), and b) established some research programmes oriented towards specific areas of national interest (promising technological fields like biotechnology, new materials, etc; areas of public concern like environment, health, etc.). Although public/private partnerships are encouraged in these programmes, the university sector remains dominant. There is only a small portion of R&D promotion which is clearly directed towards the private sector (programmes financed by the Commission of Technology and Innovation); in this case, however, the promotion of diffusion is at least as important as R&D in the narrow sense.

In view of the dominant role played by private R&D, our research concentrates on the analysis of the (emerging) patterns of R&D prevailing in Swiss firms; the public sector is only taken into account in its role as partner of private firms. More specifically, the research pertains to three areas, that is a) R&D networking (contract-R&D, R&D co-operation), b) internationalisation of R&D, and c) financing R&D-driven innovative activity. The first two refer to phenomena which play an ever increasing role in private R&D. The third one is relevant, since, in designing an optimal policy of promoting

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[7] The data used in this introductory section are mainly from OECD (2001) and the R&D statistics published by the Swiss Federal Office of Statistics (Bundesamt für Statistik, 1999 and earlier editions)

private R&D, it is necessary to know whether there are capital market imperfections leading to an underinvestment in R&D.

The analysis is descriptive (meso-level: sectors, industries, size classes) as well as explicative (firm-level). In the first place, we use data from the Swiss innovation survey of 1999 which is based on a stratified sample (28 industries; 3 industry-specific size classes). The survey yielded information for 2172 firms. By correcting for non-response and adequate weighting we obtained results which are representative for the underlying population (census firms with at least 5 employees). Additionally, we use data from earlier innovation survey (1990, 1993, 1996) to get information on the change of relevant variables. Moreover, we take into account data from a survey on "Internationalisation of the Swiss economy" we conducted in winter 1998/99. The questionnaires used in these surveys can be downloaded from www.kof.gess.ethz.ch.

In the next section, we present selected results from a descriptive analysis of R&D networking based on out-contracting of R&D as well as on R&D co-operation (see Arvanitis et. al., 2001a, Ch. 7). Section 3 is devoted to a descriptive and econometric analysis of the internationalisation of R&D (see Hollenstein, 2000; Arvanitis and Hollenstein, 2001; Arvanitis et al. 2001b). In Section 4, we present some empirical results regarding the financing of R&D based on Arvanitis and Marmet (2002). Finally, we draw some (policy) conclusions.

8.2 Knowledge networks

8.2.1 Internal vs. external R&D strategies

Competition based on innovative products and/or processes has intensified in recent years, since, among other things, a growing number of countries developed strong innovative capacities based on R&D, human skills, etc., and, at the same time, technological innovations tend to become more complex and (therefore) more expensive. In these circumstances, it is not surprising that a growing number of firms are coming under pressure to use their R&D funds more efficiently: Specialisation by concentrating R&D on very specific fields of activities; combining internal R&D, which is focused on core areas, with external R&D based on R&D contracts and/or R&D co-operations.

Table 8.1 shows that in 1999 more than 50% of Swiss firms followed R&D strategies which involve a combination of internal and some form of external R&D ("external R&D strategies"); 21% of firms relied on both forms of external R&D, i.e. contracts as well as co-operations (external strategy of type 3). The table gives the corresponding results by sector as well as for the most innovative industries. Among the industries for which external R&D is particularly important, we find almost exclusively highly innovative ones. In other words: less innovative industries are more inclined to concentrate on purely internal R&D strategies. The same holds true for small firms, whereas large firms rely more often on external strategies, and, among these, particularly on the most developed external strategy (type 3). Nevertheless, even among the three lowest size-classes (5-19, 20-49, 50-99 employees), a substantial amount of firms follows an external strategy of type 3. We conclude from these results that the knowledge network in the Swiss economy, in particular in the most innovative segments, is very tight.

Table 8.1: Importance of Internal and External R&D Strategies 1997/99

(% of R&D performing firms)

	Internal R&D-strategy	External R&D-strategies Type 1	Type 2	Type 3
	Internal R&D only	Internal R&D and contract-R&D	Internal R&D and R&D co-operation	Internal R&D, contract-R&D and R&D co-operation
Business sector total	46.7	22.5	10.0	20.8
Sector				
Manufacturing	47.7	24.9	6.2	21.2
Services	45.9	17.1	18.1	18.9
Industries with above-average external R&D				
Textiles	34.9	29.9	4.1	31.1
Chemicals/Pharma	32.3	29.5	3.9	34.3
Machinery	38.8	21.8	8.6	30.8
Electrical machinery	44.8	33.2	0.5	21.5
Electronics/instruments	36.7	24.9	3.6	34.8
Transport/Telecom	29.7	22.8	28.6	18.9
Banking/Insurance	36.6	12.6	24.7	26.1
R&D-/ICT-services	14.9	24.1	25.3	35.7
Business services	46.6	23.6	14.4	15.4

Source: Arvanitis et al. (2001a)

At this stage of research, we are not yet able to present results with respect to the development over time of the relative importance of the four types of strategies distinguished in Table 8.1. Nevertheless, we notice a distinct tendency towards external strategies, since R&D contracts as well as R&D co-operations have become more frequent during the nineties.

8.2.2 R&D-contracts

The share of firms out-contracting R&D (solely or in combination with R&D co-operations) strongly increased in recent years, more precisely, from 25% in the years before 1997 to 43% in the period 1997/99.

Firms out-contract R&D most frequently to other firms (70% of all out-contracting firms). 50% of contracting is with the university sector, and 33% with other research institutions (specialised laboratories, etc.), which is a sector not so well-developed in Switzerland as in other countries like, for example, Germany. The frequency of contracts with other firms is about the same for small and for large firms, whereas contractual relationships with universities and other research institutions are more important in case of large firms. Nevertheless, it is quite remarkable that one third of out-contracting firms with less than 50 employees rely on university research.

Almost all firms out-contract R&D to Swiss partners. Nevertheless, contractual relationships are also international to a remarkable degree (what is obviously more probable in case of small countries), with EU countries as the most important partner (32%); 20% of out-contracting firms choose partners from other countries; the USA are the most important one (13%). It is not surprising that international out-contracting is size-dependent; this holds true more for partnerships with US firms/institutions than with European ones. However, almost 10% of out-contracting firms of each of the three lowest size-classes (5-19, 20-49, 50-99 employees) do so (also) with US partners. We conclude that Swiss firms, even the small ones, are capable of looking for the best supplier of the required knowledge on a world scale. In a policy perspective, it is worth noticing that distance matters. There is thus scope for national and European policy to reducing "distance" in the wide sense of the word (decentralised competence centres, efficient information flows over longer distance, etc.).

There is not much known about the motives for and determinants of out-contracting R&D, the relationship between internal R&D and out-contracting, the impact of out-contracting on R&D outcomes, etc. It is an objective of future work to investigate these relationships empirically based on econometric analyses of firm-level data. At this stage, we are able to present some descriptive results with respect to the motives of out-contracting and the problem of substitutionality vs. complementarity of out-contracted and in-house R&D.

The 1999 Innovation Survey yielded data on the firms' assessments of four motives for out-contracting R&D (five-point scale ranging from"not important at all" to "highly important"):

- Efficiency-oriented substitutionality: Out-contracting combined with a reduction of internal R&D capacity; the same type of R&D can be performed at lower costs by other firms/institutions.
- Knowledge-oriented substitutionality: Out-contracting combined with a reduction of internal R&D; internal know-how is (and remains) insufficient to produce the required new knowledge.
- Efficiency-oriented complementarity: Out-contracting of R&D to complement own R&D (whose level is not reduced) with knowledge in very specific fields which can be produced at lower costs by other firms/institutions.
- Knowledge-oriented complementarity: Out-contracting of R&D to complement efficiently internal R&D (whose level is not reduced) with knowledge in fields of technology which are completely new for the firm.

Table 8.2 shows that, on balance, about 40% of firms substitute contract-R&D for own R&D, whereas for more than 60% of firms internal R&D and out-contracting are complementary (col. 3 vs. col. 6). Complementarity is more important than substitution in all industries and firm size classes, although to a different extent. The dominance of complementarity is particularly strong for large firms. The main driver behind complementary as well as substitutional out-contracting is not the anticipation of lower costs but rather the opportunity to source new (specialised) knowledge (col. 1 vs. 2 and col. 4 vs. 5 resp.). This again holds true for all industries and size classes, and is more accentuated for large firms, in particular in case of complementary out-contracting.

Table 8.2: Motives for R&D out-contracting by industry and firm size, 1997/99

(Share of firms for which a certain contracting strategy is highly important (multiple answers possible)

	Substitution			Complementarity		
	Efficiency-oriented	Knowledge-oriented	All	**Efficiency-oriented**	**Knowledge-oriented**	All
Industry						
Chemicals/Pharma	10,3	34,5	34,5	20,7	51,7	58,6
Plastics	7,7	46,2	46,2	30,8	61,5	61,5
Machinery	9,8	35,4	39,0	26,8	54,9	61,0
Electrical machinery	25,0	55,0	65,0	40,0	60,0	75,0
Electronics/Instruments	9,6	36,5	38,5	32,7	59,6	71,2
Banking/Insurance	10,5	31,6	36,8	31,6	73,7	73,4
R&D-/ICT services	16,7	50,0	50,0	33,3	83,3	83,3
Business services	19,0	33,3	38,1	38,1	23,8	42,9
Firm size						
6-19	14,9	40,4	40,3	34,0	38,3	44,3
20-49	18,5	46,2	42,3	27,7	47,7	50,7
50-99	11,3	40,8	41,3	28,2	47,9	48,8
100-199	19,1	44,9	46,8	34,8	53,9	61,7
200-499	8,1	37,4	40,2	22,2	57,6	61,8
500-999	7,3	24,4	26,8	31,7	75,6	82,3
> 999	7,1	28,6	27,3	35,7	64,3	60,1
Total	12,9	39,5	40,9	29,7	54,0	59,1

Source: Arvanitis et al. (2001a)

In sum, we observe a strongly increasing trend of out-contracting R&D independent of industry and firm size. “Distance”, widely interpreted, is an important parameter influencing the (regional) choice of partners. Both contracts between firms and those involving firms and research institutions are very important. Whereas the first type of partnership probably indicates a high potential for a two-way co-operation, the second one underlines the importance of an optimal (policy) design of science-industry relationships.

8.2.3 R&D co-operation

In 1997/99 about every third R&D performing firm co-operated with other firms or with research institutions (data from the 1999 Innovation survey, grossed up to census data). R&D co-operations have become a core element of National Innovations Systems. In what follows, the main features of the pattern of R&D co-operation are given; a more detailed analysis can be found in Arvanitis et al. (2001a).[8] At this stage of research, we are not yet able to present results from econometric work dealing, for example, with the explanation of the frequency and type of co-operations, the role of strategic variables such as the motives for co-operations. It might also be sensible to look for specific profiles of co-operating firms by means of cluster analysis of the various dimensions of this phenomenon (form, partner, regional orientation, motives), in order to see, for example, whether there are specific profiles, that are particularly successful in terms of innovativeness or whether they differ by firm size. This type of questions will be at the core of future work.[9]

R&D co-operations can take different forms. We distinguish five forms ranging from informal technology-related information exchange as the loosest form of engagement up to equity-based joint ventures with a majority stake as the tightest one. The most frequent forms of co-operations (multiple answers) are contract-based agreements to execute common research projects, and, not surprisingly, informal information exchange (about 60% of firms). Nevertheless, more than 20% of co-operating firms are (also) engaged in equity-based co-operations (majority or minority stakes).

We distinguished eight types of partners which are grouped in three categories, that is a) vertical co-operations (co-operation partners in this case are: users, suppliers of materials/intermediate goods and services, suppliers of investment goods, other partners like consultants or firms of the same enterprise group), b) horizontal co-operation (competitors), and c) co-operation with research institutions (universities/polytechnics, other public or private research institutes). Vertical co-operation is the most frequent type of co-operation (90% of firms), followed by science-related partners (62%) and horizontal partnerships (42%). Differences between sectors/industries and size classes with respect to this pattern are quite small; services firms are more often engaged in horizontal co-operations, and the manufacturing sector as well as large firms are, compared to the business sector as a whole, somewhat overrepresented in science-oriented relationships.

Firm co-operate most frequently with Swiss partners (44% of all partnerships; multiple answers rebased to 100%). However, partners from other regions are also very important, in the first place institutions located in the EU (31%), but, to a lesser extent, also partners from overseas (USA 14%, Japan 5%). Looking at the structure of regional

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[8] A comparison of the pattern of R&D co-operation in 1997/99 with those of 1991/93 and 1994/96 is not presented because there are some methodological problems to be solved to ensure comparability.

[9] For an econometric analysis of R&D co-operation based on data collected in the course of the Swiss Innovation Survey 1993, see Lenz (1998).

partnerships by type of partner, we find no differences between the various regions with respect to vertical co-operation. Horizontal co-operations are particularly frequent in co-operations with Swiss and EU partners, whereas US partners take a prominent position in science-oriented relationships. The size-dependence of the three types of partnerships is weak; only in case of science-related co-operations we find that large firms are overrepresented. There is also a positive relationship between firm size and the distance of the partner (region); in particular, partners from overseas are not easily accessible for smaller firms.

From the results for R&D co-operation by type of partner and its regional orientation we conclude a) that distance matters and b) that world-wide orientation of partnership is characteristic for the Swiss economy, even for SME's. These results reflect the small size of the country, but also its tradition of outward-looking economic activity. Nevertheless, there are some specific features in case of SME's, that is its underrepresentation in science-related co-operations and its smaller geographic radius. These characteristics may be a rationale for supporting SME's through public policy or measures taken by industry associations (e.g. information, support for co-operative research). Information about the motives for engaging in R&D co-operations allow some insight into the importance of specific R&D strategies. To this end, Table 8.3 shows the importance of seven categories of motives differentiated by type of co-operation. The motive "pooling together complementary knowledge" and "access to specific knowledge" which, together with "building know-how in new fields of technologies", aim at an enhancement of firms' knowledge base. This category of motives is clearly the most important one, whereas the "classical" instruments of internalising the benefits of new knowledge (risk and cost sharing) are not very relevant. This is also true for the motive of profiting from public support, which is not surprising, since technology policy in Switzerland is rather "low key" (see Section 1). The differences between firm size classes are small for each of the seven motives we distinguish. In sum, we find that R&D co-operation is overwhelmingly related to a strategy of enhancing a firm's knowledge base, to some extent, we presume, in the course of specialisation of R&D resources on core competencies. The three categories of partners differ somewhat with respect to the role played by the various motives. Vertical co-operations shows a patterns which is very similar to the average reflecting the high frequency of this type of co-operation. In case of horizontal co-operations, "speeding-up R&D projects" and "access to specific technologies" are less important than on average, probably because these two motives affect sensitive parameters of (horizontal) innovation competition. For science/industry partnerships, except for the first two motives which are primarily related to market transactions, all motives are more important than in case of the two other categories of co-operation. Obviously, this type of partnership is compatible with a broad array of objectives; in other words, universities and other research institutions are seen as particularly well suited partners to contribute to the enhancement of the firm's knowledge base. This result underlines the importance of an optimal design of the relationship between science and private business. It is thus not surprising that "profiting from public support" is a quite important motive for R&D co-operation with science institutions.

Table 8.3: Motives for R&D co-operation by partner type, 1997/99

(Share of firms for which a specific motive is highly important; multiple answers possible)

Partner	Motive						
	Risk sharing	Cost sharing	Speeding-up R&D projects	Access to specific technology	Pooling together complementary knowledge	Building of know-how in new technology fields	Profit from public support
Vertical co-operation	19,7	26,9	51,7	61,2	60,9	41,2	11,6
Horizontal co-operation	17,6	28,2	39,7	55,7	60,3	36,6	10,7
Co-operation with research institutions	21,4	27,9	54,7	68,7	66,2	52,2	18,9
Total	18,4	26,8	48,3	59,7	60,3	41,3	12,9

Source: Arvanitis et al. (2001a)

As already mentioned, R&D co-operation is of growing importance; however, is it also successful? To answer this question, in many cases, measures of economic performance are used to investigate whether performance is higher in case of firms co-operating in R&D compared to those exclusively relying on internal R&D. However, since R&D co-operation is only one, and certainly not the most important factor determining economic performance, it is may be more sensible to look at some "intermediate goal variable" that is directly linked to R&D co-operation. In this vein, we collected information on various components of "co-operation output" ranging from science-related outcomes (publications) onto market oriented results in terms of new products ready to be introduced on the market or production techniques ready to be adopted by the firm (see Table 8.4).

In general, R&D co-operations, as assessed by the firms themselves, seem to have been very successful, with a (very) high percentage of firms having realised new products or processes ready to be introduced. It looks quite plausible that the share of co-operating firms bringing out patents and publications is lower than that generating new products/processes, since the appropriation strategy of some of the firms are based on other strategies than patenting (i.e. time lead) and some co-operations are, from the very beginning, not science-related (i.e. publications are no objective of co-operation). Against this background, the fact that co-operation led to publications in case of every third firm points to a high science-orientation of R&D co-operation.

This assessment also holds true for smaller firms, since there is no significant relationship between firm size and publication output (at least if only the criterion "publication yes/no" is used). The co-operation output in terms of new products and processes is also not size-dependent. We can find such a relationship only for patents (probably reflecting, in case of small firms, the higher costs of patenting and difficulties to enforce patents if they are challenged by large firms), and, to a lesser extent, for prototypes.

As shown in Table 8.4, vertical co-operations and those with research institutions are more successful than horizontal ones. Science-oriented co-operations are clearly the most "productive" ones in terms of the output criteria used in this comparison. Since this type of partnership, at the same time, is motivated more often than others by "profiting from public support", we conclude that technology policy fostering public/private R&D partnerships is an effective way of strengthening innovative activity.

Table 8.4: Output of R&D co-operation by type of partner

(Share of firms with co-operations leading to a specific type of output; multiple answers)

Partner	Publications	Patents	Prototypes/ test versions	New products	New Processes
Vertical co-operation	31,4	47,6	67,9	89,3	54,8
Horizontal co-operation	33,9	36,9	57,7	83,9	59,2
Co-operation with research institutions	44,8	56,7	77,6	90,1	57,7
Total	31,8	46,0	65,7	88,0	54,0

Source: Arvanitis et al. (2001a)

8.2.4 Conclusion

External R&D strategies based on out-contracting R&D and/or R&D co-operations have become much more important during the last decade. By now, R&D networking is a core element of the Swiss Innovation System. This networking is primarily home-oriented but it also has an international dimension. This holds true, although to a lesser extent, also for SME's. Nevertheless, distance matters in choosing co-operation partners. Reducing "distance", for example, in the framework of European technology policy could help to improving the technological position of SME's.

Research institutions are important recipients of R&D contracts and a frequent partner in R&D co-operations. Science/industry relationships, for which public support is an important incentive, turned out to be very effective in terms of various output indicators. Therefore, supporting joint R&D projects (in particular in case of SME's) is a sensible policy measure. Moreover, since SME's are somewhat underrepresented in this type of partnerships, it is necessary to facilitate their access to research institutions, not only through subsidies but also by measures to improve information flows between these two agents (awareness, information about knowledge potentially useful for SME's). In this field, private institutions could also play a beneficiary role.

8.3 Internationalisation of R&D

The internationalisation of economic activity very much increased in the course of the last two decades, as shown by various statistics published by international organisations (OECD, 2001; UNCTAD, 2000 et al.). Until the mid-eighties the driving force has been international trade with foreign direct investment (FDI) increasing about at the same rate as GDP. Afterwards, FDI grew much faster than trade and production; between the mid-eighties and the end of the nineties, FDI increased by about factor 10, compared to factor 4 in case of the trade volume. Although FDI originating from Switzerland did not increase at this pace (what is not surprising given the already large stock of capital held in foreign countries in the base year), the degree of internationalisation, measured by the stock of FDI as a percentage of GDP, is (still) the highest (together with that of the Netherlands) among the developed countries.

This trends refers to investment capital flows. In case of Switzerland, we also dispose of information referring to the number of firms having engaged in international activities. These data collected in the course of the Swiss Internationalisation Survey 1998 (see Arvanitis et al., 2001b) are based on a broader definition of “internationalisation” covering also international activities which do not (necessarily) involve FDI. A firm is defined as being internationalised if it is engaged in foreign countries by one (ore various) of the following activities: distribution, manufacturing, sourcing, R&D and some specific contractual agreements (e.g. franchising or licensing). In these terms, 21% of Swiss firms (employment-weighted) with at least five employees have been internationalised in 1998. In the nineties, this share doubled with even higher growth rates in case of services firms and SME’s (defined as firms with less than 100 employees in Switzerland).

The process of internationalisation is often accompanied by foreign activity in R&D (OECD, 1998, 2001). Switzerland takes a top position also in this respect. Swiss affiliates in the USA perform as much R&D as UK, Canada and Germany which are the most significant investors in that country; taking into account the small size of the Swiss economy, it is by far the top R&D investor in the USA. Besides, more than 40% of patent applications to the European Patent Office owned by Swiss residents are based on foreign research; this share is almost the highest among the OECD countries.

According to data from our Internationalisation Survey, there is no Swiss-based firm performing foreign R&D which, at the same time, did not internationalise other business functions as well (see Table 8.5). This result is consistent with the stages approach to internationalisation hypothesising that this process starts with exporting and reaches its highest stage with foreign R&D activities (see, for example, Johanson and Vahlne, 1977). The table shows that 25% of the firms engaged in (any type of) foreign activities do so also in R&D. This high percentage reflects the high R&D intensity of the Swiss economy as well as the very strong presence at foreign locations in general; this holds also for SME’s.

Table 8.5: Percentage of Swiss firms with international activities by combination of business functions, 1998

Combination of business functions	SME’s	Large firms	All firms
Distribution/other activities *	33.2	29.5	31.3
Fabrication/sourcing only	13.0	9.2	11.1
R&D only	0.0	0.0	0.0
Distribution/other and fabrication/sourcing	28.2	31.3	29.8
R&D and distribution/other **or** R&D and fabrication/sourcing	5.2	3.8	4.5
Distribution/other and fabrication/sourcing and R&D	20.4	26.2	23.3
Total	100	100	100

* Other activities: franchising; licensing, service centres, consulting or management contracts

Source: Arvanitis et. al. (2001b) and Hollenstein (2001)

It is interesting to notice that foreign R&D engagements rely most frequently on full control, probably as a means of appropriating new knowledge as completely as possible (18% of firms performing R&D at foreign locations do so through fully-owned affiliates or R&D laboratories). If full control is not guaranteed, firms prefer the relatively loose form of (purely) contractual engagements (12%), whereas capital-based joint ventures (including minority stakes) are relatively rare (5% of firms).

The build-up of R&D activities abroad has been a cause for concern in Switzerland as well as in other countries (OECD, 1998), because it is feared that the technology base of a country may erode. In the Swiss case, it is pointed to differences between the patent portfolio "produced" in Switzerland and that of Swiss-owned firms (irrespective of the origin of patenting). Based on data for about 40 Swiss multinationals, it is shown that the firm-specific portfolio is oriented stronger towards "new", fast-growing patent fields than the location-specific portfolio (Hotz and Küchler, 1999). These authors conclude that the internationalisation of R&D substitutes for domestic R&D.

The opposite hypothesis posits that foreign and domestic R&D are complements. It is argued that the internationalisation of R&D is a strategy to get access to technology and knowledge which complements the technology base at home; in other words, it is a means to exploit specialisation advantages in R&D in a similar way as it is the case with other business functions since many years.

To assess the two conflicting hypotheses, we performed a) a descriptive analysis based on information about the motives for foreign R&D stemming from the Internationalisation Survey 1998 (Arvanitis et al., 2001b), and b) two econometric investigations based on firm-level data, the first one (Arvanitis and Hollenstein, 2001) using information of Swiss Innovation Survey 1996, the second one (Hollenstein, 2000) based on the Internationalisation Survey.If one accepts this interpretation, what can we conclude from Table 8.6? It shows that both categories of motives (1 to 4 vs. 5 to 7) are important, but it is not clear which type of motives are more relevant. Although, there is some hint that the complementary relationship is more important than substitutionality at a more disaggregated level, the descriptive analysis is not able to discriminate between the two hypotheses.

Table 8.6 shows the importance of various motives for undertaking R&D abroad as assessed by the surveyed firms. The motives 3 and 4 are consistent with the complementarity hypothesis, whereas the motives 5 to 7 are in accordance with substitution of foreign for domestic R&D. We argue that the motives 1 and 2 are also related to complementarity, since they stand for the exploitation of foreign R&D potentials which are not available at home (e.g. make use of the proximity to top universities or to highly innovative firms concentrated in a certain region like the Boston area).

If one accepts this interpretation, what can we conclude from Table 8.6? It shows that both categories of motives (1 to 4 vs. 5 to 7) are important, but it is not clear which type of motives are more relevant. Although, there is some hint that the complementary relationship is more important than substitutionality at a more disaggregated level, the descriptive analysis is not able to discriminate between the two hypotheses.

Table 8.6: Motives for performing R&D activities at foreign locations 1998

(% of internationalised firms assessing a specific motive as important: value 4 or 5 on a 5-point scale; multiple answers)

Motives	%
Proximity to leading universities/research institutions	49.8
Proximity to innovative firms (networks)	56.4
Knowledge transfer to Swiss locations	47.3
Support for fabrication/marketing abroad	40.7
Profit from higher availability of R&D personnel	56.5
Profit from lower R&D costs	39.5
Profit from more intensive promotion of R&D (subsidies, taxes, etc.)	54.6

Source: Arvanitis et. al. (2001a)

In contrast to the descriptive analysis, the results of the econometric work are unambiguous. Both studies mentioned above clearly support the complementarity hypothesis. Using the OLI paradigm developed by John Dunning (for a recent account of this approach, see Dunning, 2000) we estimated the probability of an R&D-performing firm to do so also at foreign locations. It turned out that firm-specific capabilities (O-advantages) and advantages based on the internalising of market transactions (I-advantages) are the driving forces for going abroad, whereas locational disadvantages (L) of Switzerland, for example, with respect to the availability of R&D personnel, the costs of R&D, the deficiency of R&D-related subsidies and tax relief or resistance to new technologies do not have any impact.

R&D performed in Switzerland by affiliates of foreign companies is another important aspect of the internationalisation in this field. There is some information on such inward investments which can easily be extracted from the Innovation Surveys of 1996 and 1999. Both data sets show that the share of R&D performing manufacturing firms is higher in case of foreign affiliates than for Swiss-owned firms (1999: 72% vs. 60%). Similarly, the intensity of R&D activities of foreign affiliates is higher than that of domestic firms. The same holds true only for 3 out of 11 OECD countries for which data are available, that is Ireland, Australia and the United Kingdom; in the USA and in Finland, the R&D intensity of these two types of firms is about the same (OECD, 1998). Since the R&D intensity of the Swiss economy is high, this result reflects the attractiveness of Switzerland as a location for R&D activities. The presence of R&D performing foreign-owned affiliates is advantageous for the Swiss economy for their direct contribution to R&D capacity (financing additional R&D) and to human resources as well as for the positive spillover effects resulting from their activity.

In sum, we conclude that R&D activities of Swiss firms in foreign countries are beneficial to the Swiss economy. They are an instrument to benefit from specific technological knowledge and human capital abroad complementing domestic capabilities. For a small country like Switzerland aiming at defending a top position on the world-wide "welfare ladder", this type of technological specialisation is indispensable. In addition, the Swiss economy gains from intensive R&D performed in Switzerland by affiliates of foreign companies. Stating that Swiss R&D in foreign countries is complementary to domestic R&D and, at the same time, that Switzerland benefits from inward R&D investment is no contradiction; it only reflects the advantages of international specialisation for both parties.

The implications of these results for policy are straightforward. Measures to make Switzerland an even more attractive location for R&D are welcome. Improving and enhancing the stock of human capital, securing the quality of university research (and its long-term orientation) and optimising science/industry relationships are probably the most effective ways to achieve this objective. Such measures help to attract R&D-intensive activities of foreign firms and improve the preconditions for exploiting the potential of R&D abroad.

8.4 Financing R&D-driven innovations

How do firms finance innovation activities, particularly R&D projects? R&D projects are above-average risky as compared to more conventional investment projects (e.g. new equipment, new buildings, etc.). Given the information asymmetry between (external) investors and managers with respect to risks and benefits of R&D projects (an important form of capital market imperfection), one should expect investors to be reluctant towards financing risky projects, thus demanding higher-than-average interest for funds lent for this purpose. This means that firms would find it in general cheaper to finance risky projects through internal funds than through loans, whereas external finance would be used to finance recurrent investments ('pecking order' theory; see e.g. Myers and Majluf, 1984). Other things kept constant, given the expected higher risk of bankruptcy for small firms (as compared to large ones) it seems reasonable for investors to discriminate against small (and young) firms with respect to lending conditions, thus rendering the access to external funds more difficult for this category of enterprises. On the other hand, small and young firms may not be able to acquire adequate internal funds to finance an innovation project of a certain magnitude just because of their small size. In sum, there may exist a clear disadvantage of small and young firms with respect to R&D financing, which leads to a suboptimal level of innovation investment for this group of firms and, consequently, often to policy correctives.[10]

[10] For a survey of theoretical as well as empirical liteature on this subject see Harris and Raviv (1991), Goodacre and Tonks (1995) and Myers (2001).

In a recent study we identified such financing impediments of innovation activity of small and young firms and investigated their determinants (Arvanitis and Marmet 2002). In the following we present selected results of this research based on data collected in an addendum to the standard questionnaire of the Swiss Innovation Survey 1999 especially for the above-mentioned study. In a second step we discuss, whether the firms' assessments of financing impediments did really exercise an influence on their choice of the financing mix. Third, we present the results with respect to the factors explaining the probability of a firm to be confronted with a certain category of financial impediments.

Table 8.7 shows the importance of seventeen instruments used to finance innovative activity and R&D which are classified in three categories, i.e. internal funding and external funding either through equity or through loans. In addition, public assistance is used as a special category of financing innovative activity. It turns out that internal funding is by far the most frequently used instrument (particularly profits). Among several types of external funding, loans (from banks in the first place) are more important than equity. Venture capital seems to be relevant only in few cases: surprisingly, firms in the age range of 10 to 14 and 15 to 19 years use venture capital more often than the very young firms. The mode of financing innovations does not much vary across firm size and age classes; only for some elements of internal funding (profits, depreciations) we find that large firms use them more often than small ones; these, however, are the most important instruments to finance innovative activities.

As already mentioned, we expect that R&D projects and far-reaching (product) innovations are financed to a larger extent by internal funds than low-profile innovations. In addition, with respect to external funding, equity financing should be more frequent in case of more risky innovations than loans. As can be seen from Table 8.7, these expectations are mostly confirmed ;see, for example, the role of financing by profits in case of R&D performing firms vs. those without R&D activities (col. 2 vs. 1), or high-intensity vs. low-intensity product innovations (col. 4 vs. 3). Quite surprisingly, we do not find that venture capital is primarily used to finance high-risk projects. This holds, however, in case of projects (co-)financed by public funds which corresponds to the intentions of policy makers.

The questionnaire also yielded information with respect to 17 obstacles to financing innovative activity which are classified in the same way into three categories as the financial instruments (impediments with respect to internal funding and external funding through equity or loans). Table 8.8 shows that 24% of firms, according to their assessment, are impeded by at least one of the seventeen potential obstacles with much variation across sectors. However, financial obstacles are distinctly less important for large than for small firms; in this respect, one can clearly distinguish three size categories (below 100, between 100 and 500, more than 500 employees). No size-dependence is detected across different categories of firm age.

Table 8.7: Financing R&D and innovative activity by financial instrument

(share of firms assessing the importance of a specific financial instrument as (highly) important; value 4 or 5 on a five-point scale; multiple answers possible)

	R&D activities		Innovation intensity				All innovating firms
			Product		Process		
	No	Yes	Low	High	Low	High	
Internal funding							
Profits	47.7	60.3	50.7	61.2	54.0	57.9	55.9
Depreciation	24.2	25.9	23.6	26.9	23.9	26.6	25.3
Reserves	13.8	16.8	14.1	17.3	13.7	17.7	15.7
Selling-off of assets	2.4	2.8	2.3	3.1	2.3	3.2	2.7
External funding							
Equity							
Increase of equity	5.1	8.5	7.1	7.6	7.9	6.8	7.4
Emission of new equity	1.5	3.5	2.4	3.2	3.4	2.2	2.8
Venture Capital	1.6	1.5	1.7	1.5	1.8	1.4	1.6
Loans, etc.							
Loans from affiliated firms	3.9	10.9	6.8	10.4	6.6	10.6	8.6
Loans from banks	14.4	14.0	12.3	16.0	13.1	15.2	14.1
Loans from suppliers	2.6	1.8	2.2	1.9	2.0	2.2	2.1
Loans from users	0.8	1.2	0.9	1.2	0.6	1.5	1.0
Leasing	7.1	6.6	6.3	7.3	6.6	7.0	6.8
Public support	1.7	3.8	2.4	3.8	3.2	3.1	3.1

Source: Arvantis und Marmet (2002)

Table 8.8: Share of firms with significant problems to finance innovations 1997/99 by sector, firm size and firm age (%)

Total	24.0
Sector	
Manufacturing	26.0
Construction	26.7
Services	22.0
Firm size (employment)	
6-19	24.8
20-49	23.7
50-99	30.7
100-199	13.9
200-499	15.3
500-999	3.8
1000 and more	2.3
Firm age (years)	
Up to 5	22.4
5-9	21.4
10-14	42.9
15-19	18.8
20 and more	23.3

Source: Arvanitis and Marmet (2002)

We also find differences with respect to the importance of obstacles if these are differentiated by the three categories mentioned above. Problems with external funding (loans: 63% of firms; equity: 61%) are more serious than those related to internal funding (51%), which is the most prominent form of financing innovative activity. This more disaggregated analysis shows also that the size-dependence of financial obstacles is primarily due to larger problems of small firms with respect to bank loans.

Did impediments (measured by firms' assessments) really hinder firms from choosing the one or other form of financing? To answer this question we estimated probit models regressing measures of the extent of using a particular financing modus against, among other things, variables measuring the importance of the impediments of this type of financing. We found that the impediments of internal financing (particularly profits) have been really a restricting factor, reducing considerably the extent of use of this type of financing (negative sign of the corresponding variable). In case of external financing positive signs of the corresponding variable showed that the assessed impediments did not virtually restrict this kind of financing, but rather reflect a high sensibility of firms with respect to financing problems.

Even if financing restrictions are binding, can we validly conclude that e.g. small and young firms have been discriminated by investors? Experiencing financial restrictions, either with respect to internal or external financing, may reflect for a considerable number of firms only a low performance (profitability) level of these firms. In this case, financial difficulties are not structural problems requiring policy intervention. To investigate this question, we estimated a probit model regressing measures of different financial obstacles (internal, external financing, etc.) on firm size, firm age, a set of performance indicators, a measure of technological and/or commercial risk as well as some control variables (industry affiliation, legal status). If structural problems are the reason for a firm to experience financial problems, then the dummies for firm size and/or firm age should explain most of the variance (the smaller and/or younger a firm, the higher the probability for this firm to be confronted with financial restrictions). On the contrary, if these dummies are not statistically significant and/or the measures of performance, risk, etc. explain most of the variance of the regression, we can conclude that the financial restrictions experienced by the firms are real structural problems to be traced back to capital market imperfections.

Our empirical results are mixed. We find that firm size, indeed, seems to be a structural problem particularly in case of external financing by loans (for firms with less than 500 employees), to a lesser extent also in case of internal (for firms with less than 100 employees) and equity funding (for firms with less than 50 employees). Firms with less than 50 (or 100) employees are also structurally impeded in getting access to venture capital. In contrast to firm size, we do not find any impact of firm age, even if firm size is excluded from the regressions. This results presumably reflects the skewed distribution of the sample by age (82% of firms are at least 20 years old). Hence, we are not able to assess whether young firms are structurally discriminated by capital markets. Further, we find that, in general, low-performing firms have more problems in financing innovations. We conclude therefore, that, although there are structural obstacles to financing innovations, these also reflect to some extent general weaknesses of the firms which are no reason for considering corrective policy measures.

In sum, innovative activities are financed primarily through internal funds; there are impediments for this type of financing which seem to restrict the use of internal financing. Obstacles to either internal or of external financing of innovations tend to be to some extent structural especially with respect to small firms, thus reflecting capital market imperfections.

8.5 Conclusions

The policy conclusions we can draw from the analysis of the pattern of R&D activity in Switzerland in this paper are straightforward. Moreover, it is interesting to notice that the policy implications of our analysis of R&D networking, the internationalisation of R&D and the financing R&D-driven innovations are similar in several respects.

There are mainly six points we want to stress: a) supporting high-quality reasearch and strengthening the human capital base is probably the most important way of enhancing the innovation capacity of the Swiss economy; b) optimisation of science/industry relationships would strongly contribute to the effectiveness of knowledge production and knowledge diffusion; c) there is some evidence for capital market imperfections which should be corrected by R&D subsidies or tax reliefs; d) geographical distance works as a barrier to exploiting knowledge potentials (e.g. lack of information on foreign knowledge sources); e) there is a need to design specific policy measures oriented towards SME's (which play an even more prominent role in case of Switzerland than in many other countries), since these firms are most hit by the problems addressed under the headings b), c) and d); finally, although, and in the first place, public policy is required (from the regional to the European level), there is also scope for non-governmental action (e.g. industry associations contributing to the overcoming of information problems).

In future work, we shall deepen our analysis of R&D networking and of the internationalisation of R&D. In the first field of resarch, we aim at the formulation and simultaneous estimation of a R&D out-contracting equation and a R&D co-operation equation.. In a further step, we shall try to extract from the data specific modes of co-operations, for example, by performing a cluster analysis of firms with respect to a set of co-operation parameters (type of partner, motives, etc), and describe them in terms of some structural characteristics of firms (size, industry affiliation, export propensity, etc.) and performance measures (co-operation output, innovation performance, productivity); based on such an analysis, one could propose policy measures which take into account the heterogeneity of co-operation patterns. Secondly, we plan a more comprehensive analysis of the factors determining the internationalisation of R&D and its impact on the domestic economy. To this end, we shall exploit more intensively the firm data we dispose of, for example, with respect to the motives for internationalisation of R&D. In addition, it is planned to collect more data in this field by means of the Swiss Innovation Survey 2002. In methodological terms, most research will be based on the econometric analysis of firm data.

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9 Conclusions and suggestions for future work

The participants of the workshop agreed on the following points:

- To disseminate all the presentations via the new ***tip website*** (already operative)
- To edit the papers which will be prepared in a ***proceedings volume*** (mid-end April) which will appear in the tip Working papers/Proceedings series.

In addition, some suggestions were made concerning future common activities.

- A ***follow-up workshop*** to discuss the progress of the different econometric studies on leverage effects (most likely towards the end of 2002) was envisaged. In the field of econometric research, there is little scope for real joint research, because one cannot reasonably pool data and harmonize approaches. Rather, one can learn from each other methodologically and compare results.
- The situation is a bit different with respect to identifying changing patterns of private R&D. Here, it would make sense to strive for ***some form of harmonisation*** between the countries embarking on ***surveys / case studies*** to identify these patterns. Switzerland has carried out such a survey (as part of the broader innovation survey) which could form the core of similar questionnaires in other countries, Austria (in all likelihood) will carry out case studies/interviews before summer and probably a survey later the year, the Flemish are considering case studies/interviews. Korea is planning such a survey.
- Disseminating the results among the Member Countries and ***ask for further interest in the activity***. At the last meeting of the OECD TIP working group a number of countries which could not be present in this workshop also indicated interest in this activity (Australia, the Netherlands, Norway, Canada and probably also the US)
- A ***presentation*** of the activity should be given ***at the next OECD TIP meeting*** in June 2002.
- An ***OECD publication*** at the end of the project summarising the results of this activity could be aimed at. One might think of a special issue of the STI review or a special monograph.

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